Online ISSN : 2249-4596
Print ISSN : 0975-5861
DOI : 10.17406/GJRE

# Global Journal

## of Researches in Engineering: A

# Mechanical & Mechanics Engineering

Leakage and Cavity Shape

Study of Minor Loss Coefficient

Highlights

Bonding of Silicon Carbide

Transient Liquid Phase Diffusion

Discovering Thoughts, Inventing Future

VOLUME 16 ISSUE 4 VERSION 1.0

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 (Ver. 1.0)

Open Association of Research Society

**Incorporation No.: 0423089**
**License No.: 42125/022010/1186**
**Registration No.: 430374**
**Import-Export Code: 1109007027**
**Employer Identification Number (EIN):**
**USA Tax ID: 98-0673427**

# Global Journals Inc.

*(A Delaware USA Incorporation with "Good Standing"; **Reg. Number: 0423089**)*

*Sponsors: Open Association of Research Society*
*Open Scientific Standards*

## *Publisher's Headquarters office*

Global Journals® Headquarters
945th Concord Streets,
Framingham Massachusetts Pin: 01701,
United States of America
*USA Toll Free: +001-888-839-7392*
*USA Toll Free Fax: +001-888-839-7392*

## *Offset Typesetting*

Global Journals Incorporated
2nd, Lansdowne, Lansdowne Rd., Croydon-Surrey,
Pin: CR9 2ER, United Kingdom

## *Packaging & Continental Dispatching*

Global Journals
E-3130 Sudama Nagar, Near Gopur Square,
Indore, M.P., Pin:452009, India

## *Find a correspondence nodal officer near you*

To find nodal officer of your country, please email us at *local@globaljournals.org*

## *eContacts*

Press Inquiries: *press@globaljournals.org*
Investor Inquiries: *investors@globaljournals.org*
Technical Support: *technology@globaljournals.org*
Media & Releases: *media@globaljournals.org*

## *Pricing (Including by Air Parcel Charges):*

*For Authors:*
22 USD (B/W) & 50 USD (Color)
*Yearly Subscription (Personal & Institutional):*
200 USD (B/W) & 250 USD (Color)

# Contents of the Issue

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN: 0975-5861

# The Effect of the Eccentric Loading on the Components of the Spine

By Samir Zahaf, Hamani Habib, Bensamine Mansouri, Abderrahmane Belarbi & Zitouni Azari
*University of Sciences and Technology*

*Abstract-* The objective of this work is to study the effect of the backpack on the components of the spine system of a child, know the effect of an eccentric load on the intervertebral discs, the creating a 3D model of the spine of child of 80 kg overall weight under the effect of three eccentric load (P2, P3, P4) plus P1 compression load and calculated by the element method ends, For the boundary conditions we fixed the sacrum (Embedding the sacrum). We propose in this section to draw up a comprehensive study of the distributions of stresses and normal elastic strain of Von Mises in the intervertebral discs based on loads supported.

*Keywords:* *child; herniated discs; lumbar-thoracic; intervertebral discs; finite element; biomechanics; von mises stress-strain; disc degeneration.*

*GJRE-A Classification:* *FOR Code: 091399*

THEEFFECTOFTHEECCENTRICLOADINGONTHECOMPONENTSOFTHESPINE

*Strictly as per the compliance and regulations of:*

# The Effect of the Eccentric Loading on the Components of the Spine

Samir Zahaf [α], Hamani Habib [σ], Bensamine Mansouri [ρ], Abderrahmane Belarbi [ω] & Zitouni Azari [¥]

*Abstract-* The objective of this work is to study the effect of the backpack on the components of the spine system of a child, know the effect of an eccentric load on the intervertebral discs, the creating a 3D model of the spine of child of 80 kg overall weight under the effect of three eccentric load (P2, P3, P4) plus P1 compression load and calculated by the element method ends, For the boundary conditions we fixed the sacrum (Embedding the sacrum). We propose in this section to draw up a comprehensive study of the distributions of stresses and normal elastic strain of Von Mises in the intervertebral discs based on loads supported. The results show that the stress and strain of Von Mises are highest and concentrated in four intervertebral discs (D1, D15, D16 and D17), which causes a problem that calls (herniated disc). We concluded that the cause of the posterior load, a 350 mm lever arm with a 200N load present maximum Von Mises stresses concentrated in four intervertebral discs (D1, D15, D16, D17), which justifies the distance between the load which is the point of application of the load and the axis of the spine plays a very important role in increasing the solicitation of the latter.

*Keywords: child; herniated discs; lumbar-thoracic; intervertebral discs; finite element; biomechanics; von mises stress-strain; disc degeneration.*

## I. Introduction

The spine or rachis consists of a movable column of 24 free vertebrae and a fixed column formed of fused vertebrae: the sacrum and coccyx \"(Fig. 2) \" ;it is the fixing strut of many essential muscles in the posture and locomotion and protects the spinal cord located in the vertebral canal ; it supports the head and transmits the weight of the body to the hip joints; with a length of about 70 cm in men (60 cm in women), its reduction may reach 2 cm when standing [1].

Intervertebral discs connect the vertebral bodies, provide the mobility of the column and amortize them pressure and shocks. Each consisting of a peripheral annulus (annulus) containing a gelatinous core (nucleus). Disc degeneration begins, after a phase of asymptomatic dehydration, with tears in the fibrous ring. The core can then migrate into the thickness of the ring and cause acute or chronic back pain. If it moves further through the ring, the ring may protrude to the rear side of the disc while forming a HERNIATED DISC this is indicated in \"(Fig. 1) \" and \"(Fig. 2) \". This hernia can migrate into the spinal canal and even exclur leaving the disc. This disc herniation can come compress or "stuck" in one or more nerve roots located near the drive. It is the cause of symptoms: pain is sciatica when the back of the thigh, cruralgie when the pain is in front of the thigh [2] see Figure 1 and figure 2.

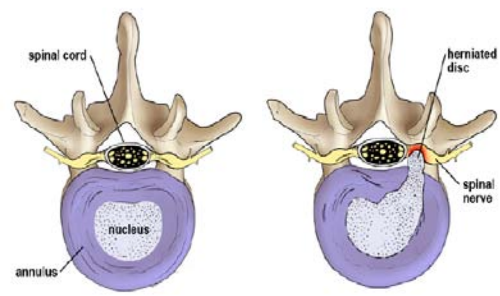



*Fig. 1:* Normal disc (top). Herniated disc (bottom) shows the gel-filled nucleus escapes through a tear in the disc annulus and compresses the spinal nerve [3].

It is the cause of symptoms when sciatic pain is in back of the thigh, crural when pain is in front of the thigh. It comprises variably pain in the lower limbs, defourmillements or tingling sensation (paraesthesia), the sensitivity to disturbance of sensation (dysesthesia) up to a complete loss of feeling (anesthesia), loss muscle strength or partial or complete paralysis or sphincter disorders. continuously exerted, the pressure of the herniated disc can cause irreversible damage [2].

*Author α σ ρ ¥: Department of Mechanical Engineering, University of Sciences and Technology, Oran, Algeria.*
*e-mails: zahafsamir1983@gmail.com, Hamanihabib31@gmail.com, Smail_mansouri@yahoo.fr, azari@univ-metz.fr*
*Author ω: Laboratory of Biomechanics, Polymers and Structures, ENIM-Metz, France. e-mail: belarbi_abd@yahoo.fr*

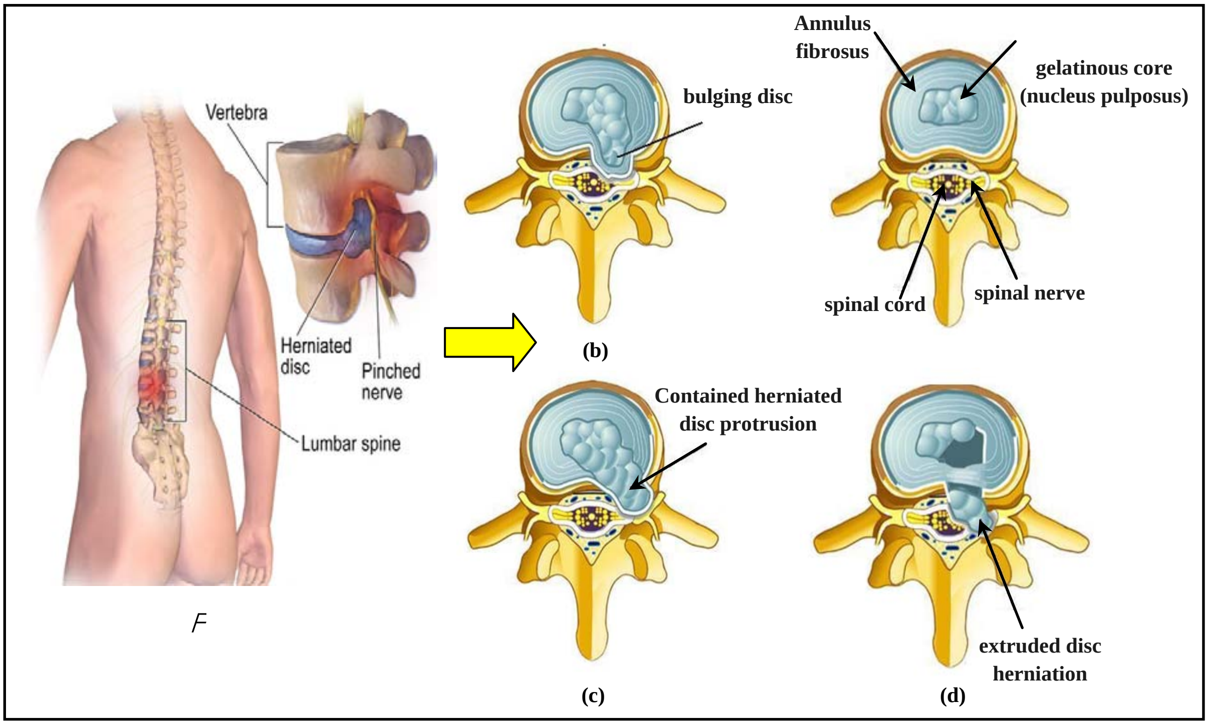



*Fig. 2:* Evolutionary forms of the herniated disc. (a) back pain. (b) - crack the annulus, (c) -progression the disc material, (d) – prolapse [4]. & www.espalda.org

Every year it is the same finding, schoolchildren satchels or bags to back are too heavy and can cause long-term back problems and deformities of the spine that is to say students complain of back pain, shoulder pain, muscle pain, knee pain, pain in the neck, numbness pain, bad posture, poor balance and falls due at the port of a backpack overloaded view \"(Fig. 3) \" [5].

*Fig. 3:* A school child wears a backpack.

Worse, their weight increases over the years from 6.5 kg in 1997 to 8 kg today in the best case. This would amount to carry to an adult of 80 kg weight 17 kg Yet the official circular of 2008 National Education clearly advocates that the weight of the backpack should not exceed 10% of the weight of the child, ie, primary, about 2.5 kg ... we're off!! It is between 8 and 15 years back is the most fragile, and scientific studies have demonstrated imaging (MRI), the risk of joint damage and intervertebral disc are real [5].

Yet the official circular of 2008 National Education clearly advocates that the weight of the backpack should not exceed 10% of the weight of the child, either primary, about 2.5 kg ... we're off!! It is between 8 and 15 years back is the most fragile, and scientific studies have demonstrated imaging (MRI), the risk of joint damage and intervertebral disc are real [5].

During this period of school age, the spine of children is particularly rough ride. With their school bags too heavy, students are real porter, causing stiffness and pain, which are themselves a source of bad posture on often inadequate seating.

It is in this context daily, as well as family education, the accumulation, repetition of these situations will cause joint damage, common causes such as scoliosis. This explains the fact that 67% of students suffer from muscle tension, 50% of back pain, 24% falling asleep during classes and 15% of pain in the shoulders [5]. The schoolbag defined as an eccentric load \"(Fig. 3) \", the load represented by the mass (P4), in other words, this load created a moment of posterior bending which tends to bend the spine and causes a problem called lumbar disc herniation is the most common cause of low back pain.

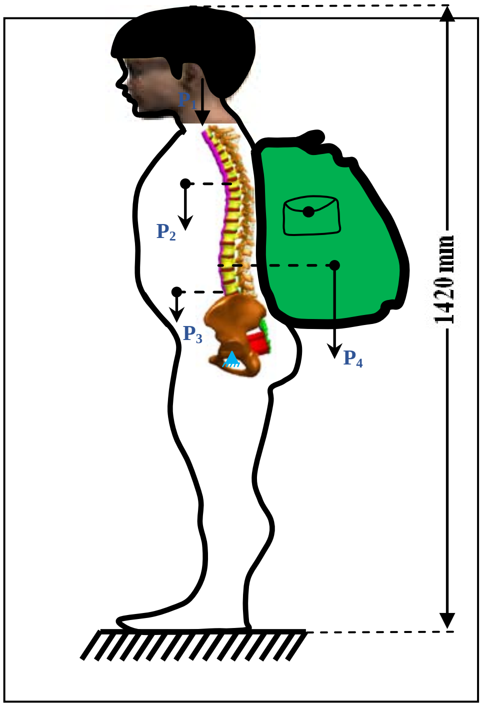



*Fig. 4:* Model biomechanics of the spine (A school child wears a backpack).

The diagram \"(Fig. 4) \" represents a child to age 10 years of overall specific weight 38 kg to wear a backpack, backpack is the mass of 15 kg representing the weight P4.

The MRI study [6], alerts of this overweight effect in the development of degenerative disc disease, back pain and then herniated disc \ » (Fig. 5) \".

In this work, the simulation of the disc degeneration, based on a finite element model of the spine depending on the mechanical properties were established ; the boundary condition has been applied in the frontal plane to define restriction on movements of translation and rotation of the spine.

We propose in this work to draw up a comprehensive study of stresses and strains in the spinal discs distributions based on supported loads. The results show that the level of degeneration increased in all intervertebral discs but concentrated in the four disks D1, D15, D16 and D17.

Fig. 5 shows two vertebrae of the spinal column with an intervertebral disc under the effect of a compound loading (compression P1+ bending moment P4). The compressive load P1 creates an internal pressure in the nucleus, this pressure will there after generate the disc degeneration or degenerative disc disease \"(Fig. 5)\" and \"(Fig. 7)\", as regards the forward flexion P4, if the load of the schoolbag increases, automatically distance between the point of load application and the axis of the spinal colum increases, we see that the posterior portion of the annulus fibrosis is compressed and the other front portion is tensioned, that is to say the nucleus pulposus burst back (posterior compression), this compression produced by disc protrusion comes into contact with a nerve root called herniated disc this mentioned in \"(Fig. 2)\".

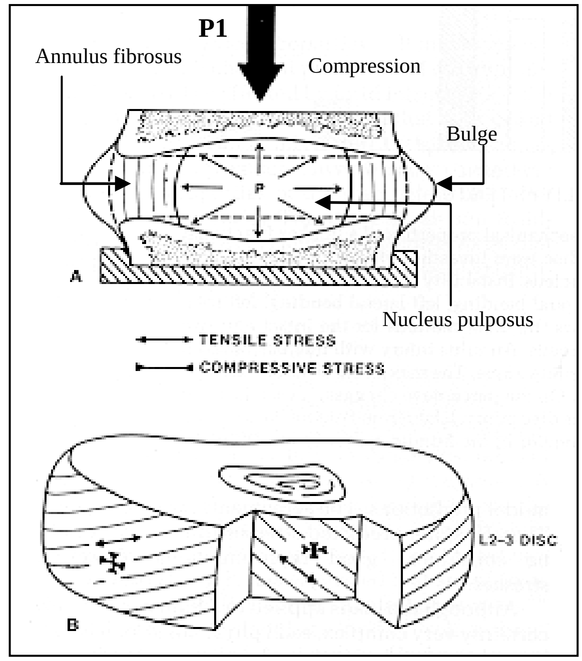



*Fig. 5:* The intervertebral disc with (a): compression [7].

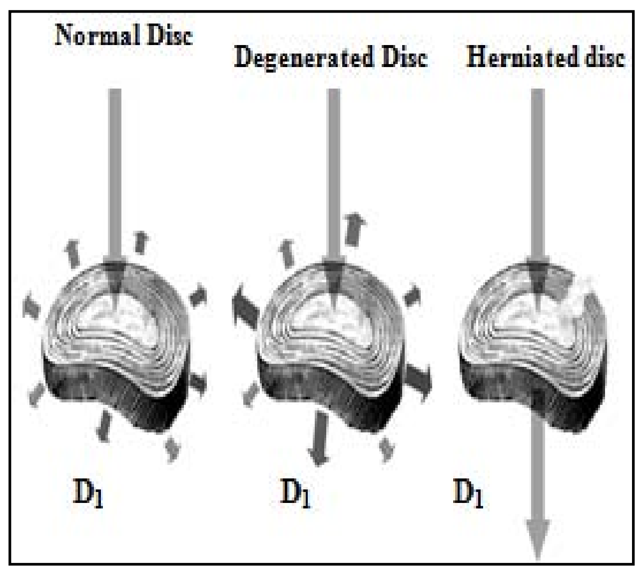



*Fig. 6:* Load distribution at the disc D1 according to his state [8].

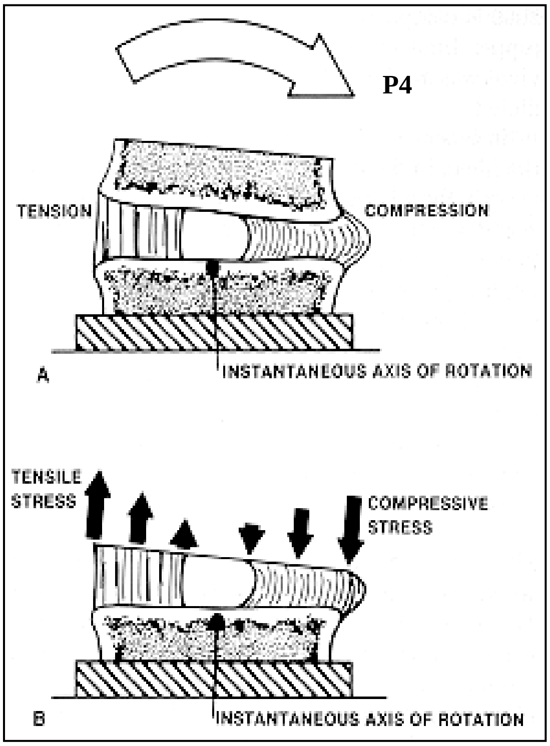



*Fig. 7:* The intervertebral disc with (b): bending [7].

## II. Material and Methods

The objective of this study was to investigate the effects induced by an eccentric load of the backpack on the back of a child, know the effect of an eccentric load on the intervertebral discs, cortical bone, cancellous bone, posterior bone, sacrum, basin, created a 3D model of spine, the total mass of person standing of specific global 80kg under the effect of three eccentric loads (p2, p3, p4) plus a p1 compression load and calculated by the finit element method, the boundary conditions we fixed the sacrum (incorporation of the sacrum) see \"(Fig. 4) \".

The analysis of biomechanical problems includes several steps.

The first is to study the form to define the geometrical configuration of the object, which allows the reconstitution of the vertebra, the ligament and bone using CAD programs.

The result is a 3D geometric model including these three components will then be prepared for use in finite element analyzes for the study of stresses and strains distribution in the system.

The steps for the execution of the 3D vertebra model \"(Fig. 8) \" are as follow:

a) Draw cortical bone that is the upper hinge and the lower hinge, then make the smoothing process; this gives a solid body called the vertebral body.
b) Secondly, draw the posterior arch (blade with the pedicle) with the spinous process.
c) Finally we draw the transverse process.

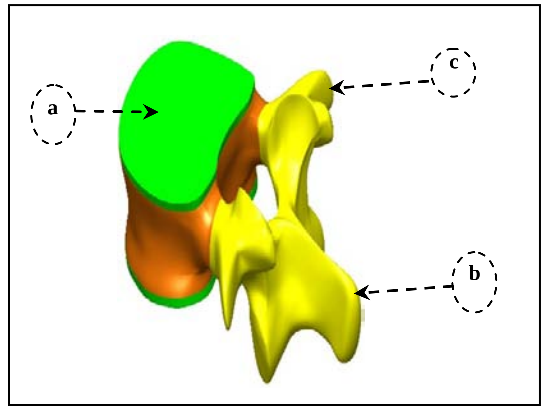



*Fig. 8:* Lumbar vertebras.

The simulation of the disc degeneration is based on a finite element model of the healthy spine. Fig. 9 shows a spine model, this consists of five lumbar vertebrae (L1, L2, L3, L4 and L5) plus the sacrum and the basin, twelve thoracic vertebrae (TH1, TH2, TH3, TH4, TH5, TH6, TH7, TH8, TH9, TH10, TH11, TH12) and 17 inter vertebral discs between (S1-L5, L5-L4, L4-L3, L3-L2, L2-L1, L1-TH12 TH12-TH11, TH11, TH10, TH10-TH9, TH9-TH8, TH8-TH7, TH7-TH6, TH6-TH5, TH5-TH4, TH3-TH4, TH3-TH2 TH2-TH1) and various ligaments thoracic lumbar spine (anterior longitudinal ligament, posterior longitudinal ligament, ligament interspinous, ligament supraspinatus, yellow ligament and capsular ligament), ligaments of the basin (sacroiliac posterior ligament, sacrotuberous ligament and interosseous ligament).

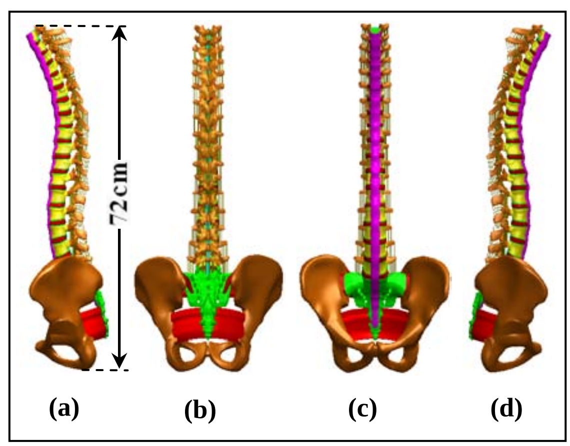



*Fig. 9:* Spine studied.

(a): Lateral (left) view. (b): dorsal view. (c): front view. (d): lateral (right) view

In static loading conditions, the model of the reconstructed spine is used in an analysis for studying the role of the inter vertebral discs and the stress distribution in these disks as well as its supporting structures. The spine is reconstructed in 3D to study the system dimensions (IVD - ligament-bone) \"(Fig. 10)\".

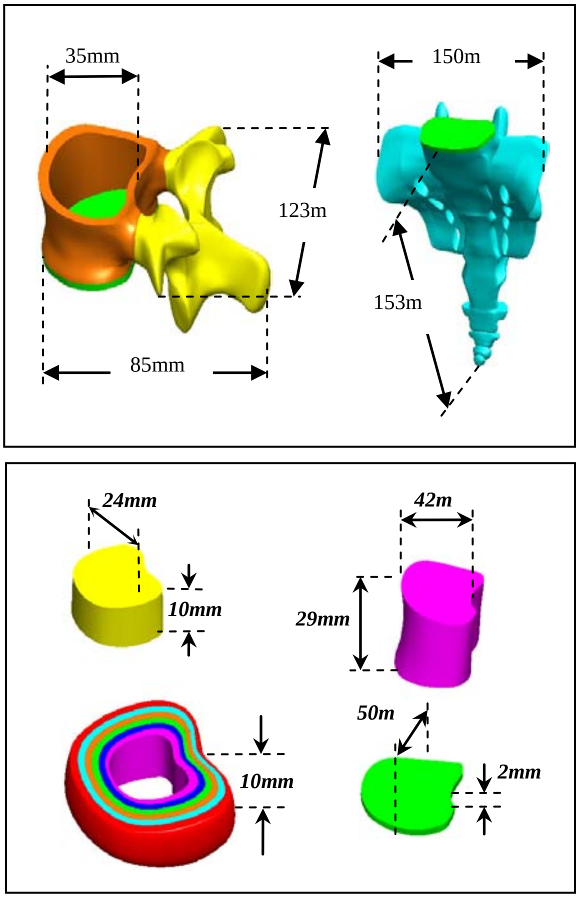



*Fig. 10:* Vertebra and sacrum dimensions.

In order to define the boundary conditions, restriction on movements of translation and rotation of the spine has been applied in the lower plane, and defined as having zero displacements. Several charges in the anterior direction were applied as follows:

- The application of the load on the upper side of the thoracic vertebra TH1.
- The fixed part applied to the body of the basin.
- The interfaces between the different components of the system of the spine, the cortical bone, the inter vertebral disk and ligament are treated as perfectly bonded interfaces \"(Fig. 10)\".

Fig. 9 shows an isometric view of an explored assembly of the spine and each component of the spine system is denoted by letters.

## Abbreviations

D4: intervertebral disk upstairs four.
N4: nucleus in the intervertebral disc upstairs four.
D2: intervertebral disk upstairs two.
N2: nucleus in the intervertebral disc upstairs two.
L2: lumbar vertebra is on level two.
D4: intervertebral disk upstairs four.
N4: nucleus in the intervertebral disc upstairs four.
AF1: annulus fibrosus one.
AF2: annulus fibrosus two.

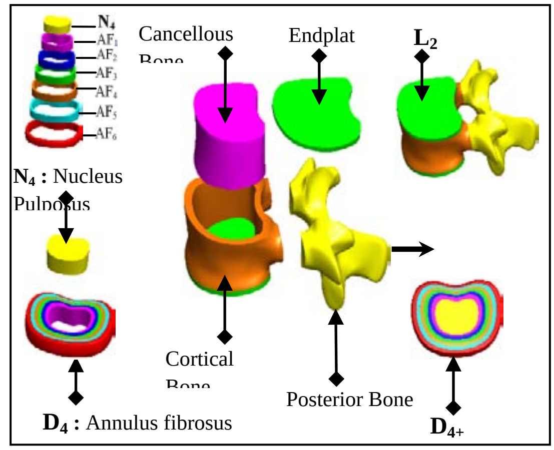



*Fig. 11:* 3D modeling thoracic vertebra L3, D4 disc of the lumbar spine (SOLIDWORKS 2016 software).

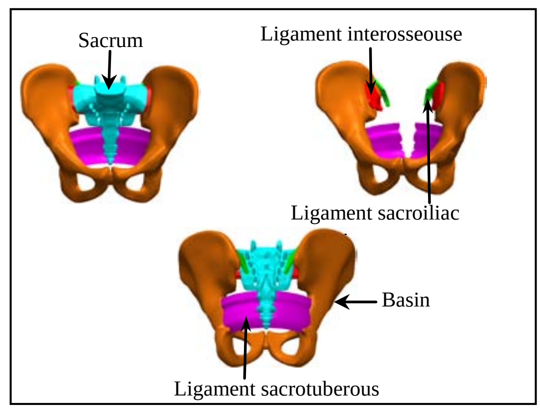



*Fig 12:* Model details of basin and sacrum (ligaments).

*Table 1:* Mechanical characteristics of disc tissue [9].

| Authors | $\sigma_r$ (MPa) |
|---|---|
| *BROWN* (axial direction) | 1.4 |
| *GALANTE* (horizontal direction) | 3.5 ± 0.3 |
| *GALANTE* (fiber direction) | 10.7 ± 0.9 |
| WU | 3.7 |

The selection of constitutive equations of the vertebral bone is defined as the part of the bone which carries the inter vertebral disc, composed of cortical bone, cancellous bone, the posterior arch, with a Young's modulus of about 12000 MPa. It is well known that cortical bone has better load capacity than the cancellous bone. Cortical bone is considered as an isotropic material, and homogeneous linear elastic. Table 1 shows the tensile strength of the structure annulus fibrosis according to different authors. These materials are anisotropic and non-linear elastic.

The behavior of inter-transverse ligament and inter-spinous ligament is nonlinear viscoelastic as in

Global Journal of Researches in Engineering ( A ) Volume XVI Issue IV Version I Year 2016

previous studies [10]; a linear elastic model is chosen to represent this behavior.

*Ansys Workbench* software was used for analyzing this geometry and generate the most suitable mesh. For the studied behavior, we used tetrahedral elements, type Solid187 conforming to defined parametric surfaces interfaces \"(Fig. 13) \".

It is necessary to mesh the components of the spine with small and confused elements to ensure optimum accuracy of the results of stresses and strains in the inter vertebral discs.

The material properties of the spine components were selected after a careful review of the published literature "Table 2"; it was considered appropriate to define the cortical and cancellous bone as homogeneous and isotropic. The magnitudes of 12000 MPa and 100 MPa (cortical and cancellous, respectively) were observed in all studies by various researchers.

*Table 2:* Material Properties Specified in the Model.

| Material | Young Modulus (Mpa) | Poisson Coefficient | References |
|---|---|---|---|
| Cortical Bone | 12000 | 0.3 | [11,13,14,15,16,17,18,19,20,21,22,27,36] |
| Cancellous Bone | 100 | 0.2 | [11,14,15,17,18,19,21,22,24,25,26,27,36] |
| Posterior Bone | 3500 | 0.25 | [13,14,15,18,19,21,22,24,27,28,37] |
| Cartilage Endplates | 12000 | 0.3 | [21,23,25,29] |
| Annulus Ground Substance | 4.2 | 0.45 | [11,14,17,19,20,21,22,23,25,33,31,32,35,36,37] |
| Nucleus Pulposus | 1 | 0.499 | [12,14,15,16,18,20,21,27,30,33,34,35,36,37] |
| Anterior Longitudinal Ligament | 20 | 0.3 | [14,15,17,18,19,37] |
| Posterior Longitudinal Ligament | 20 | 0.3 | [14,15,17,18,37] |
| Ligamentum Flavum | 19.50 | 0.3 | [14,15,17,18,37] |
| Intertransverse Ligament | 58.7 | 0.3 | [14,15,17,18,37] |
| Inter-Spinous Ligament | 11.6 | 0.3 | [14,15,17,18,37] |
| Supra-Spinous Ligament | 15 | 0.3 | [14،15،17،18،37] |
| Capsular Ligament | 32.9 | 0.3 | [14,15,17,18,37] |
| The basin | | | [38] |
| Sacrotuberous Ligament | 40 | 0.3 | [38] |
| Sacroiliac posterior Ligament | 40 | 0.3 | [38] |
| Interosseous Ligament | 40 | 0.3 | [38] |

Since physiologically the nucleus is fluid filled, the elements were assigned low stiffness values (1MPa) and near incompressibility properties (Poisson's ratio of 0.499). Biologically, the annulus fibrosus is comprised of layers of collagen fibers, which attributes to its non-homogenous characteristics. However, due to limitations in modeling abilities, the annulus was defined as a homogenous structure with a magnitude of 4.2 MPa.

This was based on the modulus of the ground substance (4.2 MPa) and the collagen fibers reported in the literature, taking into account the volume fraction of each component. The complete model of the spine \"(Fig. 13)\" was realized by the SOLIDWORKS SOFTWARE VERSION 2014 and was then transferred to the software Calculates each element ends ANSYS 16.2 WORKBENCHE generated the default mesh then generated linear global custom mesh tetrahedra 10 nodes conform to surface.

The three views of spine model with condensed mesh are shown in \"(Fig. 13)\". All element and node numbers are specified in "Table 3".

Fig. 13 shows a complete model that consists of 1178694 elements and 2005025 nodes. Cortical bone

*Table 3:* Element and node numbers in the column vertebral system components.

| COMPONENT | NODES | ELEMENTS | Thickness |
|---|---|---|---|
| Cortical Bone | 961810 | 644683 | 3mm |
| Cancellous Bone | 244460 | 164441 | 3mm |
| Posterior Bone | 226389 | 132464 | 3mm |
| Cartilage endplates | 160055 | 87710 | 3mm |
| Annulus Ground Substance | 244800 | 114036 | 3mm |
| Nucleus Pulposus | 42449 | 26112 | 3mm |
| Anterior Longitudinal Ligament | 45798 | 24467 | 3mm |
| Posterior Longitudinal Ligament | 14414 | 6607 | 3mm |
| Ligamentum Flavum | 30226 | 13447 | 3mm |
| Transverse Ligament | 285328 | 131648 | 3mm |
| Inter-Spinous Ligament | 28968 | 13158 | 3mm |
| Supra-Spinous Ligament | 17833 | 8279 | 3mm |
| Capsular ligament | 51816 | 24072 | 3mm |
| Sacrotuberous Ligament | 20878 | 10128 | 3mm |
| Sacroiliac posterior Ligament | 5876 | 3280 | 3mm |
| Interosseouse Ligament | 13756 | 8306 | 3mm |
| TOTAL | 2005025 | 1178694 | 3mm |

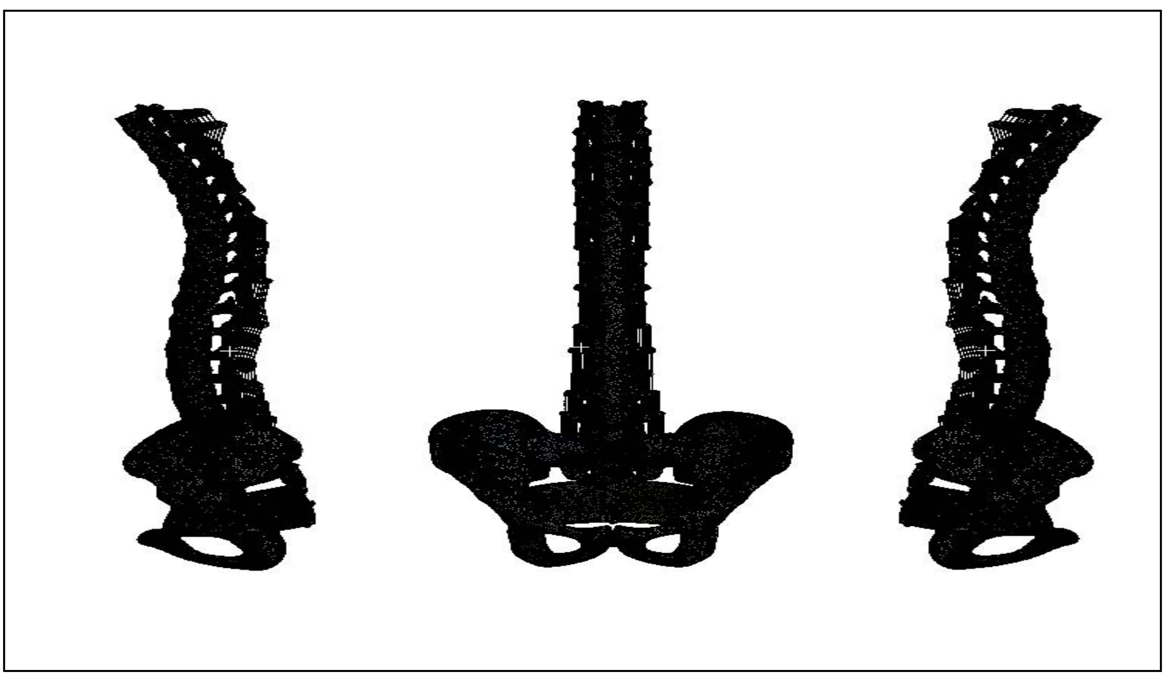


*Fig. 13:* Spine 3D finite element modeling (ANSYS 16.2 software).

The posterior arch was modeled with tetrahedral elements to 10 nodes contains (132464 elements, 226389 nodes), the nucleus pulposus in the annulus fibrosus were modeled with tetrahedral type elements 10 nodes (26112 elements 42449 nodes), the annulus fibrosus were modeled with elements of type tetrahedral to 10 nodes (114036 elements, 244800 nodes).

The gelatinous cartilage modeled with a tetrahedral element to 10 nodes (87710 elements, 160055 nodes). Finally, the different types of ligaments generated by a tetrahedral mesh to 10 nodes “Table 3”. The diagram in \ "(Fig. 4) \" shows a person standing of specific global 80kg weight, the overall mass (Head, Neck, Arm (left + right), Forearm (left + right), hand (left + right)) is 13,4517kg to divided by the top surface of the thoracic vertebrae Th1 representing the pressure P1, P2 load represents the mass of the body superior Trunk is 12,768kg, the distance between the point of application of the load and axis (yy ') is 200 mm \ "(Fig. 14) \".

The total mass of the lower trunk of the human body is equal to 22 kg; represented by P3, the distance between the point of application of the load and the axis (yy ') is 250 mm \ "(Fig. 14) \" P4 represents the maximum mass of the backpack is (20 kg), the distance between the point of load application and the axis (yy ‘) of the spine is (350 mm) \ "(Fig. 14) \".

For the boundary conditions we fixed the sacrum (Embedding the sacrum) \"(Fig. 14) \". We propose in this section to draw up a comprehensive study of the distributions of stresses and elastic strain in the intervertebral discs, the cortical bone, cancellous bone, the posterior arch, anterior longitudinal ligament and posterior according to the supported loads. Distributions of global stress state for each component of our model were presented.

A quantitative analysis was performed based on a scale of progressive visual colors predefined by the software used (ANSYS Workbench 16.5), ranging from dark blue to red.

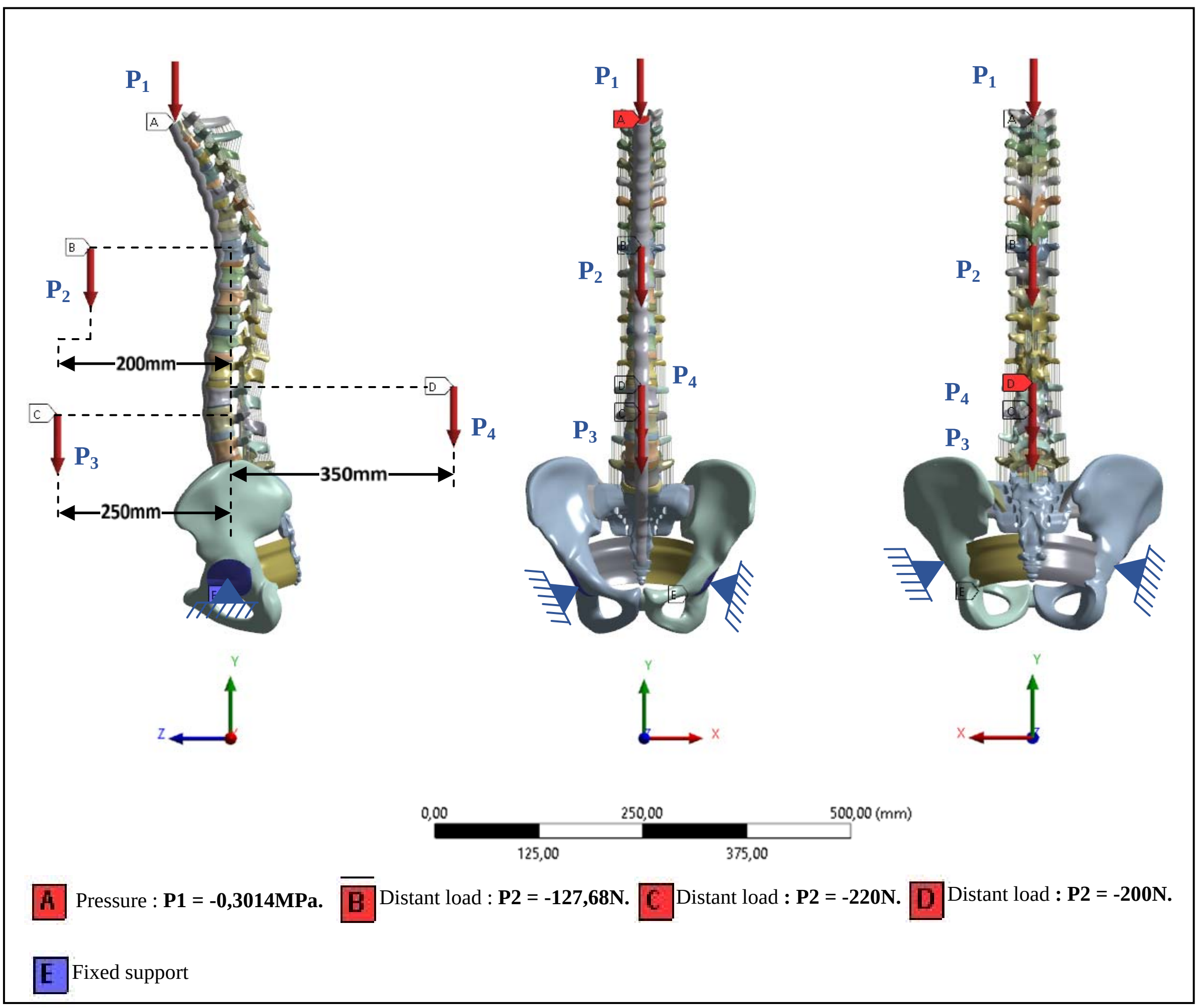



*Fig. 14:* Model biomechanics of the spine (posterior loading).

## III. Results

Fig (15) shows a histogram of stress and maximum strain of Von Mises, we notice that the spine undergoes a concentration of maximum stresses in the thoracic region, in the order word the stresses in the thoracic vertebrae (Th3, Th4, Th5, Th6, Th7) are respectively equal to (995,68MPa, 754.61 MPa, 467.09 MPa, 483.08 MPa, 369.65 MPa) as mentioned in \ "(Fig. 17) \".

Fig 16 shows a load applied to the upper surface of the thoracic vertebra TH1 of the spinal column causes a high concentration of maximum Von Mises strains in the anterior part of vertebral bodies (red section) this is mentioned in \ "(Fig. 17) \".

On the other hand, Fig 17 shows that the posterior arch of the thoracic vertebrae (Th3, Th4, Th5, Th6, Th7) absorbed the maximum von Mises stresses, these stresses were observed on a posterior side of the spine (red contour) with respect to other components of the system of the spine. Proceeding from the fact that the Fig (17) and (16) that watches the posterior load presents greater strains within two thoracic vertebrae (Th3, Th4) which are equal to (0.29194, 0.21867), which means that the so-called vertebrae are the most stressed in the case of posterior bending.

Fig (18) shows that the posterior loading presents maximum stresses and strains concentrated in the intervertebral disc D1 that is to say between the sacrum and the lumbar vertebra L5, in the order word the \ "(Fig. 19) \" clearly shows that the loading posterior with a lever arm equal 350mm presents maximum Von Mises stresses and strains concentrated in the disc D1 and are respectively equal to (6,9797MPa, 1,7347mm / mm).

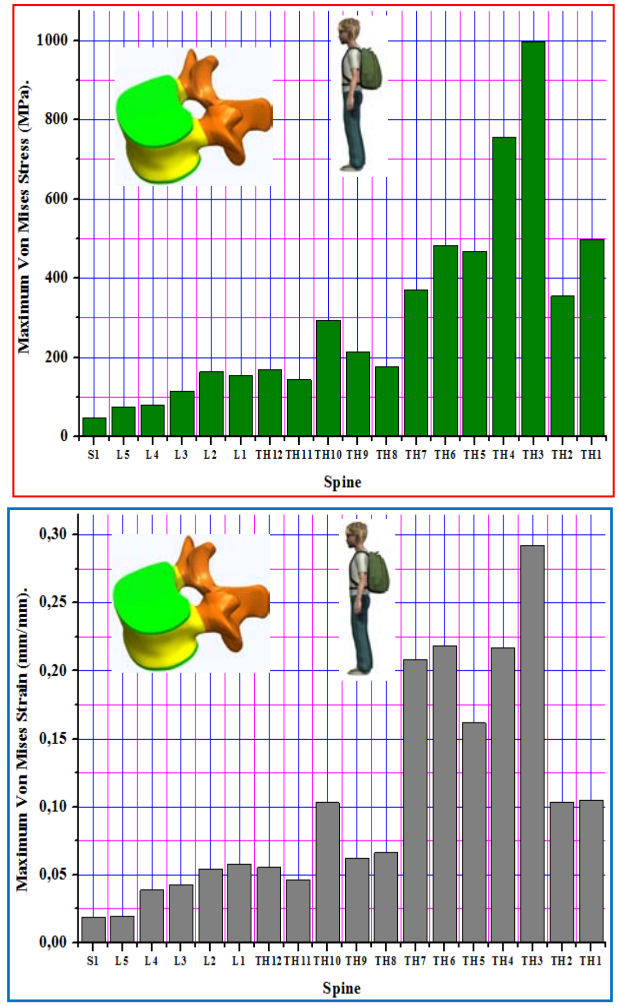



*Fig. 15:* Histogram of stress and strain in the spine for a load of 20kg.

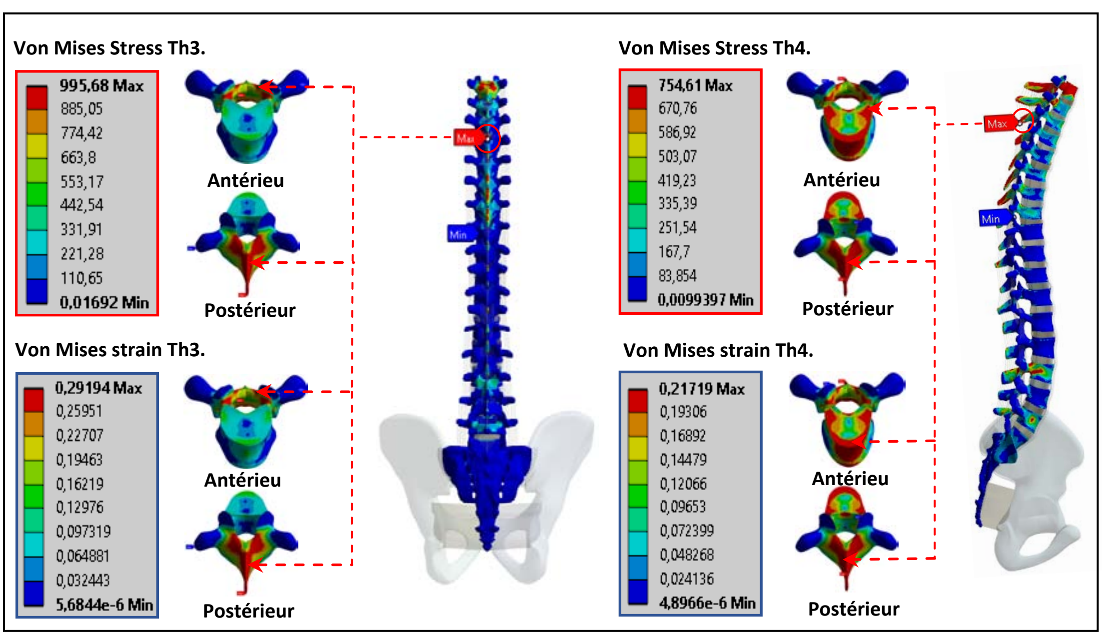



*Fig. 16:* Distributions of stresses and strains in the thoracic vertebrae (Th3, Th4) for a load of 20kg.

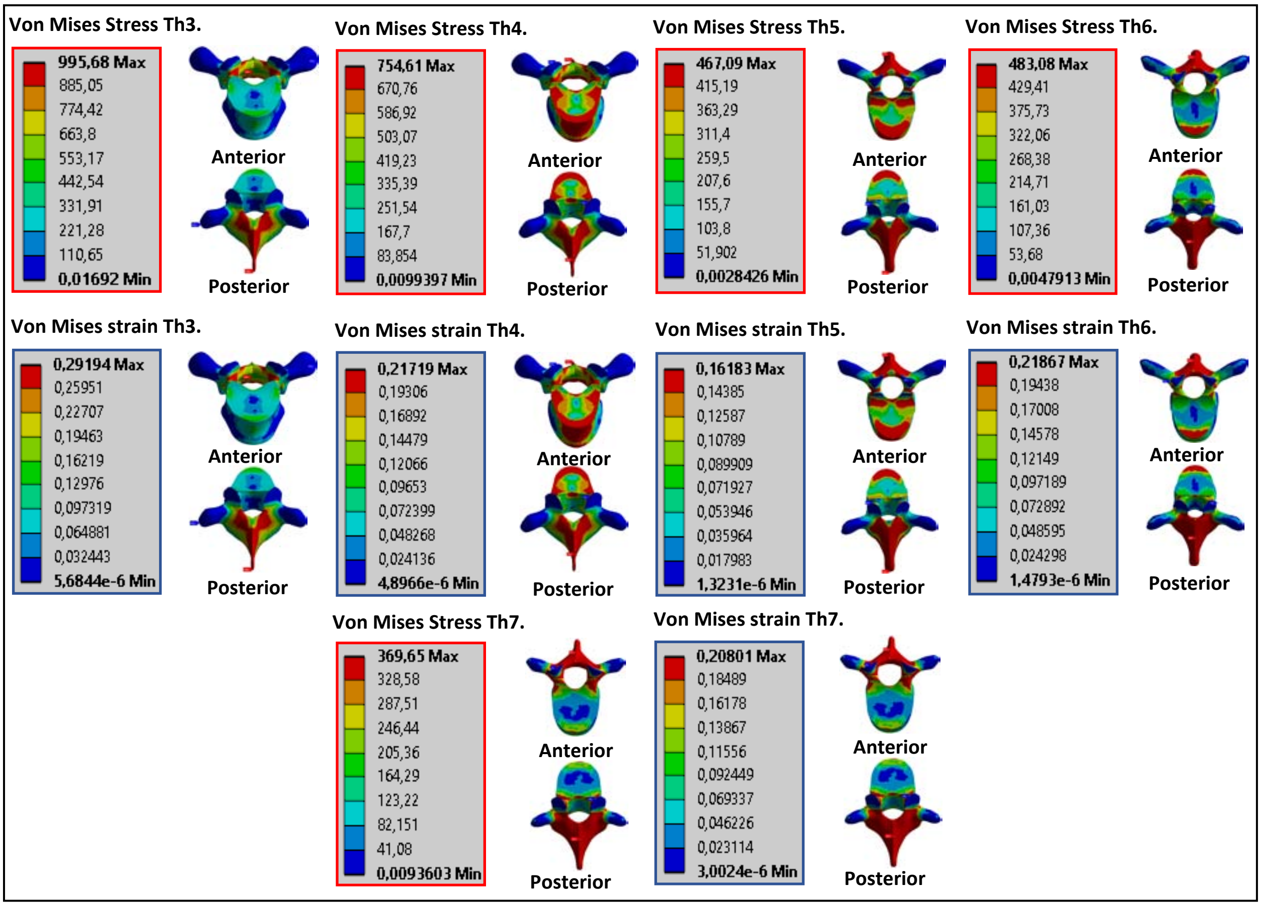



*Fig. 17:* Distributions of stresses and strains in the thoracic vertebrae a load of 20kg.

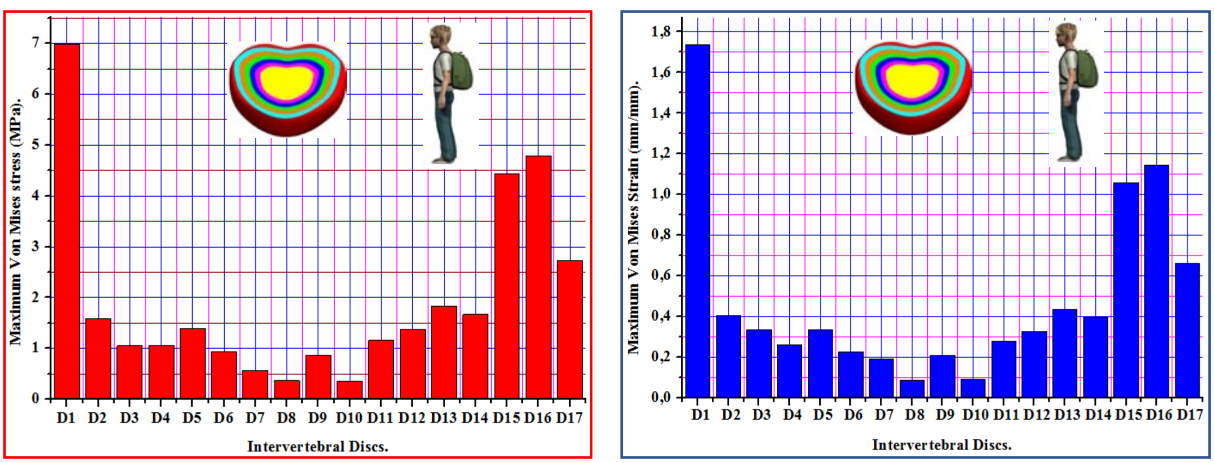



*Fig. 18:* Histogram of stresses and strains in the DIV for a load of 20kg.

We see in Fig (18) the intervertebral discs (D1, D15, D16, D17) absorbed the maximum stresses that equal (6,9797MPa, 4,4374MPa, 4,7858MPa, 2,7365MPa), On the other hand the posterior loading presents of maximum strains concentrated in the intervertebral discs (D1, D15, D16, D17) which are respectively equal to (1.7347, 1.0586, 1.1463, 0 66065) as mentioned in \ "(Fig. 19) \". Figure (9) shows that the mixed loading (P1 compression + bending moment (P3)) has a contour of maximum red part stresses in the disc D1 and we see in this figure the front part of the disc D1 is pulled and another compressed part, other hand figure (9) clearly shows that the backpack is a repeated effort back into everyday life ultimately cause disc problems, particularly at the lumbar region (lumbar disc herniation).

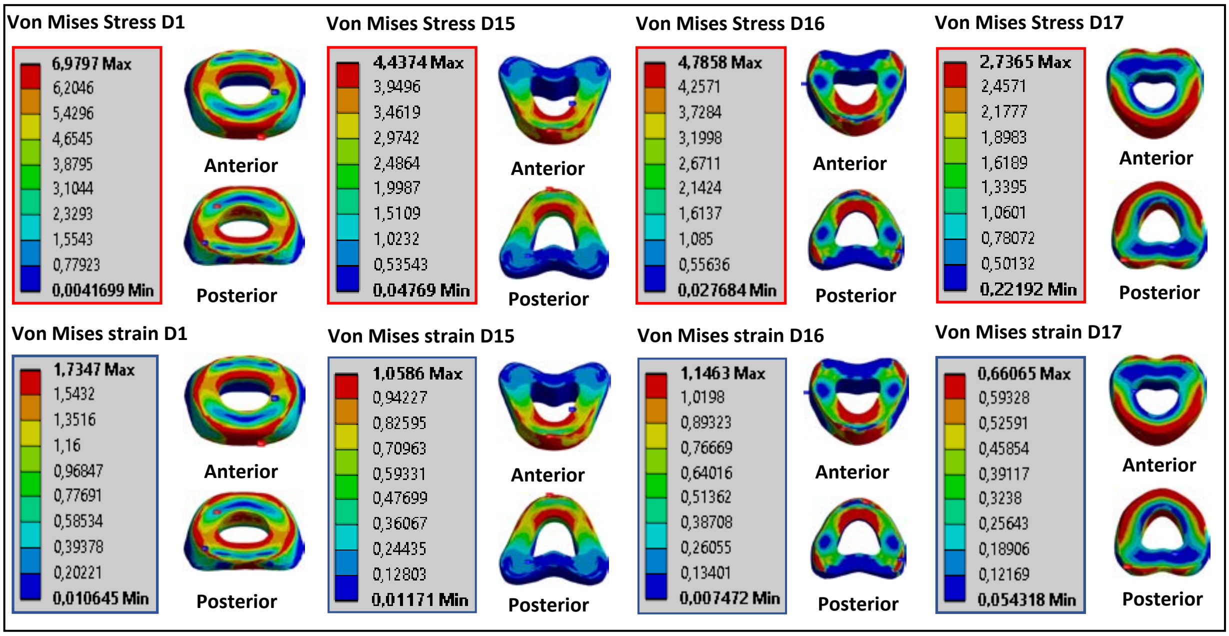



*Fig. 19:* Distributions of stresses and strains in the DIV for a load of 20kg.

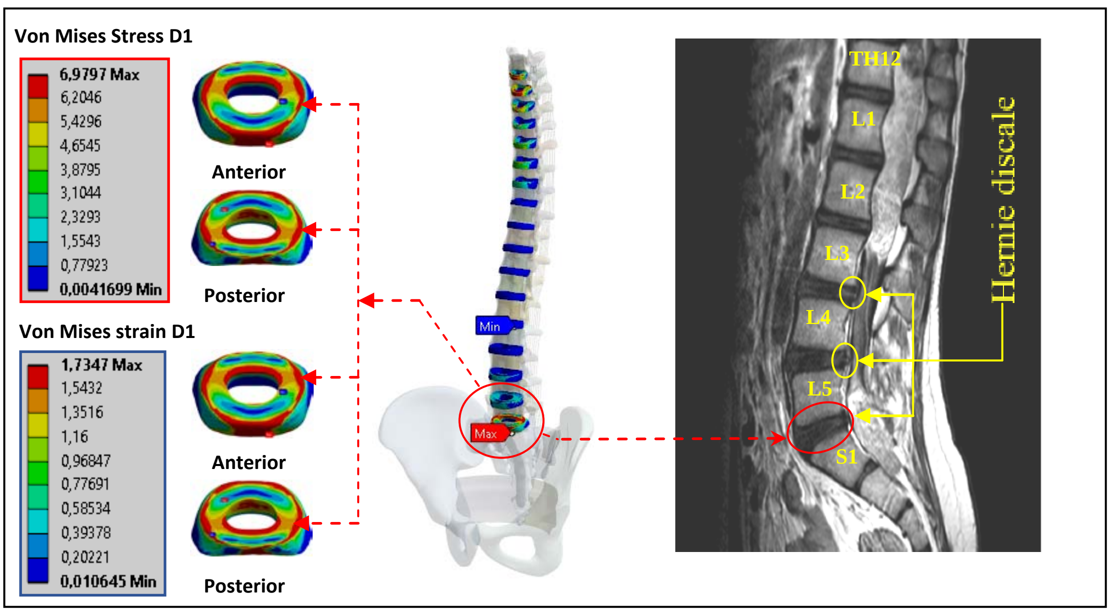



*Fig. 20:* Distributions of stresses and strains in the intervertebral disc D1 for a load of 20kg.

Fig (20) shows that the mixed loading (P1 compression + bending moment (P3)) has a contour of maximum stresses red part in the disc D1 and we see in this figure the front part of the disc D1 is pulled and another compressed part, other hand \ "(Fig. 20) \" clearly shows that the backpack is a repeated effort to back into everyday life ultimately cause disc problems, particularly at the lumbar region (lumbar disc herniation).

We see in Fig 21 that the backpack it's a very dangerous loading and with time creates pain in the 1st, 2nd intervertebral disc and causes sciatica or cruralgia, regarding the spinal nerve compressed by the two disks (D1, D2) and the pressure causes intense pain radiating throughout the leg, the path of pain follows closely the path of the nerve. In extreme cases, this results in partial or complete paralysis of the leg.

A load applied to the upper surface of the thoracic vertebra TH1 of the spinal column causes a high concentration of normal maximum von Mises stresses in the anterior and posterior part of the cortical bone (S1, Th12, Th5, Th1) (parts by red) this is indicated in \ "(Fig. 22) \".

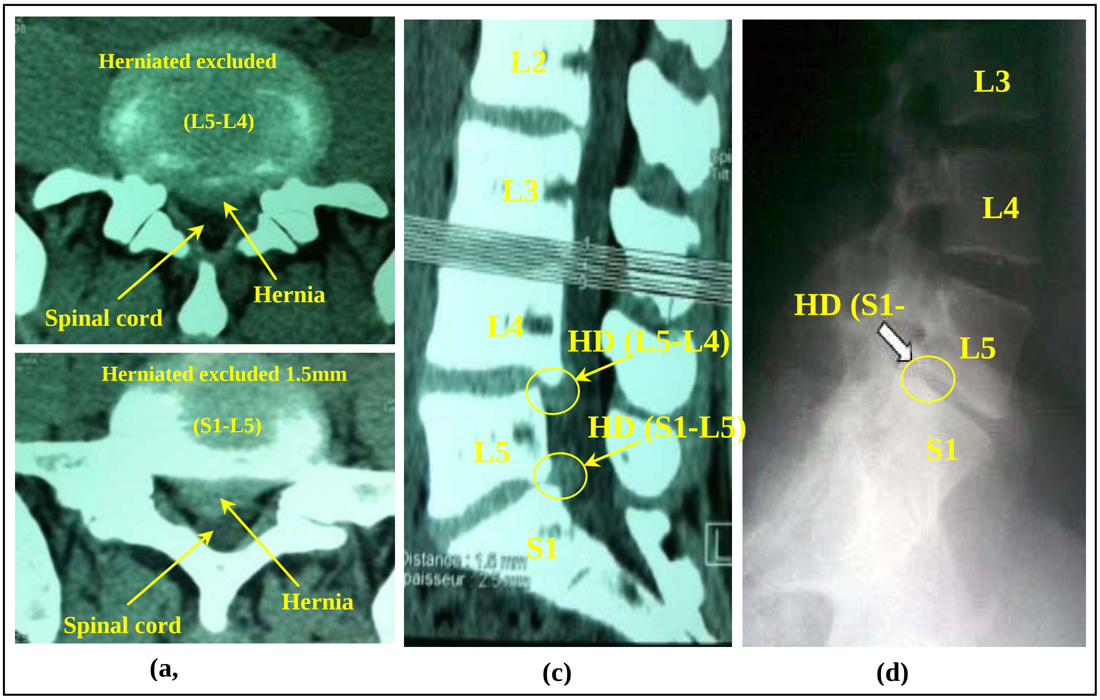



*Fig. 21:* Images of a girl 17 years old suffering back pain so severe, she was unable to walk. TDM spine lumbosacral axial section (a, b) and sagittal reconstruction (c) showing a double HD L4-L5 and L5-S1 (d) Standard radiography spine profile lumbosacral showing a pinch last intervertebral disc L5-S1.

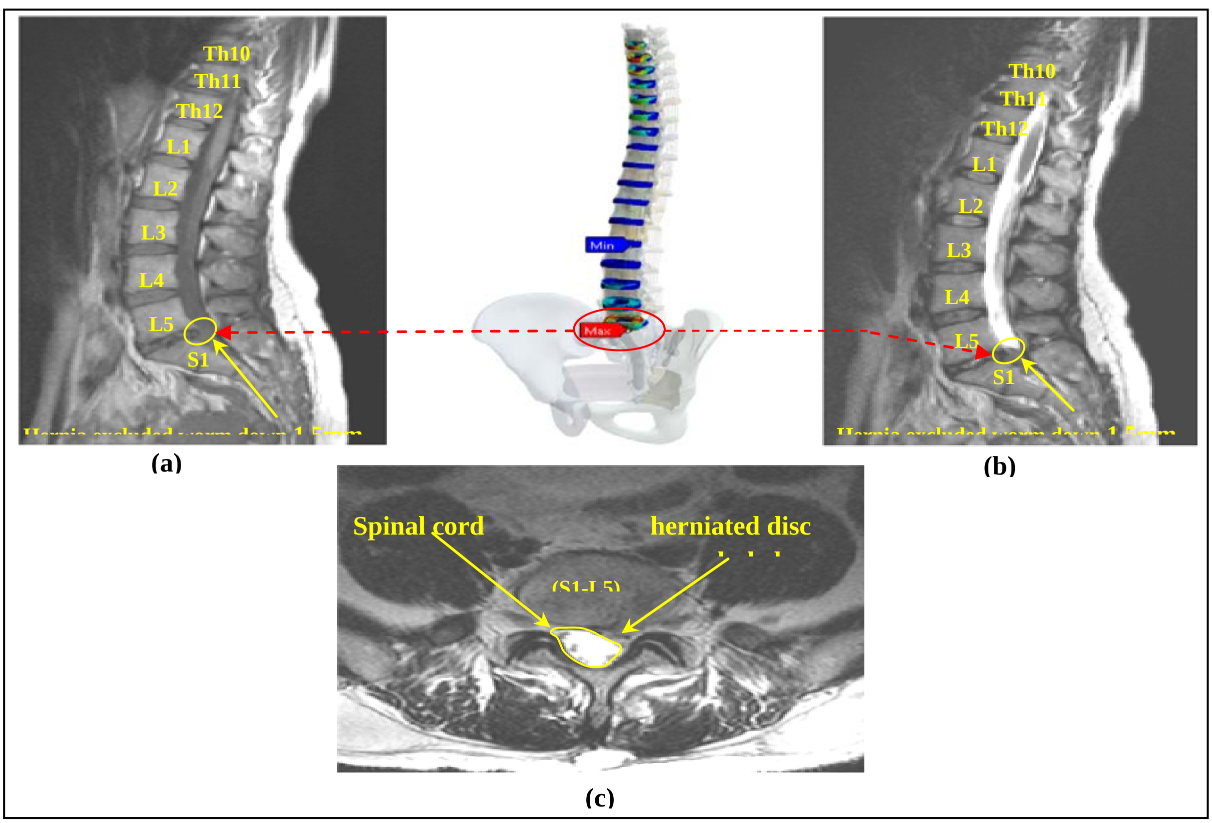



*Fig. 22:* MRI of the lumbar sacral spine of a 16-year-old boy showing: (a) MRI weighted sagittal sequence T1, T2, (b) weighted axial T2, (c) showing a herniated disc L5-S1 posterolateral left side and migrated down.

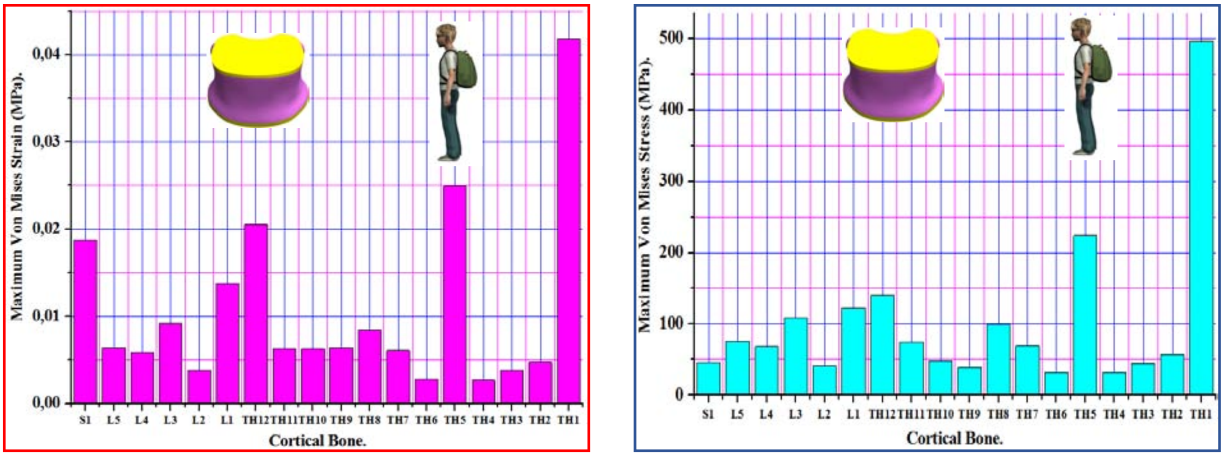



*Fig. 23:* Histogram of stresses and deformations in the cortical bone for load of 20kg.

On the other hand, \ "(Fig. 22) \" shows that the maximum von Mises stresses in the cortical bone (S1, Th12, Th5, Th1) are equal to (40,069MPa, 140.15 MPa 223.82 MPa 496, 69 MPa) as compared to other components of the system of the spine see \ "(Fig. 24) \". A loading of the posterior backpack applied on the upper surface of the thoracic vertebra TH1 of the spinal column causes a high concentration of maximum normal strains in the anterior part of the thoracic vertebra Th (red part) this is mentioned in \ "(Fig. 23) \", with regard to the said vertebra supported Von strain value set which are equal to (0,041791mm / mm) relative to the other components of the system of the spine.

Fig (25) shows a histogram of the stresses and strains Von put supported by the cancellous bone and it is noted that the maximum stress is concentrated in the cancellous bone of the thoracic vertebra Th1 as shown in \ "(Fig. 26) \".

The posterior load \ "(Fig. 3) \" shows clearly that the stresses and strains of Von Mises are concentrated in the two cancellous bone (Th1, Th5) and are respectively equal to (4.6282Mpa, 5.7386MPa) and (0.049594, 0.057685) this is mentioned in the (Fig 26)

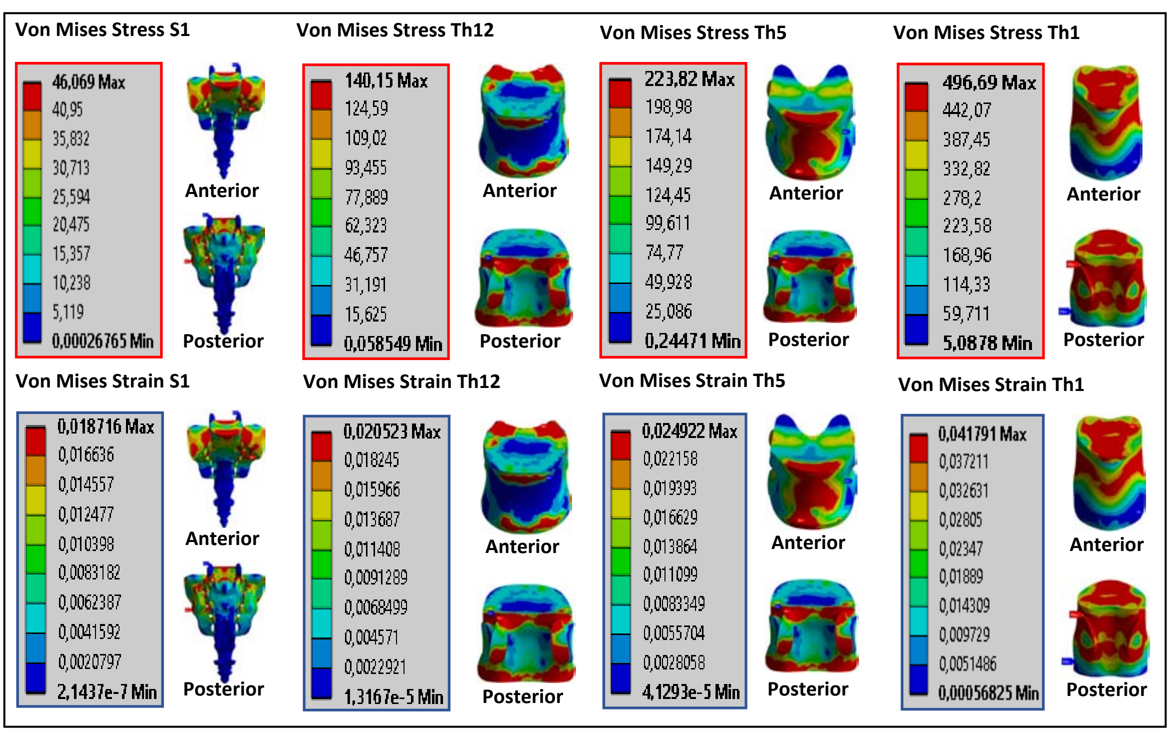



*Fig. 24:* Distributions of stresses and strains in the cortical bone for load of 20kg.

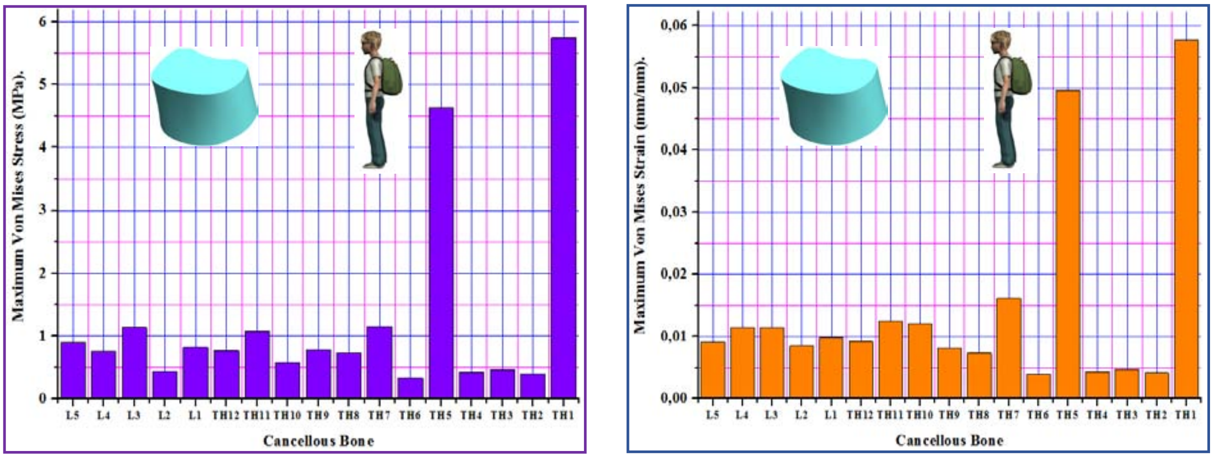



*Fig. 25:* Histogram of stresses and strains in the cancellous bone with a load of 20kg.

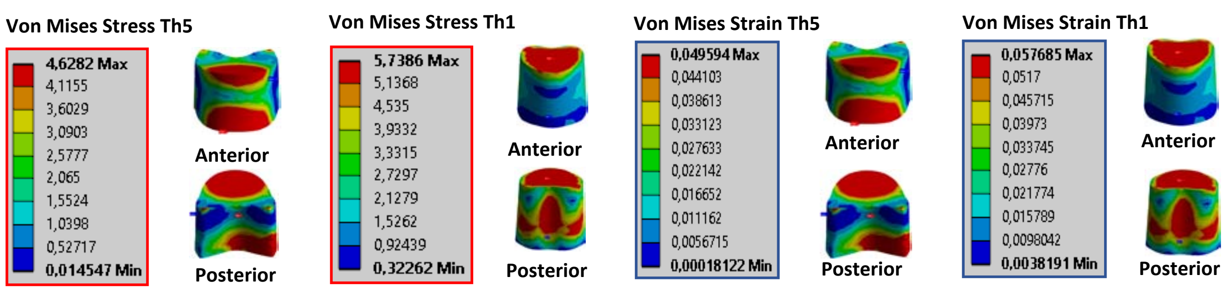



*Fig. 26:* Distributions of stresses and strains in the cancellous bone with a load of 20kg.

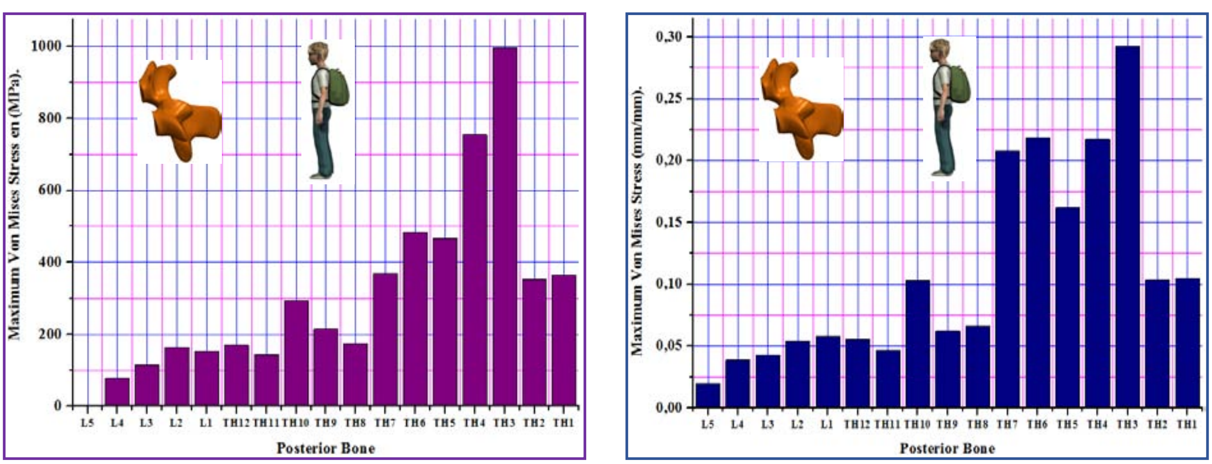



*Fig. 27:* Histogram of stresses and strains in the posterior arch for a load of 20kg.

Global Journal of Researches in Engineering ( A ) Volume XVI Issue IV Version I Year 2016

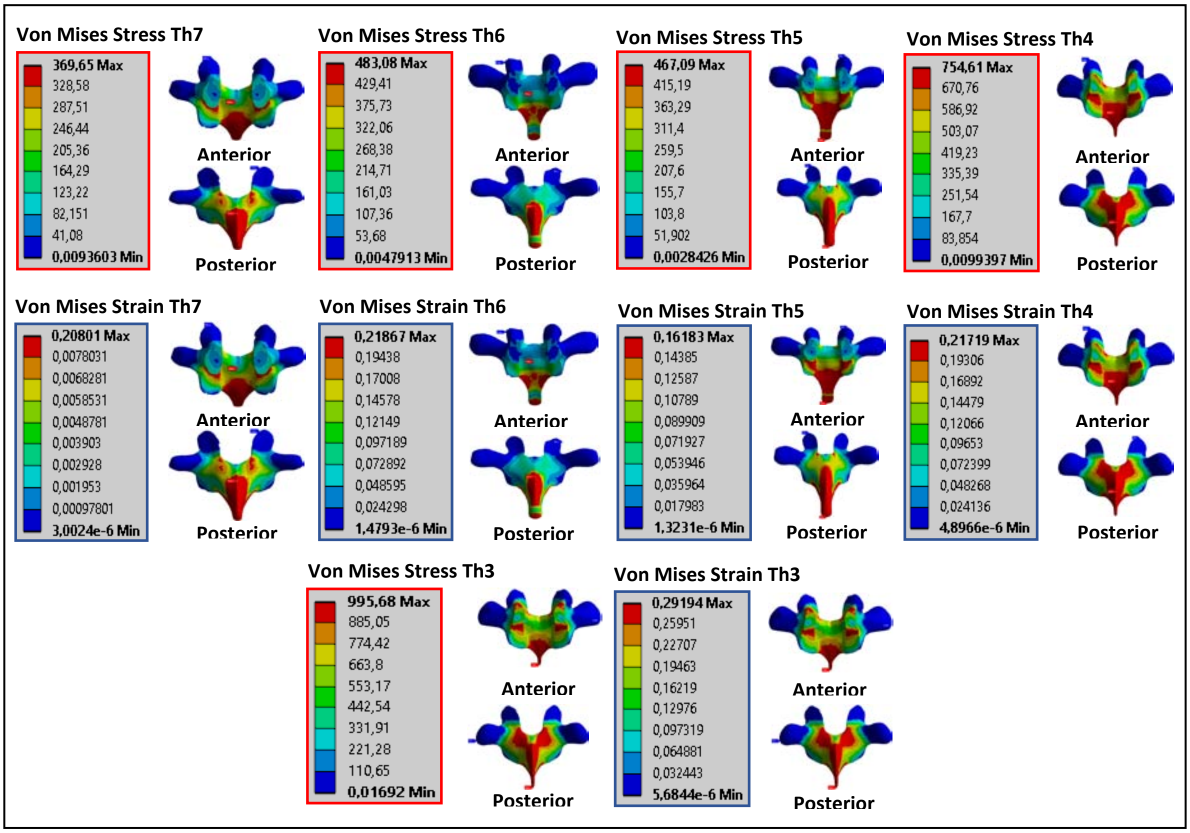



*Fig. 28:* Distributions of stresses and strains in the posterior arch for a load of 20kg.

The posterior loading of the backpack with a 350mm lever shown that increased stresses and strains of Von Mises illustrated in the face of upper and lower articulation of the posterior arch of the thoracic vertebrae (Th3, Th4, Th5 , Th6, Th7) (red outline) \ "(Fig. 27) \", on the other hand \ "(Fig. 28) \"shows clearly legend stress and strain of Von Mises put in the thoracic region (Th3, Th4, Th5, Th6, Th7) are respectively equal to (995,68MPa, 754,61MPa, 467,09MPa, 483,08MPa, 369,65MPa) and (0.29194, 0.21719, 0.16183, 0.21867, 0.21867) compared to other components of the system spine. We see in Figure 18 the role of the basin to transmit the load to the lower part of the human body and absorbation stresses and strain Von bets (red outline), we note that the two bodies (basin, sacrum) supported stresses and normal elastic deformations which are equal to (46,069MPa, 28,201MPa) and (0.012947, 0.0187) relative to the other components of the system of the spine.

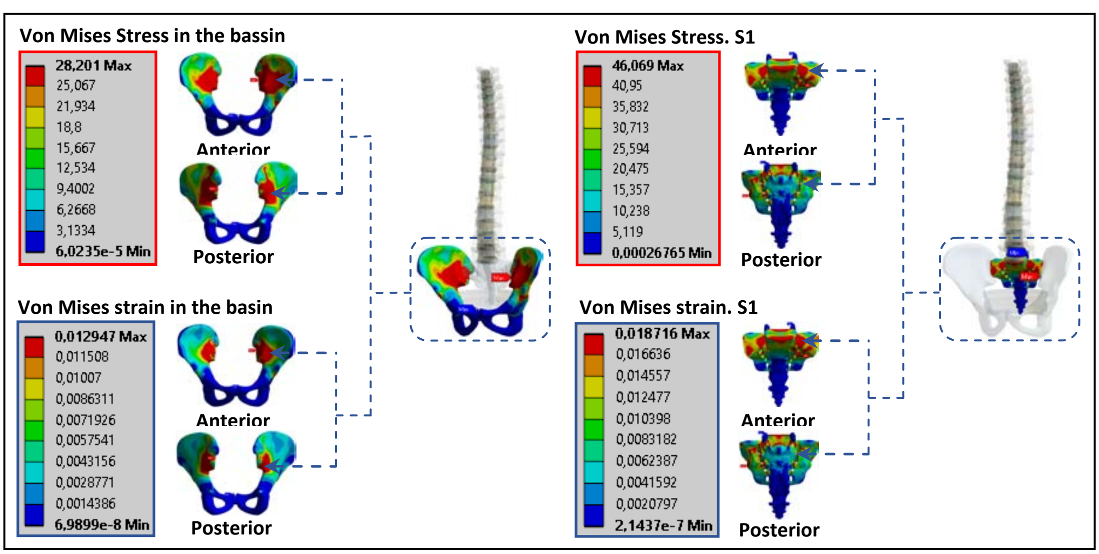



*Fig. 29:* Distributions of stresses and strains in the basin and sacrum for a load of 20kg.

## IV. Discussion

In sum, we concluded that the posterior loading is certainly an aggravating factor, and may cause long term back problems and strains of the spine, the 3D model of the spine of a child under the effect of an eccentric load and calculate by the FEM provokes stress and strains maximum of Von Mises concentrated in the intervertebral disc (D1) and are equal to (6,9797MPa, 1,7347mm / mm) as noted in the \ "(Fig. 18) \", with regard to \ "(Fig. 19, 20, 21) \" show that the intervertebral disc (D1) is the most damaged which is disc degeneration often occurs after a phase asymptomatic dehydration cracks, tearing of annulus fibrosus (D1 ), the nucleus (N1) can then along these cracks migrate into the ring thickness (D1), and cause acute or chronic back pain, If the core (N1) move around more through the ring (D1), the core can project to the posterior surface of the disc while forming a lumbar disc herniation, this hernia can complete rupture of the ring, migrate laterally into the vertebral canal, or up or down, and even exclude leaving the disk, herniated disc that can come be compressed one or more nerve roots "stuck" near the disc, causing the symptoms of pain "sciatica" when the rear seat of the thigh or "cruralgie" when the seat of pain in the front of the thigh. This justifies that the distance between the load which is the point of application of the load and the axis of the spine plays an important role in increasing stresses at the intervertebral discs.

## V. Conclusion

In sum, we concluded the case of posterior loading 350mm lever arm with a load 200N posterior indicate normal maximum Von Mises stresses in four intervertebral discs (D1, D15, D16, D17) and are equal to (6,9797MPa, 4,4374MPa, 4,7858MPa, 2,7365MPa) these mentioned in \ "(Fig. 18) \", on the other hand \ "(Fig. 19) \"clearly shows the elastic strain is higher in the four intervertebral discs (D1, D15, D16, D17) that are equal (1.7347, 1.0586, 1.1463, 0 66065), which justifies that the distance between the load which is the point of application of the load and the axis of the spine plays a very important role in increasing the solitation of the latter.

## VI. Acknowledgements

The authors extend their appreciation to the Director of Scientific Research at LaBPS for funding the work through the Biomechanics Research Group.

## References Références Referencias

1. Thomas, M. Contribution A L'analyse Biomécanique Et A L'évaluation Des Implants Rachidiens, L'école Nationale Supérieure D'arts Et Métiers Spécialité “Biomécanique”, Paris, 2008.
2. Hernie Discale Lombaire, Service de Chirurgie orthopédique et Traumatologique, Hôpital Beaujon.
3. Robert Bohinski, MD. Herniated Lumbar Disc. Mayfield Clinic, universty of cincinnati department of neurosurgery, cincinnati, Ohio, mayfieled brain and spine, 1998-2016.
4. Dr. Kilcup. Herniated disk fixed without harmful, Addictive Drugs and Surgery, 20 October 2011.
5. Karine, L. Institut Français D'étiopathie (IFE) Paris, le 16 Septembre 2014.
6. Dr Kassab M. Centre Avicenne Médical, 2 Av Tahar Sfar, 2092, El Manar 2, Tunis, Tunisie.
7. White Iii AA, And Panjabi MM. Clinical Biomechanics Of The Spine. 1990.
8. Marcovschi Champain S. Corrélations Entre Les Paramètres Biomécaniques Du Rachis Et Les Indices Cliniques Pour L'analyse Quantitative Des Pathologies Du Rachis Lombaire Et De Leur Traitement Chirurgical, Enam, Paris. 2008.
9. Pr. Francois L. Biomécanique Et Ostéosynthèse Du Rachis Ensm-Lbm Conférences D'enseignement De La Sofcot. 1997.
10. Starmans FJ, Steen WH, Bosman F. A Three-Dimensional, Finite-Element Analysis Of Bone Around Dental Implants In An Edentulous Human Mandible. Arch Oral Biol. 1993; 38: 491– 6.
11. Ibarz E, Más Y, Mateo J, Lobo-Escolar A, Herrera A. And Gracia L. Instability Of The Lumbar Spine Due To Disc Degeneration. A Finite Element Simulation. Advances In Bioscience And Biotechnology. 2013; 4: 548-556.
12. Mingzhi S, Zhen Z, Ming L, Junwei Z, Chao D, Kai M and Shouyu W. Four Lateral Mass Screw Fixation Techniques In Lower Cervical Spine Following Laminectomy. A finite Element Analysis Study Of Stress Distribution.
13. Steven A, Rundell, MS, Jorge E, Isaza MD, Steven M, Kurtz Phd.) Biomechanical Evaluation Of A Spherical Lumbar Interbody Device At Varying Levels Of Subsidence. Exponent, inc, philadelphia, pa, sas journal. 2011; 5: 16-25.
14. G, Vijay K, PhD, M Ankit, BS, J, Jayant, BS, Faizan A, BS, K, Ali MS, Hoy R.W, MEng, and Fauth AR, PhD. Anatomic facet replacement system (AFRS) restoration of lumbar segment mechanics to intact. a finite element study and in vitro cadaver investigation. SAS Journal. 2007; 1: 46–54.
15. Holekamp S, MS Goel V, PhD K Hiroshi, MD H Janet MS and E Nabil MD. Optimal Intervertebral Sealant Properties for the Lumbar Spinal Disc. A Finite-Element Study. SAS Journal. Spring. 2007; 1: 68–73.
16. CAE, MD, Huang H, PhD, Vestgaarden Tov, PhD, Saigal S, PhD, Clabeaux DH, RN, and Pienkowski D, PhD. Stress Reduction in Adjacent Level Discs Via Dynamic Instrumentation. A Finite Element Analysis. SAS Journal. Spring. 2007; 1: 74–81.

17. López E, Elena I, Herrera A, Mateo J, Lobo-Escolar A, Puértolas S, Gracia L. Probability Of Osteoporotic Vertebral Fractures Assessment Based On DXA Measurements And Finite Element Simulation. Advances in Bioscience and Biotechnology. 2014; 5: 527-545.
18. Kiapour A, Kiapour AM, Kodigudla M, Hill GM, Mishra S and Goel VK. A Biomechanical Finite Element Study of Subsidence and Migration Tendencies in Stand-Alone Fusion Procedures. Comparison of an In Situ Expandable Device with a Rigid Device. J Spine. 2012; 1: 2165-7939.
19. Zheng SN, Yao QQ, Wang LM, Hu WH, Wei B, Xu Y, Zhang DG. Biomechanical Effects Of Semi Constrained Integrated Artificial Discs On Zygapophysial Joints Of Implanted Lumbar Segments. Experimental and Therapeutic Medicine. 2013; 6: 1423-1430.
20. Byun DH, Ah Shin D, Kim JM, Kim SH, Kim HI. Finite Element Analysis of the Biomechanical Effect of CoflexTM on the Lumbar Spine. laboratory investigation. Korean J Spine. 2012; 9 (3): 131-136.
21. Lan ChCh, Kuo ChS, Chen ChH, Hu HT. Finite element analysis of biomechanical behavior of whole thoraco-lumbar spine with ligamentous effect. The Changhua Journal of Medicine. 2013; 11: 26-41.
22. Natarajan RN and Andersson GBJ. Modeling the annular incision in a herniated lumbar intervertebral disc to study its effect on disc stability. Comput Struct. 1997; 64: 1291-7.
23. Pitzen T, Geisler FH, Matthis D, Storz HM, Pedersen K And Steudel WI. The influence of cancellous bone density on load sharing in human lumbar spine: a comparison between an intact and a surgically altered motion segment. Eur Spine J. 2001; 10: 23-9.
24. Polikeit A. Finite element analysis of the lumbar spine: Clinical application. Inaugural dissertation. University of Bern. 2002.
25. Denozi´Ere G. Numerical modeling of a ligamentous lumber motion segment, M.S. thesis, Department of Mechanical Engineering. Georgia Institute of Technology. Georgia. USA. 2004.
26. Gwanseob Shin. Viscoelastic responses of the lumbar spine during prolonged stooping. Ph.D. dissertation, NCSU, USA. 2005.
27. Sairyo K, Goel VK, Masuda A, Vishnubhotla S, Faizan A, Biyani A, Ebraheim N, Yonekura D, Murakami RI and Terai T. Three-dimensional finite element analysis of the pediatric lumbar spine. Eur Spine J. 2006; 15: 923-9.
28. Rohlmann A, Burra Nk, Zander T, Bergmann G. Comparison of the effects of bilateral posterior dynamic and rigid fixation devices on the loads in the lumbar spine. Eur Spine J. 2007; 16: 1223-31.
29. Wilke Hj, Neef P, Caimi M, Hoogland T, Claes Le. New intradiscal pressure measurements in vivo during daily activities. Spine. 1999; 24: 755-62.
30. Smit T, Odgaard A, Schneider E. Structure and function of vertebral trabecular bone. Spine. 1997; 22: 2823-33.
31. Sharma M, Langrana Na, Rodriguez J. Role of ligaments and facets in lumbar spinal stability. Spine. 1995; 20: 887-900.
32. Lee K, Teo E. Effects of laminectomy and facetectomy on the stability of the lumbar motion segment. Med Eng Phys.2004; 26: 183-92.
33. Rohlmann A, Zander T, Schmidt H, Wilke Hj, Bergmann G. Analysis of the influence of disc degeneration on the mechanical behaviour of a lumbar motion segment using the finite element method. J Biomech. 2006; 39: 2484-90.
34. Ng Hw, Teo Ec. Nonlinear finite-element analysis of the lower cervical spine (C4– C6) under axial loading. J Spine Disord. 2001; 14: 201-10.
35. Ng HW, Teo ECh and Zhang QH. Influence Of Laminotomies And Laminectomies On Cervical Spine Biomechanics Under Combined Flexion-Extension. Journal Of Applied Biomechanics. 2004; 20: 243-259.
36. Gong Z MM, Chen Z MD, Feng Z MD, Cao Y MM, Jiang Ch MD, Jiang X MD. Finite Element Analysis of 3 Posterior Fixation Techniques in The Lumbar Spine. Feature Article. 2014; 37: E441- E448.
37. Kim HJ, Tak Kang K, Chang BS, Lee ChK, Kim JW, And Yeom JS. Biomechanical Analysis of Fusion Segment Rigidity Upon Stress at Both the Fusion and Adjacent Segments-A Comparison between Unilateral and Bilateral Pedicle Screw Fixation. Yonsei Med J. 2014; 55(5): 1386-1394.
38. Claire B-R, MASc, Pierre-Jean A, PhD, Rohan-Jean B, PhD, Yves G-R, MEng L F, PhD,Carl-Éric A-P. Finite Element Analysis of Sacroiliac Joint Fixation under Compression Loads. International Journal of Spine Surgery.2016 ; 10.14444/3016.

This page is intentionally left blank

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN: 0975-5861

# Leakage and Cavity Shape Studies of Labyrinth Seals

By R Mohana Rao & Dr. Manzoor Husain
*JNTU*

*Abstract-* Labyrinth seals are a non-contacting sealing device consists of a series of cavities connected by small clearances. They are used in many places in gas turbine engine to optimize and improve their design using CFD, is of interest to this study with newer designs of labyrinth seal. Preliminary investigations were carried out to establish the baseline capability for CFD analysis of labyrinth seals using Fluent and also to finalize the turbulence model with mesh type, thereafter detailed 2-D axi-symmetric analyses with different geometries and configurations. The applications of the new labyrinth seal designs are important to meet future performance of gas turbine goals. This paper presents improved design of canted seal design using RANS equations, with Turbulence two equations k-w turbulence model using Computational Fluid Dynamics (CFD).

*Keywords:* *labyrinth seal, CFD, ansys workbench, canted shape*

*GJRE-A Classification: FOR Code: 290501*

LEAKAGEANDCAVITYSHAPESTUDIESOFLABYRINTHSEALS

*Strictly as per the compliance and regulations of:*

# Leakage and Cavity Shape Studies of Labyrinth Seals

R Mohana Rao [α] & Dr. Manzoor Husain [σ]

*Abstract*- Labyrinth seals are a non-contacting sealing device consists of a series of cavities connected by small clearances. They are used in many places in gas turbine engine to optimize and improve their design using CFD, is of interest to this study with newer designs of labyrinth seal. Preliminary investigations were carried out to establish the baseline capability for CFD analysis of labyrinth seals using Fluent and also to finalize the turbulence model with mesh type, thereafter detailed 2-D axi-symmetric analyses with different geometries and configurations. The applications of the new labyrinth seal designs are important to meet future performance of gas turbine goals. This paper presents improved design of canted seal design using RANS equations, with Turbulence two equations k-w turbulence model using Computational Fluid Dynamics (CFD).

*Keywords: labyrinth seal, CFD, ansys workbench, canted shape*

## Nomenclature

ε - Dissipation of turbulent kinetic energy
κ - Turbulent Kinetic energy
s- Tooth pitch, mm
A: Area [m2]
H: Step height [mm]
h: Teeth height [mm]
k: Specific heat ratio
m: Mass flow rate [kg/s]
N: Number of teeth
Po: Total pressure [kPa]
PR: Pressure ratio, Poin/Pout
s: radial clearance [mm]
To: Inlet total temperature [K]

*Abbreviations*
RANS – Reynolds-Averaged Navier- Stokes

## I. Introduction

Aviation industry face challenges when crude oil price increase that influence the economic conditions of world. This will directly impact on the engines running on crude oil products which convert chemical energy into mechanical energy for transportation, power generation etc., lead to optimization of turbo machinery future fuel conservation requirements. Studies show that reducing the high pressure turbine seal leakage of engine airflow would produce significant improvement of engine specific fuel consumption.

Gas path sealing is therefore a fundamental area of interest when seeking improvements in the efficiency and performance of aircraft engines. By reducing the level of leakage from the gas flow, efficient sealing helps retain the energy. As the performance improvement becomes marginal, reduction in leakage flows becomes more important. Therefore, labyrinth seals are used more intensively, their clearances are more tightly designed hence configurations are evolving continuously. Therefore, the requirement for an accurate leakage prediction is becoming more crucial. Labyrinth seals are the most common flow path seals applied to turbine engines. They consist of several knife edges in close clearance in a number of Configurations. Labyrinth seals rely on controlled leakage across the seal driven by the pressure difference between the seal ends. The design of the seal forces the flow to separate at the knife edge causing loss of kinetic energy and pressure from the gas flow.

## II. Present Work

In order to finalize the combination of parameters to be changed to improve the seal design, the experimental case of advanced seal configuration, Design 5; reported by H. L. Stocker in [3] is considered as baseline case. In the present work, the authors have conducted a CFD investigation on different configurations of canted teeth. The design evolved while conducting a parametric study on teeth height, teeth tip thickness, stepped teeth, inclined teeth etc. The baseline configuration is a simple sharp teeth labyrinth seal. The results obtained for the baseline configurations using this methodology were validated by comparing against 2D and 3D experimental data on stationary labyrinth seals with smooth land.

### a) *Baseline geometry: Canted Sharp Teeth*

Fig. 1 shows labyrinth seal geometry with dimensions. The labyrinth seal test section consists of an upper part, stepped, and a lower part with teeth. In a real engine, the upper and lower parts correspond to the stationary and rotating parts, respectively, have 4 teeth with inclined called Canted Seals. The two seals have almost similar teeth dimensions. Geometry definition:

*Author α: Post graduate from BITS Pilani, India pursuing PhD from JNTU Hyderabad. e-mail: mohan.ramanadham@gmail .com*
*Author σ: PhD, Professor, JNTU Hyderabad, Telangana.*
*e-mail: manzoorjntu@gmail.com*

Pitch – 7.62 mm; step height – 3.05 mm; Knife height – 3.81 mm and seal canted angle 50 deg

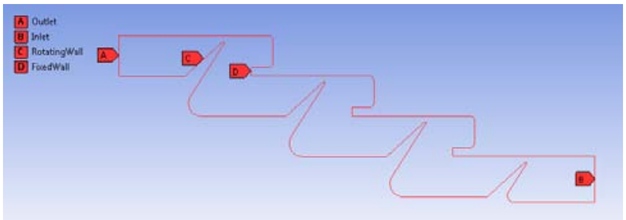



*Fig.1:* Base line teeth with 50 degree canted

*b) New geometry: Canted Advanced Teeth*

Fig.2 depicts the advanced sharp teeth are modified to increase the base of seal called Canted Advanced teeth. Except base width rest of parameters are kept same as original design.

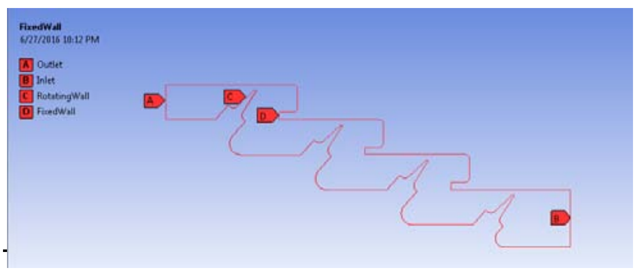



*Fig.2:* Modified advance seal teeth with 50 degree canted

c) *Performance Parameters*

The performance of a seal can be described by the relation between the pressure ratio and a flow parameter. The most common flow parameter is the following flow function:

$$\frac{m\sqrt{T_o, in}}{A_c P_O, in}$$

## III. Analysis

*a) Numerical analysis*

Computational Fluid Dynamics (CFD) is extensively used because its capability to analyze a large number of design configurations and parameters in a relatively short period of time. Therefore, with the development of commercial codes, the use of CFD analysis has been increasing rapidly in recent years in 2 or 3 dimensional analysis. The test cases adopted in this work are two-dimensional with number of different operating conditions are analyzed.

*b) Boundary Conditions*

A commercial finite volume code, Ansys Workbench with Fluent 16.1v [10] is used. This commercial tool has wave linking geometry that eliminates loss of geometry while importing from CAD model to Fluent, manages entire problem in project charter. It was assumed that air was an incompressible ideal gas and the flow was steady and adiabatic. Various turbulence models available in Fluent [10] were considered for the current simulations.

A realizable two-layer k-ε turbulent model was used closest to Stocker [3], This model combines the realizable k-ε turbulent model with the two-layer approach. The realizable k-ε turbulent model uses equivalent kinetic energy and dissipation rate equations, but has additional flexibility of all y+ wall treatment that gives reasonable results for intermediate meshes where the cell falls in the buffer layer. Polyhedral mesh elements were used to create unstructured meshes in the entire domain. Fig.3 & 4 shows an example of generated computational grids.

The grid density in the clearance area was refined to locate sufficiently large number of meshes, this is done using inflation of smooth transition with 8 ~ 10 layers. For a given geometry, the inlet temperature is kept ambient and the exit pressure was essentially ambient (99.5kPa) and inlet pressure is varied to corresponding inlet total pressure was obtained thru calculation.

c) *Mesh*

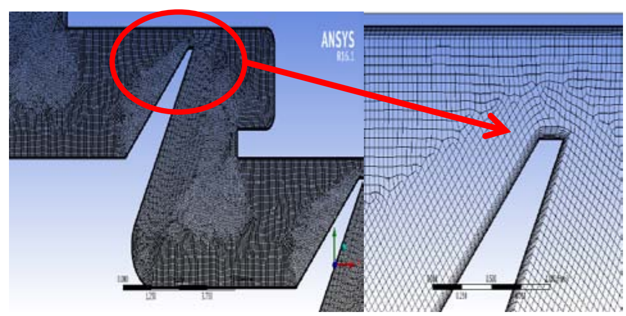



*Fig. 3:* Baseline geometry mesh (Model A)

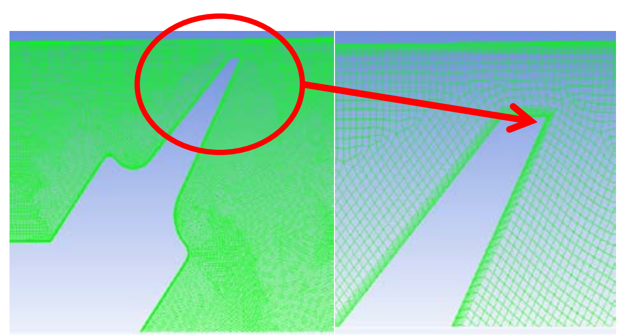


*Fig. 4:* Modified Advance seal mesh (Model B)

*d) Mesh Sensitivity*

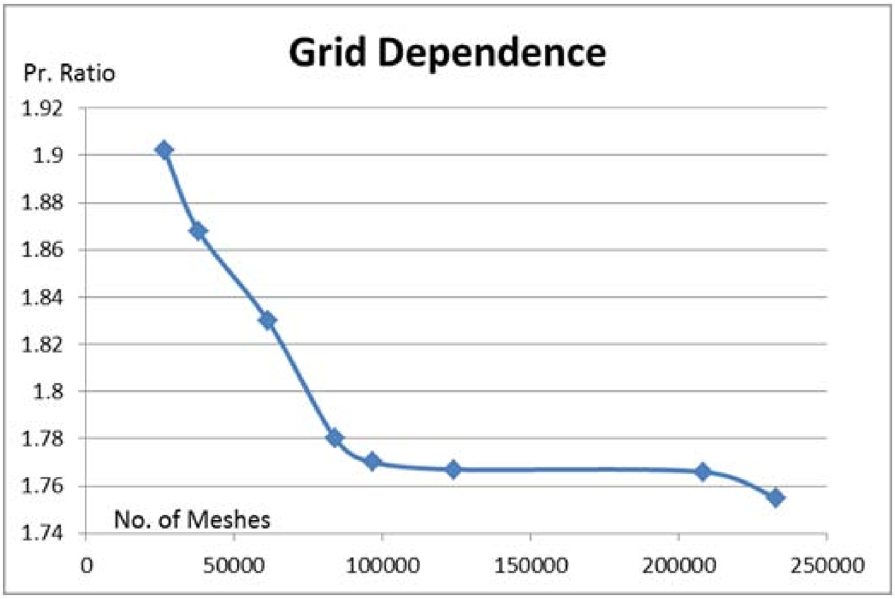



*Fig. 5:* Grid dependence of the CFD result

Grid dependence was checked to produce sufficiently converged solutions according to mesh size. Fig. 5 shows an example of grid dependence in the case of the Base geometry seal, presenting a variation of pressure ratio with the number of meshes for a given mass flow rate. The number of meshes ranges from 26,000 to 220,000 for the sharp teeth seal and from 43500 to 250,000 for the modified stepped seal, depending on the clearance size.

*e) Single Vs Double Precision Solver Comparison Study*

To study use of single and double precision solvers, baseline case was analyzed using single precision solver. The results from single precision solver were similar to those obtained except inlet velocity from the double precision solver. The CPU time for single precision solver was found more than double precision solver.

*Table 1*

| | | | At Inlet | | | At Exit | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| S.no | Analysis Description | No. of Cells | Mass flow (m/s) | V (m/s) | Temp (k)* | V (m/s) | Mass flow (m/s) | Pt (psa)* | Temp (k) | Del. T (k) | Pr = Pt(in)/ Ps(out) |
| 1 | Single Precision Solver | 177644 | 0.0073 | 9.5577 | 295.14999 | 14.203 | -0.007 | 99500 | 323.14679 | 27.997 | 2 |
| 2 | Double Precision Solver | 177644 | 0.0077 | 10.047 | 295.14999 | 12.977 | -0.008 | 99500 | 323.14999 | 28 | 2 |

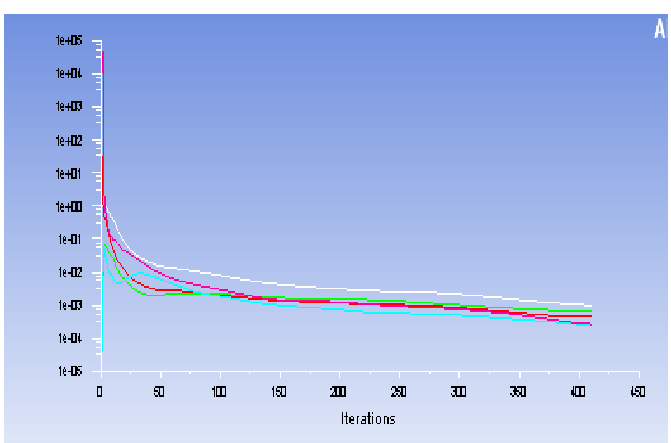



*Fig. 6:* Convergence plot for Double Precision

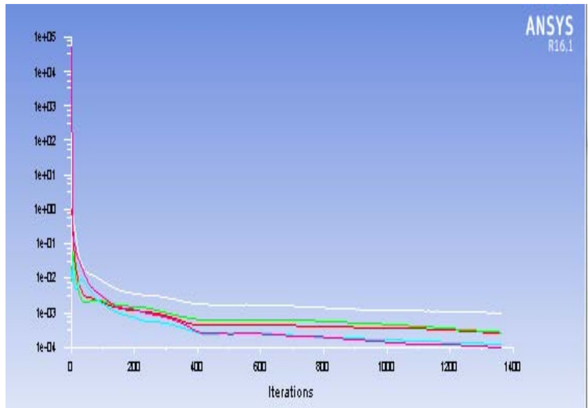



*Fig. 7:* Convergence plot for single Precision

*f) Model A case with Experimental data*

The Model A and Model B are run through by varying inlet pressure with ambient temprature and at exit ambient pressure. Models are run the pressure ratio reaching 3.0

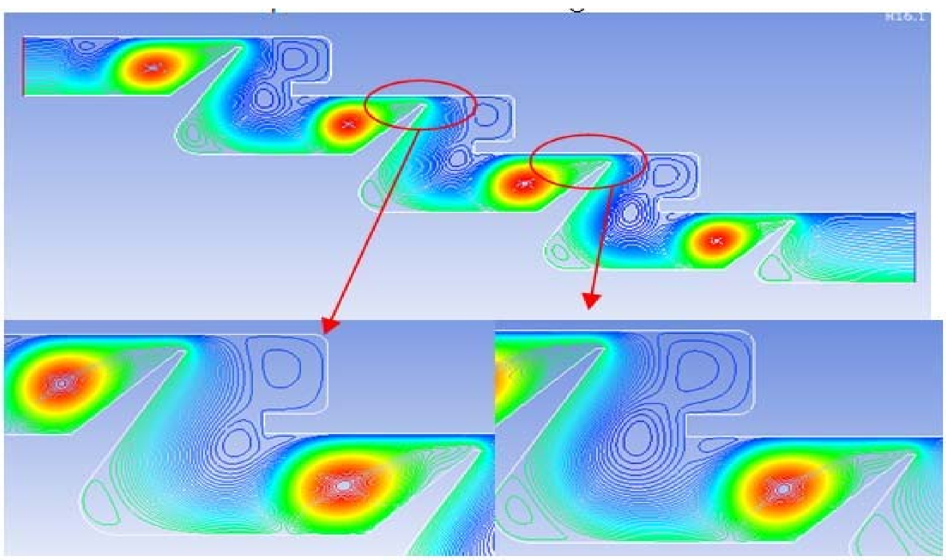


*Fig. 7:* Model A velocity contours

The model A results are plotted with experimental results. This is in line with the data. Refer the fig. for the graph showing experimental results CFD data which is ~ 5% variation.

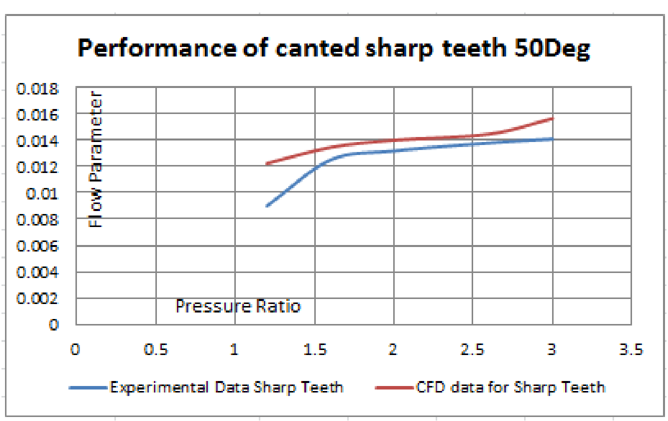



*Fig. 8:* Model a results with Experimental results

## IV. Results and Discussion

Analysis of Results with different Seal Configurations

In this paper following studies are carried:

- Various Turbulence Models Studied
- Model A case with canted angle:70, 60, 40
- Step height: 2.0 mm and 3.05 mm
- Knife-edge clearance: (0.25 and 0.51 mm)
- Rotor speeds (rpm): 0,10000, 20000, 30000

### a) *Turbulence Model Study*

2D axi-symmetric analysis of the modified Labyrinth Seal geometry (with rotation speed of 10,000 rpm) was first carried out. The objective was to establish baseline capability to run lab seal CFD analysis using Fluent and validate the experimental results.

*Table 2:* Turbulence Models

| S.no | Analysis Description | No. of Cells | At Inlet | | | | At Exit | | Del. T (deg R) | Pr = Pt(in)/ Ps(out) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Pin (Pas Cal) | temp | Mass flow | Vin (m/s) | Vout (m/s) | Tout (k) | | |
| 1 | Std. k-e (T.I-10%,L.s-5%),2layer zornal model | 197061 | 199200 | 295.14999 | 0.00754186 | 10.37968 | 15.023524 | 300 | 4.85001 | 2 |
| 2 | Std. k-e (T.I-3%,L.s-3%),2layer zornal model | 197061 | 199200 | 295.14999 | 0.00753624 | 10.37896 | 15.023502 | 300 | 4.85001 | 2 |
| 3 | Std. k-e (T.I-1%,L.s-3%),2layer zornal model | 197061 | 199200 | 295.14999 | 0.00754114 | 10.38819 | 15.04188 | 300 | 4.85001 | 2 |
| 4 | Spalant - Allmaras (T.I-3%,L.s-3%),strain Vorticity based production | 197061 | 199200 | 295.14999 | 0.00475953 | 6.729263 | 11.53694 | 300 | 4.85001 | 2 |
| 5 | K-omega (T.I-3%,L.s-3%),Compressibility effects, shear flow correction | 197061 | 199200 | 295.14999 | 0.00600749 | 8.296661 | 39.94806 | 300 | 4.85001 | 2 |
| 6 | R.S.M (T.I-3%,L.s-3%),Wall B.C from K equation, Wall reflection effects | 197061 | 199200 | 295.14999 | 0.00613915 | 9.127268 | 28.85895 | 300 | 4.85001 | 2 |

The Fluent results matched with the experimental results. This analysis was followed by turbulence models studies. The baseline model was analyzed first with Standard k-ε model (Turbulence Intensity = 10% and Length Scale = 5%). The same model was then analyzed with standard k-ε turbulence model but for different turbulence parameters, namely, Turbulence Intensity (T.I.) of 3% & 1%, and Length Scale (L.S.) 3% & 1% respectively. Standard k-ε, Spalart-Allmaras, k-omega, Reynolds's Stress Model were tried out with the baseline geometry. All the turbulence models showed consistent results except RSM & Spalart-Allmaras, with less mass flow and low velocities. It was decided to use Standard k- ε model for all future analyses.

### b) *Model A case with Canted angle*

For Base line case (Model A) the canted angle is varied with 40, 60 and 70 degree and the analysis is carried with same boundary condition but the results show no improvement in flow parameter. Flow parameter values are much higher (15 % to 60%) compared with base line canted 50 degrees. Refer fig. 9 for velocity contours. The studies reveal that 50 degree is optimal canted angle for seal design for leakage flow.

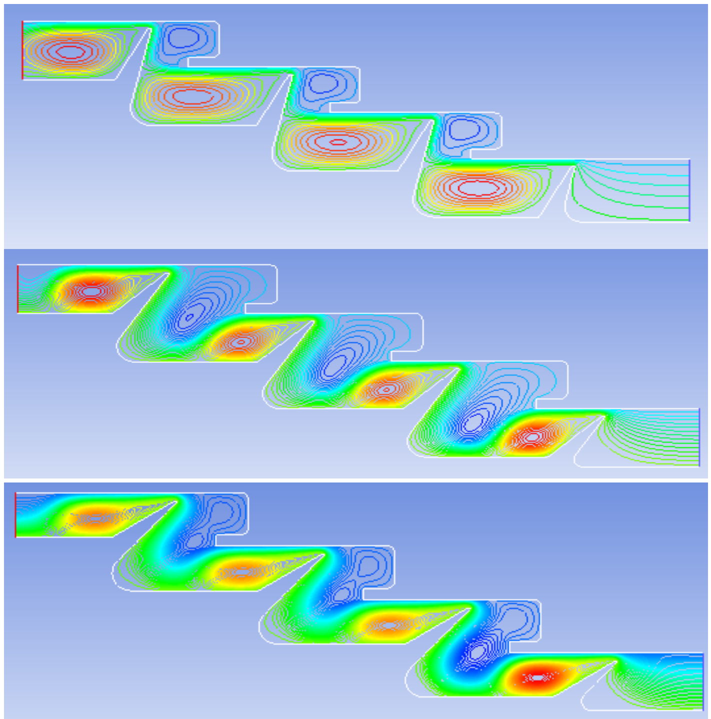


*Fig. 9:* Model A with various canted angles of velocity contours

*c) Model B studies with step height and clearance*

Analyses with step height and wall clearance between fixed wall and rotating wall are carried. Refer Fig. 10, 11,12, 13 with wall clearance ( 0.25, 0.51) and step heights (2.0 & 3.05) are analyzed based on review of minor differences in flow feature, the spacing of 0.25 was finalized for future axi-symmetric analyses. The models are analyzed for 10000 rpm. This analysis was considered as baseline analysis for all subsequent analyses. To improve the sealing efficiency, several labyrinth seal designs with varying geometries were analyzed

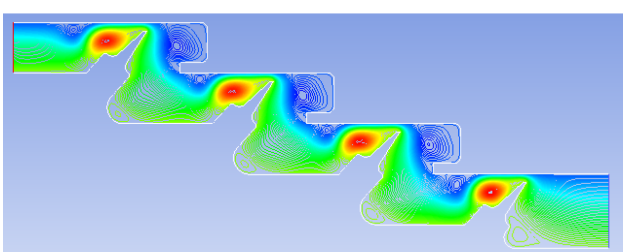


*Fig. 10:* Model B with .51 clearance and 3.05 step height- velocity contours

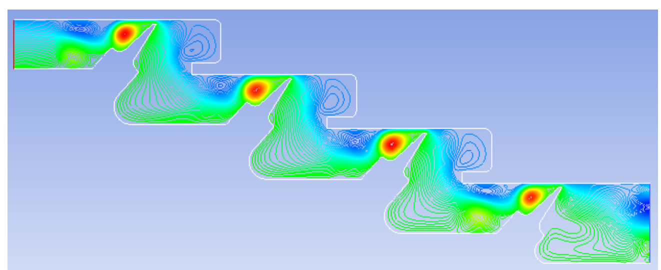


*Fig. 11:* Model B with .25 clearance and 3.05 step height- velocity contours

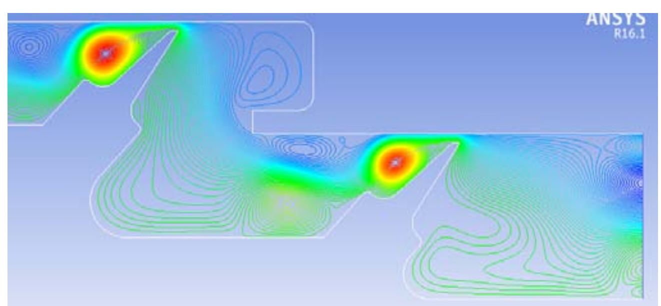



*Fig.12 :* Model B with .25 clearance and 3.05 step height- velocity contours of Tooth 1 and 2.

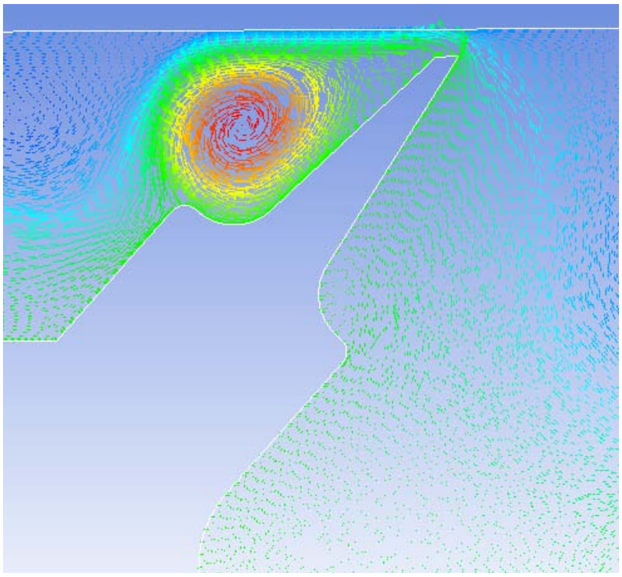


*Fig. 13:* Model B with .25 clearance and 3.05 step height- velocity vectors (stream function) of Tooth 2.

Comparing Figures 7, 10 and 11 the model B with .25 with step height 3.05 has created more turbulence in the flow thereby creating frictional flow resistance. Also since the stepped walls are inclined in the direction opposing the flow, there is direct resistance created for the flow to move downstream.

As observed in Figures 12 and 13 vortices are formed in the stepped wall zone at the outermost portion of the cells between sharp teeth also the vortices in the lower zone of the cells appear to be intensified. The step disrupts flow entering the clearance region and increases flow lockage upstream of and in the clearance area thereby reducing the exit pressure at each tooth (following the second tooth) overall leakage as compared to the baseline sharp teeth design.

Fig. 14 shows the seal performance of various models. Model B with .51 clearances has not shown much improvement. The flow parameter vs pressure ratio for this case is very high compared to base line sharp teeth model but Model B with .25 clearances is shown much higher improvement than any model.

Model B with .25 clearances shows 14.9% improvement when compared to Baseline Model A.

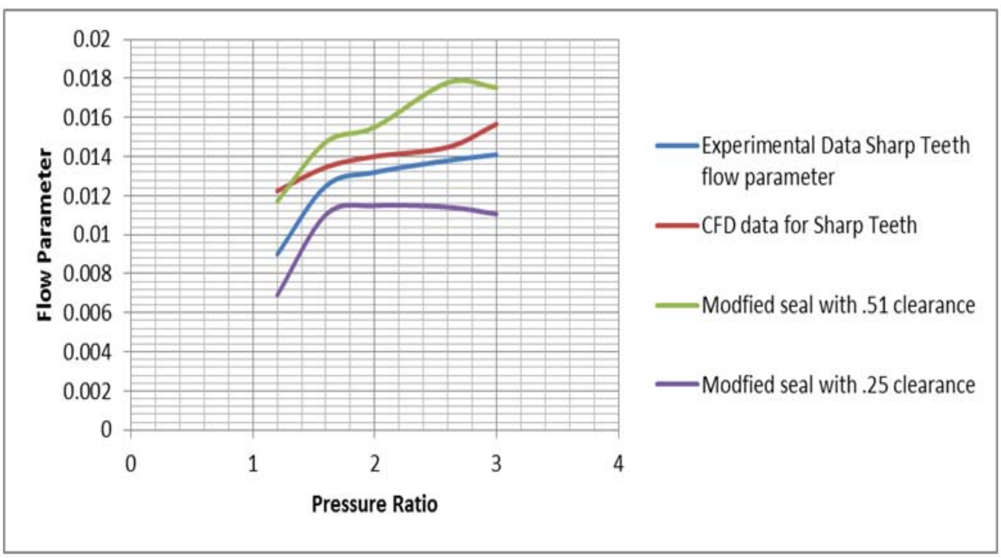



*Fig.14:* Seal performance of various models

The high performance seal Model B is further studied with various speed parameters. It shows the speed increase performance further improved this is because of radial velocity creates turbulence flow in the flow path that restricts movement. Refer Fig. 15 for seal performance at various speeds.

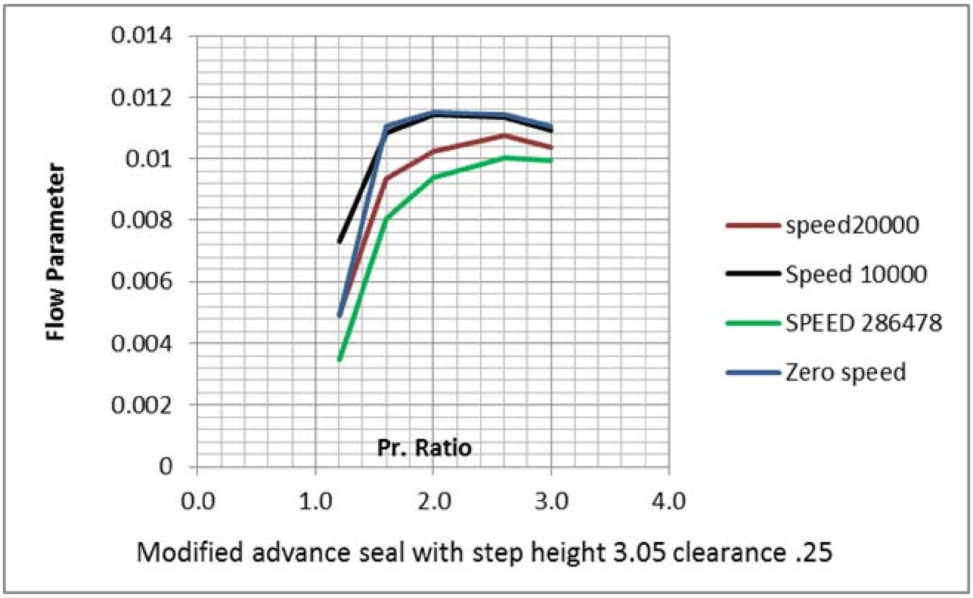



*Fig.15:* Seal performance of various models with different speeds

## V. Conclusions

a) Standard k-ε, Spalart-Allmaras, k-omega, and RNG k-ε models give similar flow field for the analyzed lab seal configuration. Reynolds Stress Model gives elevated temperature field inside the domain. RNG k-ε turbulence model predicted less temperature rise and more pressure drop. The effect of throttling process in tooth clearance and the vortex flow are two main factors which influence flow resistance and leakage in seal.
b) The solution time is more with single precision solver than double precision solver
c) Model B with .25 clearance shows 14.9% improvement than baseline Model A.

Further work may be carried out for honeycomb wall with various diameters. Also air injection study with holes (modeled as slots in the 2d axi-symmetric analysis) to introduce in between the knife-edges in order to disturb the jet studies may be carried out.

## VI. Acknowledgment

The authors wish to thank Kondalarao N and Suresh B for their contributions during case studies.

## References Références Referencias

1. Suryanarayanan S., and Gerald M., 2009, "Analysis of Flow Parameters Influencing Carry-Over Coefficient," GT2009-59245, Proceedings of ASME Turbo Expo 2009, Orlando, Florida, U.S.A., June 8–12.
2. Bambang I. Soemarwoto, Johan C. Kok, Koen M.J. de Cock, Arjen B. Kloosterman and Gerrit A. Kool 2007, "Performance Evaluation of Gas Turbine Labyrinth Seals using computational Fluid Dynamics," GT2007-27905, Proceedings of GT2007 ASME Turbo Expo 2007: Power for Land, Sea and Air May 14-17, 2007, Montreal, Canada
3. H. L. Stoker, Determining and improving labyrinth seal performance in current and advanced high performance gas turbines, AGARD Conference Proceedings 237, Paper 13, (1978).
4. Jun Li, Shengru Kong, Shinnosuke Obi, Zhengping Feng, 2010, "Numerical Investigations on Leakage Performance of the Rotating Labyrinth Honeycomb Seal" journal of engineering for Gas Turbines and Power.
5. Sir David King, Dr Oliver Inderwildi, Dr Chris Carey, " Sealing technologies –signed, sealed and delivering emissions savings," Aviation and the Environment, 04/09
6. Hasham H Chougule., Alexander Mirzamoghadam, Douglas Ramerth, 2014, "CFD simulation of Single step and Double Notched tooth for labyrinth seals," Proceedings of ASME Turbo Expo 2014: Turbine Technical Conference and Exposition, GT2014-26286.
7. J. T. Han, A Fluid mechanics model to estimate the leakage of incompressible fluids through labyrinth seals, Date Published - August 1978
8. Pawel Kaszowski, Marek Dzida, Piotr Krzyslak, 2013, "Calculations of labyrinth seals with and without diagnostic extraction in fluid-flow machines," POLISH MARITIME RESEARCH 4(80) 2013 Vol 20; pp. 34-38 10.2478/pomr-2013-0038
9. N. Herrmann, K. Dullenkopf, H.-J. Bauer, 2013, "Flexible seal strip design for advanced labyrinth seals in turbines" Proceedings of ASME Turbo Expo 2013: Turbine Technical Conference and Exposition GT2013 June 3-7, 2013, San Antonio, Texas, USA Ansys workbench V 16.0

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN: 0975-5861

# Study of Minor Loss Coefficient of Flexible Pipes for Different Bend Angles and Different Bend Radius by Experiment and Simulation

By M. S. Islam, Avizit Basak, M. A. R. Sarkar & M. Q. Islam
*Bangladesh University of Engineering & Technology*

*Abstract-* The aim of this work is to investigate the minor loss for locally available bended flexible pipes of different dimensions. Minor loss coefficients for different bend angles and different bend radius of these pipes are ascertained, using both experimental method and numerical analysis. Different parameters on which Minor Loss depend were observed and their relations to the Minor Loss were analyzed. Minor loss coefficient for different bend angles and two bend radiuses were determined. Minor losses were measured under different flow rates. The Minor Loss Co-efficient was also determined by solving Navier-Stokes Equation, with the help of standard computer program. For Turbulent Stresses Boussinesq assumption is used. As Turbulence model $\bar{k}$-ε is implemented. Navier-Stokes equations for viscous, incompressible flow shows mixed elliptic-parabolic behavior. So, semi-implicit method for pressure linked equation (SIMPLE) was used.

*Keywords: Minor Loss Co-Efficient, Bends, $\bar{k}$-ε Turbulence Model.*

*GJRE-A Classification: FOR Code: 091399p*

STUDYOFMINORLOSSCOEFFICIENTOFFLEXIBLEPIPESFORDIFFERENTBENDANGLESANDDIFFERENTBENDRADIUSBYEXPERIMENTANDSIMULATION

*Strictly as per the compliance and regulations of:*

# Study of Minor Loss Coefficient of Flexible Pipes for Different Bend Angles and Different Bend Radius by Experiment and Simulation

M. S. Islam [α], Avizit Basak [σ], M. A. R. Sarkar [ρ] & M. Q. Islam [Ѡ]

*Abstract-* The aim of this work is to investigate the minor loss for locally available bended flexible pipes of different dimensions. Minor loss coefficients for different bend angles and different bend radius of these pipes are ascertained, using both experimental method and numerical analysis. Different parameters on which Minor Loss depend were observed and their relations to the Minor Loss were analyzed. Minor loss coefficient for different bend angles and two bend radiuses were determined. Minor losses were measured under different flow rates. The Minor Loss Co-efficient was also determined by solving Navier-Stokes Equation, with the help of standard computer program. For Turbulent Stresses Boussinesq assumption is used. As Turbulence model $\bar{k}$-ε is implemented. Navier-Stokes equations for viscous, incompressible flow shows mixed elliptic-parabolic behavior. So, semi-implicit method for pressure linked equation (SIMPLE) was used.

*Keywords: minor loss co-efficient, bends, $\bar{k}$-ε turbulence model.*

## I. Introduction

The losses that occur in pipelines due to bends, elbows, joints, valves etc are called minor losses. Minor loss in a bend is due to flow separation on the curved walls and a swirling secondary flow arising from the centripetal acceleration. Since the flow pattern in valves, bends and fittings are quite complex, the theory is very weak. The losses are usually measured experimentally and correlated with the pipe flow parameters. In turbulent flow, the Minor Loss varies as the square of the velocity. The form of Darcy's equation used to calculate minor losses of individual fluid system components is expressed by the equation

$$h_m = k\, v^\wedge 2/2g \quad \text{......................... (1)}$$

Where, $h_m$ = minor loss for a fitting, k = minor loss coefficient, v = velocity of the fluid for the time. Bends are provided in pipes to change the direction of flow through it. An additional loss of head, apart from that due to fluid friction, takes place in the course of flow through pipe bend. The fluid takes a curved path while flowing through a pipe bend as shown in figure 1. Whenever a fluid flows in a curved path, there must be a force acting radially inwards o n the fluid to provide the inward acceleration, known as centripetal acceleration. This results in an increase in pressure near the outer wall of the bend, starting at some point A and rising to a maximum at some point B. There is also a reduction of pressure near the inner wall giving a minimum pressure at C and a subsequent rise from C to D.

Therefore, between A and B and between C and D the fluid experiences an adverse pressure gradient (the pressure increases in the direction of flow).

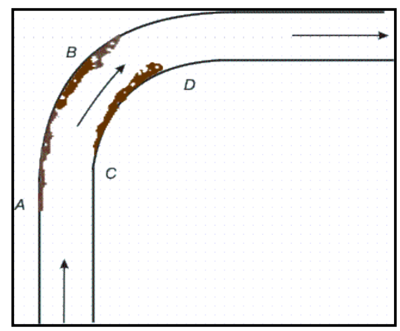



*Figure 1:* Flow through bend pipe

Fluid particles in this region, because of their close proximity to the wall, have low velocities and cannot overcome the adverse pressure gradient and this leads to a separation of flow from the boundary and consequent losses of energy in generating local eddies.

Losses also take place due to a secondary flow in the radial plane of the pipe because of a change in pressure in the radial depth of the pipe. This flow, in conjunction with the main flow, produces a typical spiral motion of the fluid which persists even for a downstream distance of fifty times the pipe diameter from the central plane of the bend. This spiral motion of the fluid increases the local flow velocity and the velocity gradient at the pipe wall, and therefore results in a greater frictional loss of head than that which occurs for the same rate of flow in a straight pipe of the same length and diameter.

In the context of our study, there are some contributions of particular importance. Khan and Islam [1] made an experimental investigation of flow through flexible pipes and bends. In their work they used metal made pipes. Two manometers were used: one for trough to trough and one for crest to crest readings. Khan, Ahmed, Jonayat [2] determined friction factor of

*Author α σ ρ Ѡ: Department of Mechanical Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh.*
*e mails: Jony06_buet@yahoo.com,rashid@me.buet.ac.bd*

Global Journal of Researches in Engineering ( A ) Volume XVI Issue IV Version I Year 2016

flow through flexible pipes and minor loss coefficient of flexible bends. Ahmed, Chakraborty and Fattah [3] did their work on locally manufactured PRR pipes bends to measure friction factor and minor loss coefficient respectively. In 1895 Reynolds [4] rewrote Navier-Stokes equation in time averaging form. Jones and Launder [5] and Harlow and Nakayama [6] developed k ¯-ε turbulence around 1970 model. In 1972 Caretto, Patanker and Spalding [7] introduced SIMPLE algorithm for solving Navier-Stokes Equations for viscous, incompressible flow. Jaiman, Oakley and Adkins [8] did CFD modeling of corrugated flexible pipes. In their work they constructed a numerical model of the corrugated flexible pipes and did simulation to show variation of velocity distribution throughout the pipe, 2011).

## II. Setup & Data Collection

*a) Experimental Setup*

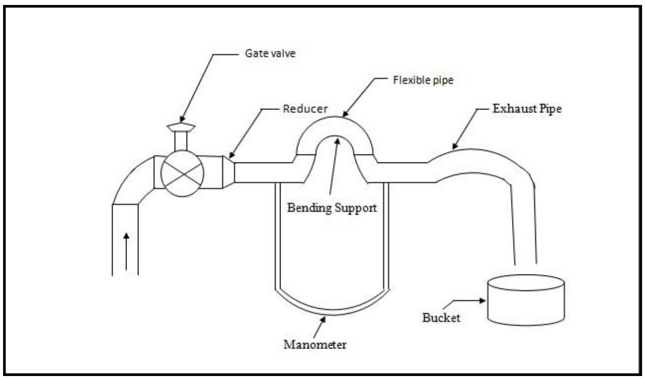



*Figure 2:* Schematic Diagram of Experimental Setup

*b) Specimen Preparation*

- At first flexible pipes are trimmed into required length using a hack-saw.
- One PVC pipe (1 inch) is selected corresponding to the diameter of reducer and threads were cut at the end of the PVC pipe to be fitted with reducer.
- The end of the PVC pipe which was to be matched with the flexible pipes was smoothened and chamfered.
- Now using drill machine, two drills transverse to the flexible pipe's length were made at two modes where manometer are required to be connected with pipe nipples With help of two pipe tubes (1.5mm diameter).
- Steps 1 to 4 were repeated for pipe bends. To hold the bended flexible pipes in the desired position stand were used.
- Now that required machining operations are done; specimen were properly washed and cleaned to eliminate dirt, oil and other undesirable internal surface matter.

*c) Construction Setup*

- One end of the flexible pipe was connected with the corresponding PVC pipe with the help of reducer (reducer is fitted with the gate valve).
- Thread tapes were used to ensure proper sealing in different connections.
- The other end of the flexible pipe was directed to the bucket.
- After preparing the manometer, manometric fluid (CCl4) was injected to it.
- The limbs of manometer were connected to the nipples attached to the specimen through flexible tubes (1.5mm diameter) and fine wires were used to ensure proper sealing.
- Priming of the manometer was performed.
- Two stands were used to maintain the specimen horizontal and wood piece was used to keep the discharge end at elevated height to ensure full flow of water.

*d) Data Collection Procedure*

In order to collecting data working fluid (water) was allowed to flow through the experimental setup for three different dimensions of the flexible pipe. Differential Manometer was used to measure pressure drop through the bend. As manometric fluid, Carbon Tetra-Chloride (CCL4) was used.

- At first, the inner diameter of the specimen was measured.
- The room temperature was observed.
- Mass of empty bucket was measured.
- The zero level of the manometer was checked.
- By opening the gate valve water was allowed to flow through the testing section and all the sealing was checked.
- Now stop-watch was turned on and water flowing through the pipe was collected to the bucket.
- Steady state manometer readings were collected.
- After a time, stop-watch was turned off and mass of water filled bucket was measured by platform scale.
- Stop-watch reading was taken.
- By changing the gate valve opening flow rate was varied and reading were taken at these flow rates by repeating step six to nine. These way four readings were taken for each bend angle.
- The above procedure was performed for three different diameters and two different bend radius.

## III. Theory

The simulation of water flow in a flexible bend pipe of different diameter, bend radius and angle was done by solving the Navier-Stokes Equation, with the help of commercial simulation software ANSYS 13 (WORLBENCH and FLUNET).

The fluid flow phenomenon is governed by the Navier-Stokes Equations. As the temperature change was slight during the experiment. So the simulation was done assuming constant temperature. This simplified the process by decoupling Continuity and Momentum equation from Energy equation. Now, Reynolds Time-averaged Navier-Stokes equation,

Continuity equation:

$$\frac{\partial \bar{u}}{\partial x}+\frac{\partial \bar{v}}{\partial y}+\frac{\partial \bar{w}}{\partial z}=0 \tag{2}$$

Momentum Equation:

x-component:

$$\rho\left(\frac{\bar{u}(\partial \bar{u})}{\partial x}+\frac{\bar{v}(\partial \bar{u})}{\partial y}+\frac{\bar{w}(\partial \bar{u})}{\partial z}\right)=-\frac{\partial \bar{p}}{\partial x}+\frac{\partial}{\partial x}\left(\mu\frac{\partial \bar{u}}{\partial x}-\rho\overline{u'^2}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial \bar{u}}{\partial y}-\rho\overline{u'v'}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial \bar{u}}{\partial z}-\rho\overline{u'w'}\right) \tag{3}$$

y-component:

$$\rho\left(\bar{u}\frac{\partial \bar{v}}{\partial x}+\bar{v}\frac{\partial \bar{v}}{\partial y}+\bar{w}\frac{\partial \bar{v}}{\partial z}\right)=-\frac{\partial \bar{p}}{\partial y}+\frac{\partial}{\partial x}\left(\mu\frac{\partial \bar{v}}{\partial x}-\rho\overline{u'v'}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial \bar{v}}{\partial y}-\rho\overline{v'^2}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial \bar{w}}{\partial z}-\rho\overline{v'w'}\right) \tag{4}$$

z-component:

$$\rho\left(\bar{u}\frac{\partial \bar{w}}{\partial x}+\bar{v}\frac{\partial \bar{w}}{\partial y}+\bar{w}\frac{\partial \bar{w}}{\partial z}\right)=g-\frac{\partial \bar{p}}{\partial z}+\frac{\partial}{\partial x}\left(\mu\frac{\partial \bar{w}}{\partial x}-\rho\overline{u'w'}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial \bar{w}}{\partial y}-\rho\overline{v'w'}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial \bar{w}}{\partial z}-\rho\overline{w'^2}\right) \tag{5}$$

Here the terms $\rho\overline{u'^2}$, $\rho\overline{u'v'}$ etc are called turbulent stresses.

According to Boussinesq assumption[9]

$$\rho\overline{u'_i u'_j}=2\mu_T S_{ij}-\frac{2}{3}\delta_{ij}\left(\mu_T\frac{\partial u_k}{\partial x_k}+\rho\bar{k}\right) \tag{6}$$

Where, $S_{ij}=\text{mean strain tensor}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$, $\mu_T=$ Turbulent viscosity, $\bar{k}=$ Kinetic energy of turbulence, $u=(u,v,w)$ Fluctuating velocity vector, $x=(x,y,z)=$ Position Vector.

According to $\bar{k}$-ε model [5][6]

$$\mu_T=\frac{C_\mu\rho(\bar{k})^2}{\varepsilon} \tag{7}$$

Here, ε= Dissipation rate.

The transport equation for kinetic energy of turbulence $\bar{k}$,

$$\rho\left(\bar{u}\frac{\partial \bar{k}}{\partial x}+\bar{v}\frac{\partial \bar{k}}{\partial y}+\bar{w}\frac{\partial \bar{k}}{\partial z}\right)=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_T}{Pr_k}\right)\frac{\partial \bar{k}}{\partial x_j}\right]-\rho\varepsilon+\left(2\mu_T S_{ij}-\frac{2}{3}\rho\bar{k}\delta_{ij}\right)\frac{\partial u_i}{\partial x_j} \tag{8}$$

The transport equation for Dissipation rate ε,

$$\rho\left(\bar{u}\frac{\partial \bar{\varepsilon}}{\partial x}+\bar{v}\frac{\partial \bar{\varepsilon}}{\partial y}+\bar{w}\frac{\partial \bar{\varepsilon}}{\partial z}\right)=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_T}{Pr_\varepsilon}\right)\frac{\partial \bar{\varepsilon}}{\partial x_j}\right]+C_{\varepsilon 1}\frac{\varepsilon}{\bar{k}}\left(2\mu_T S_{ij}-\frac{2}{3}\rho\bar{k}\delta_{ij}\right)\frac{\partial u_i}{\partial x_j}-C_{\varepsilon 2}\rho\frac{\varepsilon^2}{\bar{k}} \tag{9}$$

Where, $C_\mu, C_{\varepsilon 1}, C_{\varepsilon 2}, Pr_k$ are constant. The values used in simulation are 0.09, 1.44, 1.92 and 1.0 respectively. And water density and viscosity used are $995.325\ kg/s$ and $7.9\times10^{-4}\ Ns/m^2$ respectively. Boundary condition for simulating water flow in bends are listed below,

1. At velocity inlet u=w=0;v=0.625 m/s
2. At pressure outlet p(gage)=0;
3. At wall no-slip condition.

Navier-Stokes equations for viscous, incompressible flow shows mixed elliptic-parabolic behavior. So, semi-implicit method for pressure linked equation (SIMPLE) [7], [12], [13] was used.

The under-relaxation Constant and Spatial Discretization Method are as follows,

| Parameter | Under-relaxation | Spatial Discretization Method |
|---|---|---|
| Pressure | 0.3 | Second Order |
| Momentum | 0.7 | Second Order Upwind |
| Turbulent Kinetic Energy | 0.8 | Second Order Upwind |
| Turbulent Dissipation Rate | 0.8 | Second Order Upwind |

And the Stopping Criterion for different equation are given below,

| Equation | Residual |
|---|---|
| continuity | 0.0001 |
| x & y - momentum | 0.00001 |
| z-momentum, kinetic energy, dissipation rate | 0.001 |

## IV. Results

The values of Minor Loss Co-efficient are tabulated for different Pipe Diameter, Bend Radii and Bend Angles. Both data from experiment and simulation are mentioned below.

a) *Experimental Results*

*Table 1:* Minor Loss Co-efficient (simulation data) at an inlet velocity of 0.625 m/s

| No. | Bend RadiD (mm) | Pipe Dia. d (mm) | Ratio $\frac{d}{D}$ | Minor Loss Co-efficient k | | | |
|---|---|---|---|---|---|---|---|
| | | | | $30^0$ | $60^0$ | $120^0$ | $180^0$ |
| 1 | 80 | 5.2 | 0.065 | 7.063 | 5.935 | 7.028 | 8.796 |
| 2 | 80 | 7.2 | 0.090 | 6.859 | 7.928 | 7.511 | 7.640 |
| 3 | 80 | 8.3 | 0.104 | 3.545 | 3.621 | 3.719 | 3.556 |
| 4 | 120 | 5.2 | 0.043 | 6.033 | 6.061 | 7.856 | 7.815 |
| 5 | 120 | 7.2 | 0.060 | 7.918 | 9.345 | 8.183 | 7.065 |
| 6 | 120 | 8.3 | 0.069 | 76.31 | 0.919 | 4.034 | 8.500 |

b) *Simulation Results*

*Table 2:* Minor Loss Co-efficient curve fitted at an inlet velocity of 0.625 m/s

| No. | Bend RadiD (mm) | Pipe Dia. d (mm) | Ratio $\frac{d}{D}$ | Minor Loss Co-efficient k | | | |
|---|---|---|---|---|---|---|---|
| | | | | $30^0$ | $60^0$ | $120^0$ | $180^0$ |
| 1 | 80 | 5.2 | 0.065 | 7.494 | 4.568 | 12.38 | 20.01 |
| 2 | 80 | 7.2 | 0.090 | 5.221 | 2.830 | 6.066 | 10.68 |
| 3 | 80 | 8.3 | 0.104 | 4.465 | 2.128 | 5.240 | 11.69 |
| 4 | 120 | 5.2 | 0.043 | 1.156 | 1.696 | 2.718 | 3.734 |
| 5 | 120 | 7.2 | 0.060 | 0.773 | 1.127 | 1.827 | 2.532 |
| 6 | 120 | 8.3 | 0.069 | 0.654 | 0.963 | 1.531 | 2.123 |

## V. Discussion

a) *Error Analysis*

The experimental data has some inevitable errors which affects the result in a little degree. These errors can be classified into two types

- Error in experimental procedure
- Error due to inaccuracy of measuring Devices

The susceptible reasons for the error in experimental data are described briefly below

(a) The pipes used for the experiment may have variable roughness and cross-sectional area. This may have caused error.

(b) Basically, the channels to fit the pipes were made by curving the wooden structure and these channels were not smooth enough to ensure precise data readings.

(c) Traditional Multiple-lever weighting system (bucket platform) was used for measuring water mass. This method has very poor accuracy.

(d) Priming of manometer was one of the major concerns. As inaccurate priming leads to erroneous pressure drop reading. It is a difficult task. Every time the pipe was changed, manometer had to be primed. It was very time consuming. Even after all the efforts, may be priming was not accurate to its desired level.

(e) Despite all the effort, experimental setup wasn't leak proof. This introduced additional pressure in the system. And in this type of experimental thesis work a small pressure variation can induce a large discrepancy from standard value.

(f) The water flow was controlled by a Gate valve, incorporated with the main water supply line of the laboratory. It is not quite accurate method for flow control. Moreover, while the data was taken from Bend Radius = 120mm, the flow was fluctuating. This induced large error which can be clearly seen from the large difference between experimental and simulation data.

(g) Pipes were flexible. When bend was formed with them, there cross-sectional area got distorted slightly, from uniform circular section to elliptical section. This also caused variable cross-sectional area in the bend.

(h) As CCl4 has low density, it showed large deflection due to small pressure variation. In the setup Manometer scale has limited range. This forced to limit the flow rate to narrow range, as manometric deflection increased with flow rate.

(i) Experiment was done with limited number of pipe, bend radius and bend angle. All the graphs, both experimental and simulation, presented in this paper are best fitted curve, based on quadratic regression.

(j) For simulation temperature variation is not considered, as it complicated matter immensely with only a little change in result. Besides, during our experimentation temperature remained nearly constant.

*b) Graph Analysis*

i. *Minor Loss Co-efficient Vs. Reynolds Number*

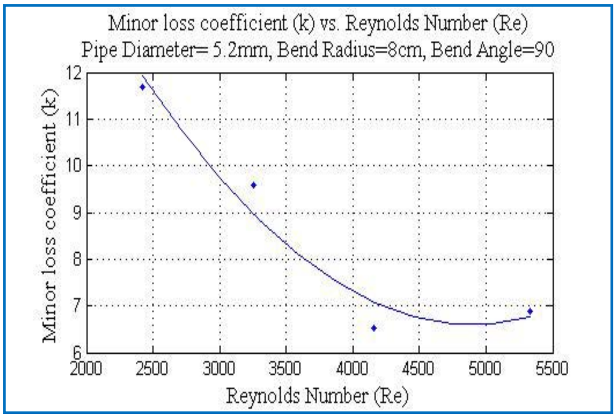



*Figure 3:* Minor Loss Co-efficient Vs. Reynolds Number

Following observation can be made from the above graph between Minor Loss Co-efficient Vs. Reynolds Number for Pipe of 5.2 mm diameter and Bend Radius and angle of 8 cm and 900.

- The Minor Loss Co-efficient decreases with increase in Reynolds Number. An inverse relation between Minor Loss Co-efficient and Reynolds Number is observed which is in accordance with Ito's formula for Minor Loss Co-efficient.

$$K = constant \times Re^{-0.17}$$

- At low Reynolds Number (2000-4000) Minor Loss Co-efficient diminished at high rate. But At large Reynolds Number (above 4000) the curve becomes flatter. This is may be due to transition from laminar to turbulent flow.

ii. *Minor Loss Co-efficient Vs. Bend Angle*

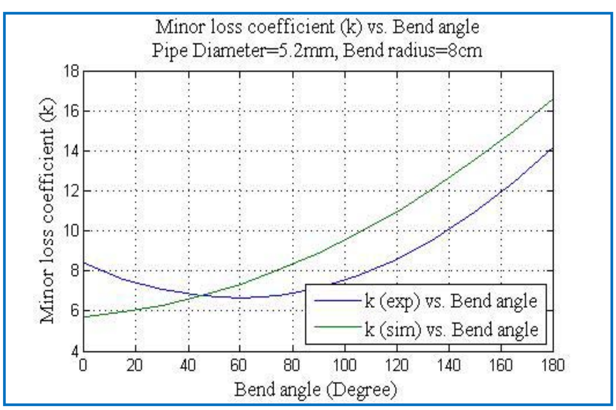



*Figure 4:* Minor Loss Co-efficient Vs. Bend Angle

The points that can be noticed are listed below:

- The Minor Loss Co-efficient increases with Bend angle, for both experimental and simulation data. These show a power relation between Minor Loss Co-efficient and Bend Angle.

$$( k = constant \times \theta^n )$$

- The experimental data closely matches with the simulation data.
- The differences between simulation and experimental data are due by many errors and limitation in both experiment and simulation which are briefly discussed in Error Analysis.

iii. *Minor Loss Co-efficient Vs. Ratio between Pipe Diameter and Bend Radius*

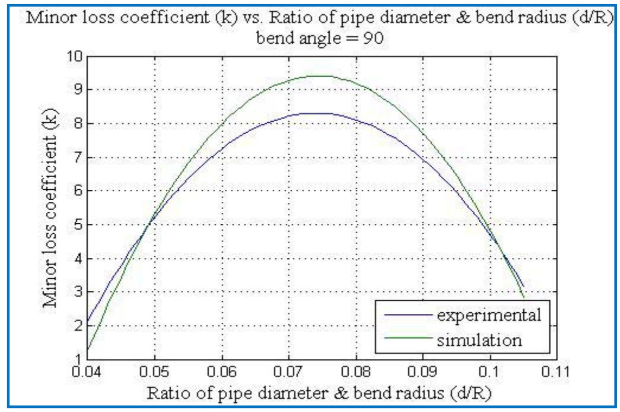



*Figure 5:* Minor Loss Co-efficient Vs. Ratio between Pipe Diameter and Bend Radius

Discussed below are some observable points,

- The Minor Loss Co-efficient rises until it reaches the maximum (between $\frac{d}{R}$ = 0.06 to 0.08) then it diminishes to lower value.
- The experimental data simulation data are similar.
- The Minor Loss Co-efficient has a parabolic relation with the Ratio of Pipe Diameter and Bend Radius.

## VI. Conclusion

This section concludes the study of the minor losses in locally available flexible pipes of diameter 5.2mm, 7.2mm and 8.3mm for bend angle of 300, 600,900,1200,1500,1800 and bend radius 12cm and 8cm.

- Minor loss coefficient in general shows a decreasing trend with respect to Reynolds number for a given angle and pipe diameter.
- For a given Pipe Diameter and Bend Radius increase in bending angle increases Minor loss coefficient.
- For a given Bend angle Minor loss coefficient increases with the ratio of Pipe Diameter and Bend Radius until it reaches a maximum value, then it decreases.

## VII. Scope for Future Works

Some guideline for future work is as follows,

1. The thesis work center on the minor losses occurred in locally available flexible pipes. Therefore it will be beneficial to determine total head loss, both minor and frictional loss, developed in a piping system

using flexible pipes and finally required power of the piping system.

2. The simulation was done using SIMPLE solution method, other solution method can be employed to see whether more accurate results are obtained or not.
3. $\bar{k}$-$\varepsilon$ turbulence model is utilized in simulating the flow. Different other model like k-ω, Spalart-Allmaras can be used and compared with experimental to find the best model suitable for this specific fluid flow problem.
4. Manometric fluid other than Carbon-tetrachloride ($CCl_4$) should be used, as $CCl_4$ manometer shows very large deflection due to small change in pressure.
5. The traditional Platform-Scale method is an outdated measuring technology. It has been a prime source of experimental error. It should be replaced by more modern measuring device like Turbine Flow Meter etc.
6. Further experiment must be conducted on more Pipe Diameter (d), Bend Angle (ϴ) and Bend Radius (R). So that an empirical co-relation between Minor Loss Co-efficient (K) and Reynolds Number (Re), d/R and ϴ can be developed. Present study concluded that K has an inverse relation with Re, parabolic relation with d/R and quadratic relation with ϴ.
7. Further experiment should be conducted to find out the velocity profile. Present study provides with simulated velocity profile.

## References Références Referencias


1. V. L. Streeter, E. Benjamin Wylie, Fluid Mechanics. First SI Metric Edition, McGraw-Hill Book Co., Singapore.
2. P.N. Modi, S.M. Seth, Hydraulic and Fluid Mechanics Including Hydraulic Machines. Fourteenth edition 2002, Standard Book House.
3. Md. Quamrul Islam, A.K.M Sadrul Islam, Fluid Mechanics Laboratory Practice, World University Service Press, ISBN 984-518-000-0
4. M.H. Khan, Md. Quamrul Islam, "An Experimental Investigation of Flow Through Flexible Pipes and Bends", Journal of Institution of Engineers, Bangladesh, Vol7,No. 3 July,1979.
5. R. K. Jaiman, O. H. Oakley Jr., J.D. Adkins, "CFD Modeling of Corrugated Flexible Pipe", OMAE 2011-20509.
6. Z. H. Ayub, S. F. Al-Fahed, "The effect of gap width between horizontal tube and twisted tape on the pressure drop in turbulent water flow, Int. J. Heat and Fluid Flow", Vol. 14, No. 1, March 1993.
7. A. W. Date, "Prediction of Fully developed Flow in a Tube Containing a Twisted Tape", Int. J. Heat Mass Transfer, Vol. 17, pp. 845-859. Pergamon Press 1974, Great Britain.
8. Md. Hafizur rahman, A. K. Roy, Md. S. Hossain, "Determination of Minor head Loss and Friction Factor for locally Available PVC pipe Reducers". BUET, September-2009.
9. Md. Rokonuzzaman Khan, Saad Ahmed, A. S. M. Jonayat, "Determination of friction Factor of Flow through Flexible Pipes and Minor Loss Coefficient of Flexible Bends", BUET, February-2011.
10. Isfak Ahmed, Pranay Chakraborty, Md. Rizwanul Fattah, "An Experimental Study of Loss Characteristics of Polypropylene Random (PPR) Pipes Pipe Elbows". BUET, February-2011.
11. F.M. White, Fluid Mechanics, 5th ed., McGraw-Hill, New York, 2003.
12. W.P. Jones and B.E. Launder. "The prediction of laminarization with a two-equation model of turbulence", Int. J. Heat Mass Transfer, vol. 15, 1972.
13. F.H. Harlow and P.I. Nakayama, "Transport of turbulence energy decay rate", Los Alamos Scientific Laboratory Report LA-3854, Los Alamos, New Mexico, 1968.


## Nomenclature

| Symbol | Meaning | Unit |
|---|---|---|
| p | Pressure | (Pa) |
| V | Velocity | (m/s) |
| Z | Elevation | (m) |
| g | Acceleration due to Gravity | ($m/s^2$) |
| $d_o$ | Outside diameter of pipe | (m) |
| d | Inside diameter of pipe | (m) |
| t | Time | (sec) |
| R | Bend radius | (m) |
| θ | Bend angle | (degree) |
| $\gamma_m$ | Specific weight of manometric fluid | ($kN/m^3$) |
| T | Temperature | ($^oC$) |
| $H_m$ | Deflection in manometer | (m) |
| γ | Specific weight of water | ($kN/m^3$) |
| ρ | Density | ($kg/m^3$) |
| $\mu$ | Absolute viscosity | ($Ns/m^2$) |
| $h_{f(total)}$ | Total head loss | (m) |
| $h_{f(major)}$ | Major head loss | (m) |
| $h_{f(minor)}$, $h_m$ | Minor head loss | (m) |
| Q | Volumetric flow rate | ($m^3/s$) |
| $Q_m$ | Mass flow rate | (kg/s) |

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN: 0975-5861

# Numerical Investigation of Spring Back on Sheet Metal Bending Process

By Alie Wube Dametew & Tafesse Gebresenbet
*Wollo University Kombolcha Institute of Technology*

*Abstract-* Spring back is the main defect in sheet metal bending process. The spring back of sheet metal bending, which is defined as elastic recovery of the part during un loading conditions. It should be taken in to considerations so as to produce bent sheet metal parts within acceptable quality. Spring back is affected by the factors such as; sheet thickness, tooling geometry, friction condition; material property and processing parameters. In this research the numerical investigation of Spring back on edge bending die process is done.. The numerical Analysis is done using ANSYS™ LS-DYNA™. The influence of sheet metal thickness, sheet metal type, friction, tool radius and tool shape on spring back for Aluminium, copper, mild steel and High strength steels, sheet metal have been considered for investigations.

*Keywords: sprint back, sheet metal, banding process, elastic recovery, numerical investigation.*

*GJRE-A Classification: FOR Code:290501*

NUMERICALINVESTIGATIONOFSPRINGBACKONSHEETMETALBENDINGPROCESS

*Strictly as per the compliance and regulations of:*

# Numerical Investigation of Spring Back on Sheet Metal Bending Process

Alie Wube Dametew [α] & Tafesse Gebresenbet [σ]

*Abstract-* Spring back is the main defect in sheet metal bending process. The spring back of sheet metal bending, which is defined as elastic recovery of the part during un loading conditions. It should be taken in to considerations so as to produce bent sheet metal parts within acceptable quality. Spring back is affected by the factors such as; sheet thickness, tooling geometry, friction condition; material property and processing parameters. In this research the numerical investigation of Spring back on edge bending die process is done.. The numerical Analysis is done using ANSYS™ LS-DYNA™. The influence of sheet metal thickness, sheet metal type, friction, tool radius and tool shape on spring back for Aluminium, copper, mild steel and High strength steels, sheet metal have been considered for investigations.

*Keywords: sprint back, sheet metal, banding process, elastic recovery, numerical investigation*

## I. Introduction and Background of the Study

Many sheet metal components are produced in different size and accuracy using various sheet metal forming processes. In order to obtain consistent and accurate product dimensions is crucial in manufacturing industry. In sheet metal forming process, a major factor preventing accurate final product dimensions is spring back in the part. Spring back is shape deviation from the design intended geometry which is due to the elastic recovery that occurs after the elastic plastic forming process. Factors that affect the amount of spring back for sheet metal forming process, including both process and material parameters such as; tooling geometry, friction condition; forming speed, die temperature, mechanical properties of materials, sheet metal type and sheet metal thickness. To obtain the desired geometry of the part; spring back prediction and optimizing is a considerable issue in sheet metal bending because tooling design primarily relies on accurate prediction of spring back.

### a) *Statement of the problem*

The Bending process needs repeated experiments to reach the final accurate product. Some sheet metal products are produced still with defects and poor product quality. One of the main accuracy problems is due to elastic spring back effects. In this thesis investigation will be conducted to identify spring back effect of wiping die bending process and analysis will be yield the spring back reduction.

### b) *Objectives*

i. General Objectives

The main objective of this study is to investigate the factors influencing spring back formation in sheet metal forming for optimizing the sheet deformation process.

ii. Specific Objectives

- To investigate factors that influence spring back during wiping die bending.
- To analyze and simulate bending variables using analytical and finite element methods.
- To validate variables obtained from analytical and numerical modeling.
- Predict spring back and.
- To optimize sheet bending operation.

### c) *Metrology of the research*

The research methodologies adopted in this study to achieve the stated objectives are presented as following: Initially a detailed survey of published literature review was conducted, This study was conducted to study spring back formation in sheet bending and predict factors affecting this phenomenon, using Numerical Analysis is done. A simple 2D and 3D bending process were investigated through numerical simulations for four sheet metal types i.e. aluminum, copper, mild steel and high strength steel, The parameters investigated in this study include; die geometry, sheet metal thickness, sheet metal type and friction condition. For the prediction and analysis of these factors done using Ansys10™ and LS-DYNA™. The analytical results were spring back for further numerical simulation analysis, since it was found that there are a number of issues which requires further study. Comparison of analytical and numerical results was also conducted, and lastly Conclusion and recommendations for a future work was provided.

## II. Literature Review

A great deal of research has been conducted in order to reduce spring back, which would optimize the sheet forming process by reducing geometrical and material variables in the formed part. Finite element technique has played a major role in carrying out sheet

*Author α: School of Mechanical Engineering, Wollo University Kombolcha Institute of Technology. e-mails: wubealie@gmail.com, alie20123@gmail.com*
*Author σ: Dr.(PhD) School of Mechanical and Industrial Engineering, Addis Ababa Institute of Technology, Addis Ababa University.*

metal forming and spring back analysis in order to gain accurate results. This chapter tries to summarize some key background references and their contributions to the problem of spring back. [Fahd Fathi Ahmed Abdi, 2000] presented the work which was concerned with the spring back experienced by the deformed sheet following the punch release stroke. He used several numerical techniques which enabled to define and determination of spring back.

A 3D hybrid membrane/shell method [Jeong-Whan, 2002] was developed in order to perform spring back analysis from the membrane mid-plane solution and also to reduce computational cost for sheet metal forming simulations. In the hybrid method, the bending strain and stresses were numerically calculated as post-processing considering incremental shape changes of the sheet obtained from the membrane finite element analysis beforehand. The stress and strain were passed on to a shell model to calculate spring back. With regard to verification purpose, the hybrid method was applied to predict the spring back of a 2036-T4 Aluminum alloy square blank is formed into a cylindrical cup. The spring back prediction was in good situation with the experimentally measured data and also with the results obtained using a shell model to simulate both loading and unloading conditions. For a bending-dominant problem, the method was also applied for the unconstrained cylindrical bending of a 6111-T4 aluminum alloy sheet, which exposes large spring back. According to W.P. Carden (2002) was the Measurement of spring back in Draw-bend have been carried out and analysed to investigate the role of typical process variables on spring back. The investigation leads to conclude that friction in the normal range encountered in sheet metal forming has little effect on spring back, This conclusion departs for fact of friction effect , most likely due to the fact that in many experiments the sheet tension cannot be controlled independently of friction. Ridha Hambli (2003) develops the effects of the die radius on the spring back angle obtained by simulation with and without the influence of damage. It can be observed that with the damage influence the spring back is lower as a consequence of the material parameters variation especially, the Young's modulus and the strain within the fibers. The difference between the curves decreases with increasing die radius. The decrease is attributed to the damage reduction within the sheet for higher die radius values. To estimate and reduce spring back of ax-symmetric part manufactured by Flex forming process was developed by [Hariharasudhan Palaniswamy, 2004] using combined optimization and FEM technique. Finite element simulations were performed in order to study the interrelationship of the blank dimensions and interface conditions on the spring back for an Axisymmetric conical part manufactured by flex forming. Sensitivity analysis are done using the finite element method (FEM) demonstrated that the magnitude of spring back and the overall dimensional quality are highly influenced by the initial dimensions of the blank. A conventional optimization method combined with FEM was used to obtain optimum blank dimensions that can reduce spring back. Finite element simulations of the forming process were conducted by Taylan Altan (2004) to study the influence of interface conditions on spring back. In the simulations, the Coulomb friction coefficient between the blank and die was varied from $\mu = 0.05$ to 0.15, within constant dimensions. FE results on the influence of friction are shows that a very small increase in spring back with increase in interface friction is observed, it implying that friction has a negligible effect on spring back formed part. They conclude that Interface friction to have negligible effect on spring back for flex forming process of the conical part considered in study.

[Buranathiti and Jian Cao, 2004] develops an effective analytical model to predict spring back for a straight flanging process to effectively predict spring back for a potential application in determining optimal tooling shapes and process parameters, understanding the mechanics of spring back, a mainly elastic recovery process, is essential. Spring back optimization of bending processes was proposed by [Daniel Lapidate, 2005] using the concept of experimental design and response surface methodology .this work described a sheet metal bending process optimization method for spring back minimization by combined finite element analysis, response surface method and gradient optimization techniques. Several work-hardening models were evaluated by [M.C. Oliveira a, 2006] in order to determine their influence on the numerical prediction of the spring back phenomenon. Variation simulation analysis method [Peng Chen b,2007] was developed for the effects of variations in material (mechanical properties) and process (blank holder force and friction) on the spring back were investigated for an open-channel shaped part. [T. Meindersa, I.A. Burchett, 2007] Proposed in the product design of spring back prediction, spring back compensation and optimization by Finite Element (FE) Analysis. The accuracy of the spring back prediction is improved; the FE simulation can be used to adapt the geometry of the forming tools and the process parameters to compensate for spring back.

## III. Results and Discussions

This section is developed for the discussion and analysis of the results obtained in the Conducted numerical investigations.The developed model is used prior to implementation by utilizing different analyses to examine the effect of each parameter in the sheet metal bending process. The analysis conducted to examine the effect on the process is using the following ways

1. Conducting analysis in the developed numerical and analytical model to analyze and investigate the effect of each parameter.
2. Analytical predictions is compared with the previous studies, and then, we discuss the result and the recommendations are done.

*a) Numerical predictions of spring back*

Finite element analysis of wiping bending process was conducted using two types of element types such as; Plane element 182 and shell element 163. Spring back of sheet should be bent depends on the yield strength of the material. As the materials yield strength increases the spring back after unloading also increase. The spring back will occur where the yield stresses of the material is greater than the stress after un-loading condition. If the yield stress is equal the stress after deformation, there is no spring back. For stress- strain diagram the materials beyond yield stress it deforms plastically. The spring back is determined from numerical results using the following formulas

*Energy Dissipation Method*

Consider elastic stretching of sheet metal up to a strain of $\varepsilon$. The energy required in this stretching operation can be expressed as

$W_{min}=\int_0^{\varepsilon min} dW = \int_0^{\varepsilon min} FdI = \int_0^{\varepsilon min} \sigma xAdI = V\int_0^{\varepsilon min} \frac{\sigma mindI}{l} = V\int_0^{\varepsilon min} \sigma min * d\varepsilon min)$

$W_{max}=\int_0^{\varepsilon max} dW = \int_0^{\varepsilon max} FdI = \int_0^{\varepsilon max} \sigma maxAdI = V\int_0^{\varepsilon max} \frac{\sigma maxdI}{l} = V\int_0^{\varepsilon max} \sigma max * d\varepsilon max$

W spring back=W max-W min

When the loads are removed from this specimen, this elastic energy will be released again. The *energy dissipation*, i.e., the applied energy per unit of volume of material, hence can be expressed as

$Umin = \frac{W}{V} = \int_0^{\varepsilon min} \sigma mind\varepsilon min$ And $Umax = \frac{W}{V} = \int_0^{\varepsilon max} \sigma max * d\varepsilon max$

U spring back=U max-U min

*For in the case of elastic deformations only, this energy dissipation can alternatively expressed as*

$$U = \int_0^{\varepsilon min} E\varepsilon mind\varepsilon min = \frac{1}{2}(E\varepsilon^2)min = \frac{1}{2}(\sigma * \varepsilon)min$$

$$U = \int_0^{\varepsilon max} E\varepsilon maxd\varepsilon max = \frac{1}{2}(E\varepsilon^2)max = \frac{1}{2}(\sigma * \varepsilon)max$$

$U_{\text{spring back}}=U_{max}-U_{min}$

The above formula predict that the amount of spring back in different conditions. The variation between maximum deformation stress and un-loading stress in different region are large the spring back increase. If the maximum and un-loading stress/strain variation is small and close to the maximum deformation stress, the spring back will be reduced. The amount of spring back is equal to the amount of these stress variations. Hence, using these information the amount of spring back are predicted from numerical results in the following way.

i. *Effect of sheet metal thickness*

$$U = \int_0^{\varepsilon min} E\varepsilon mind\varepsilon min = \frac{1}{2}(E\varepsilon^2)min = \frac{1}{2}(\sigma * \varepsilon)min$$

$$U = \int_0^{\varepsilon max} E\varepsilon maxd\varepsilon max = \frac{1}{2}(E\varepsilon^2)max = \frac{1}{2}(\sigma * \varepsilon)max$$

$U_{\text{spring back}}=U_{max}-U_{min}$

- *At 0.8mm of aluminium sheet metal energy dissipation is*

$U_{min}=\frac{1}{2}[\sigma min x\varepsilon min = \frac{1}{2}[-0.699948 * (-0.702)] = 0.24$

$U_{max}=\frac{1}{2}[\sigma max\varepsilon max = \frac{1}{2}[0.865889 * (0.0327)] = 0.0141$

$U_{\text{spring back}}=U_{max}-U_{min}=\ 0.0141 - 0.24 = -0.22$

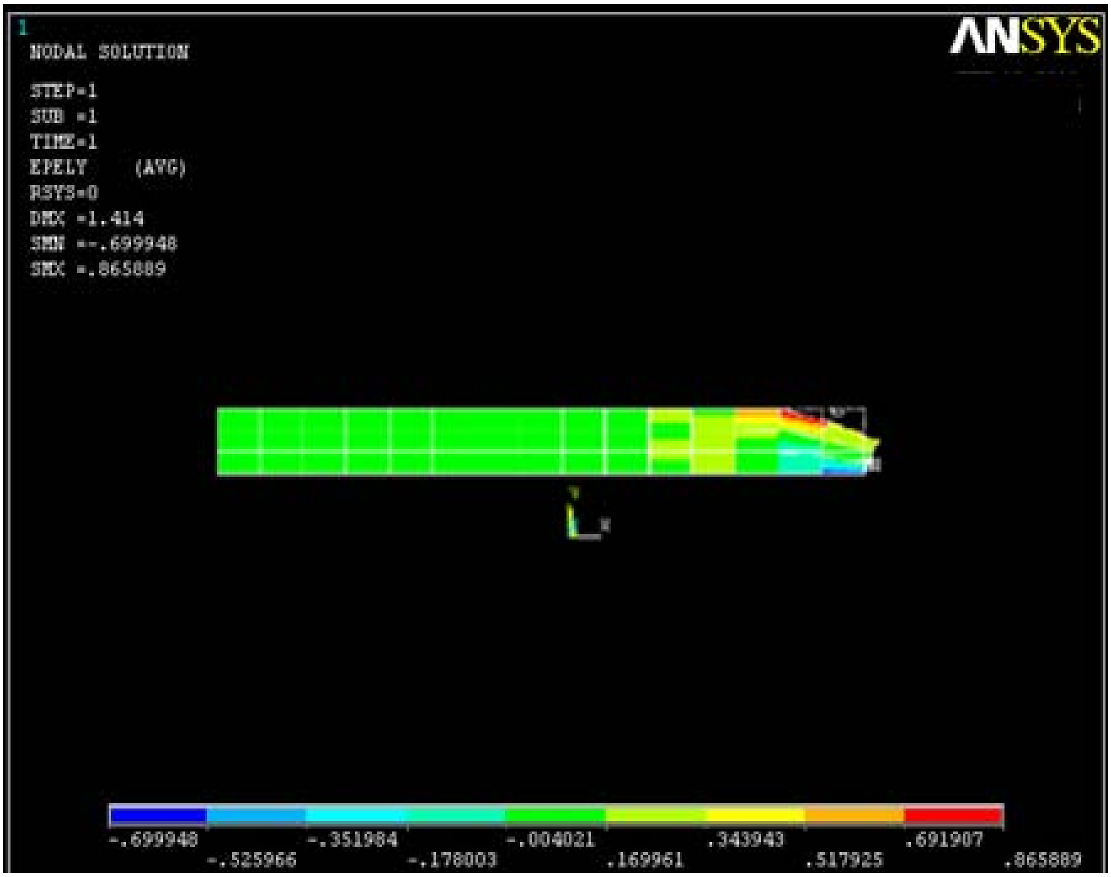
- *At 4.5mm of aluminium sheet metal energy dissipation is*

$U_{min}=\frac{1}{2}[\sigma min x\varepsilon min = \frac{1}{2}[-0.303525 * (0.851 * 10^{-3})] = -0.1291 * 10^{-3}$

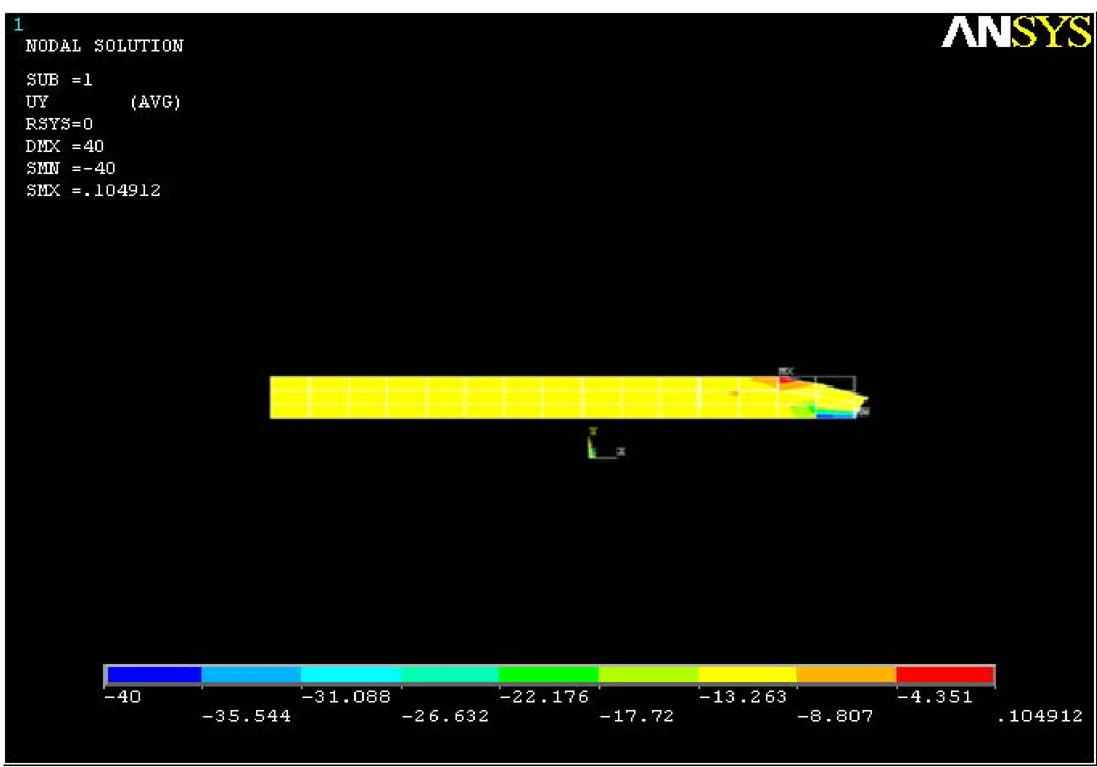
$U_{max}=\frac{1}{2}[\sigma max\varepsilon max = \frac{1}{2}[0.123278 * (0.206)] = 0.01602$

$U_{\text{spring back}}=U_{max}-U_{min}=\ [0.01602 - (-0.1291 * 10^{-3})] = 0.016149$

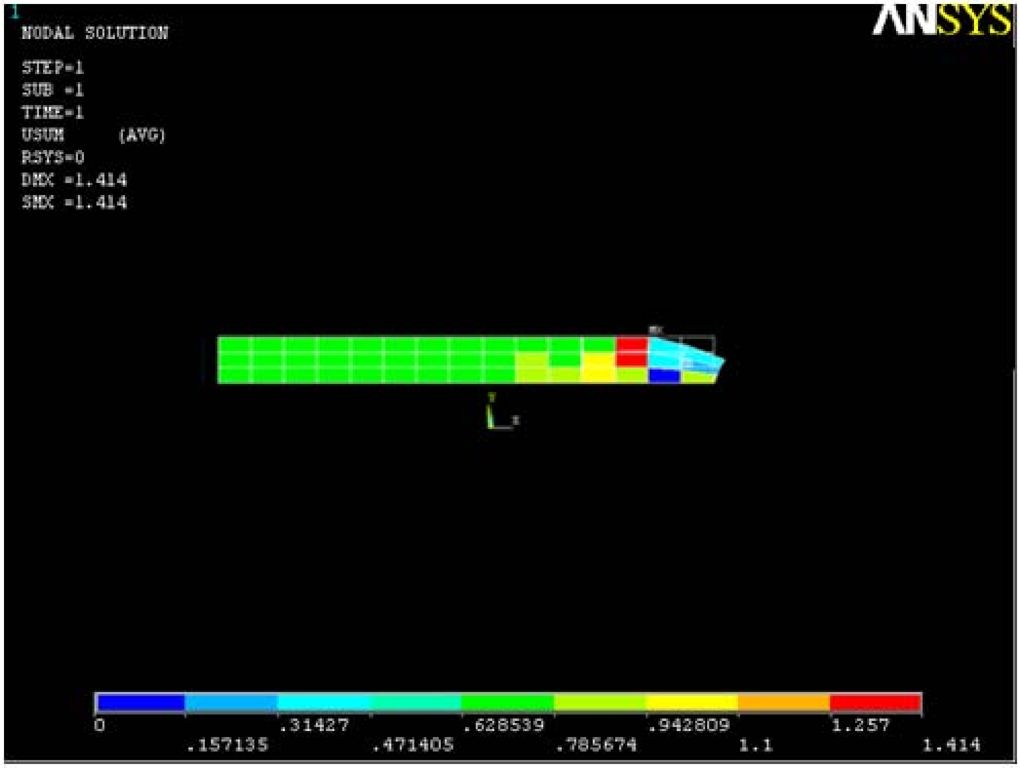
From the numerical result the minimum (SMN), and maximum stresses/ strain (SMX), in different coordinate system the results are display. On the result shown Figure 6.6 (a-h) indicates that, with the smaller sheet metal thickness the energy dissipation due to elastic deformation_is large. But when increasing of sheet thickness from (0.8 mm to 4.5mm) the energy dissipation due to stress/strain variation is reduced from -0.22 to 0.01615, this implies that maximum energy dissipation_is close to the minimum energy dissipation value. When the minimum energy dissipation approach to the maximum value the material is deform plastically. Hence, the spring back is reduced while increasing of sheet metal thickness. Hence, increasing of the thickness from 0.8mm 4.5mm within this range the spring back is reduced 20.35%



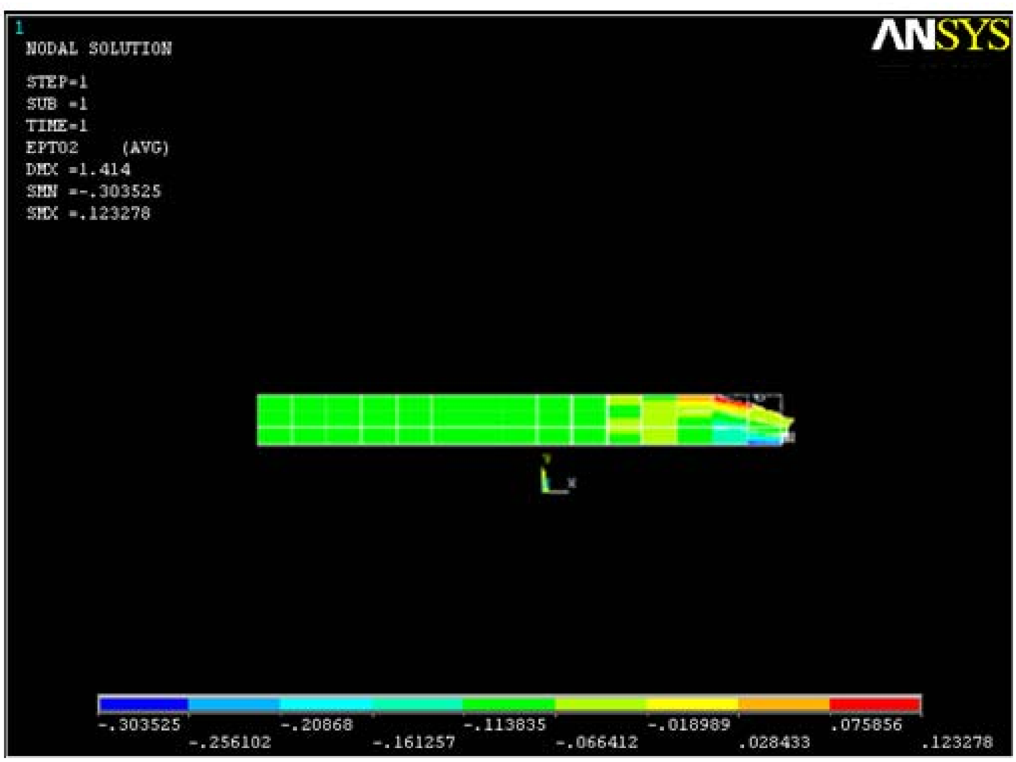

a) Nodal solution x-component (0.8 mm thickness)



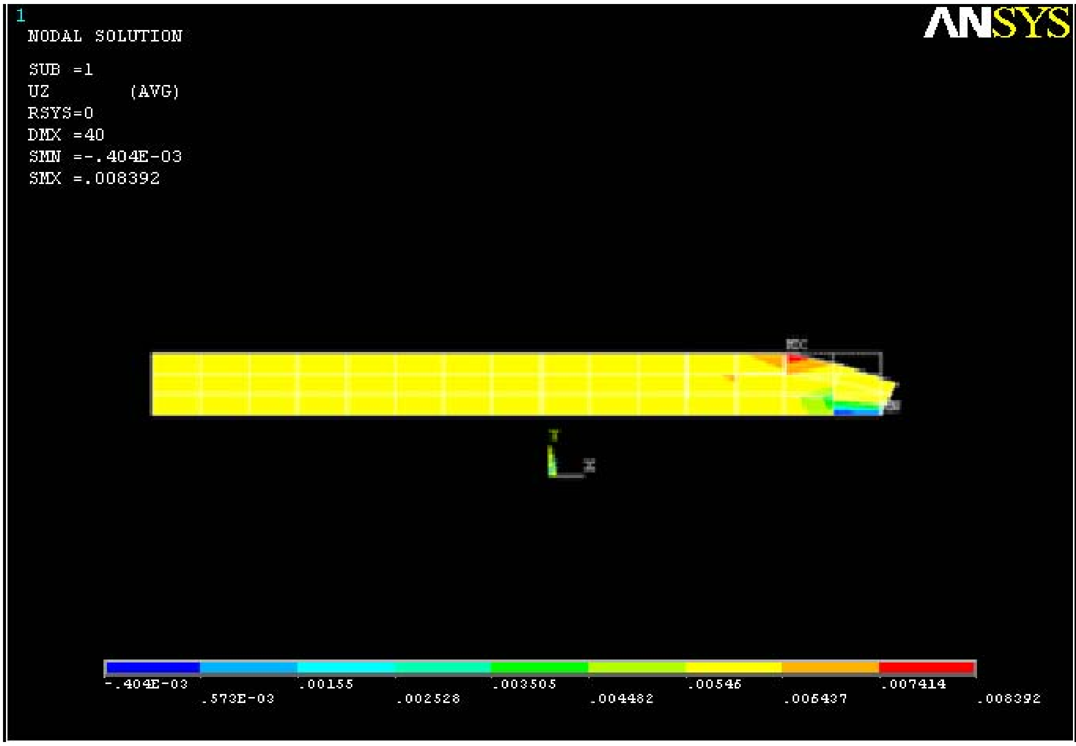

b) Nodal solution y-component (0.8 mm thickness)



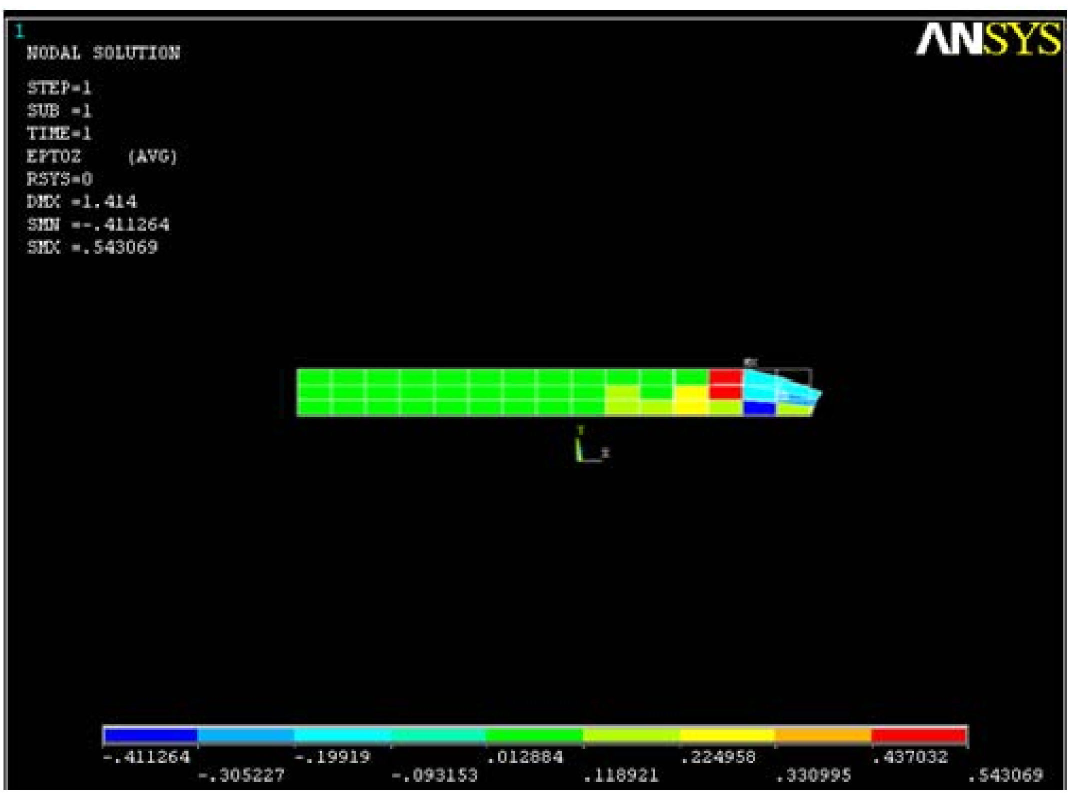

c) Nodal solution z-component (0.8 mm thickness)



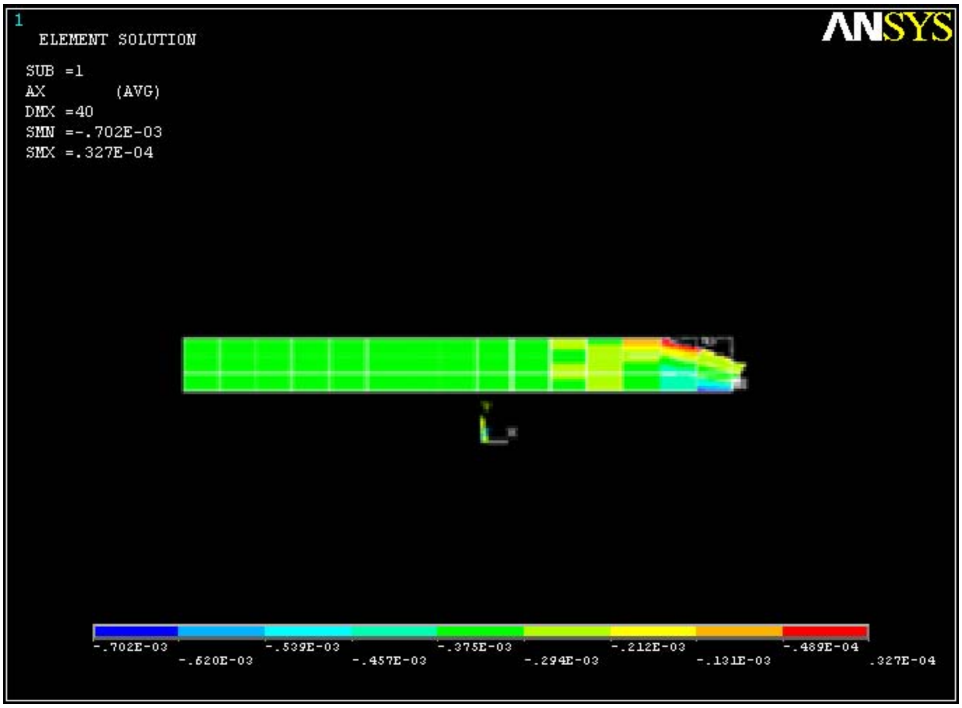

d) Nodal solution x- component (4.5 mm thickness)



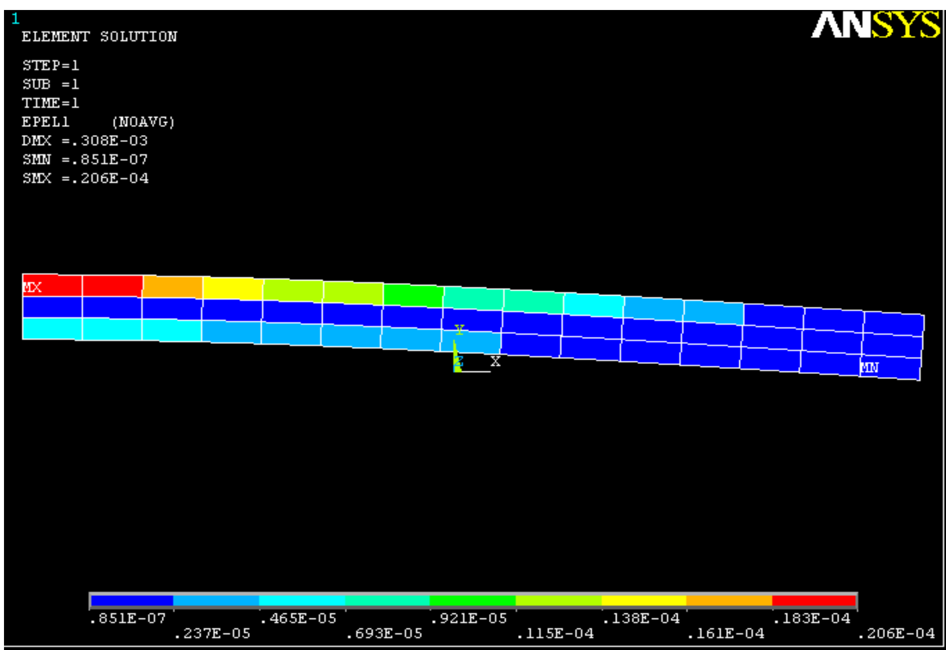

e) Nodal solution y-component (4.5 mm thickness)




f) Nodal solution z-component (4.5 mm thickness




g) Elastic Strain and Element solution for Aluminum sheet metal (at 0.8mm)




h) Elastic Strain and element solution for Aluminum sheet metal (at 4.5mm)

*Fig. 6.6:* The effect of sheet metal thickness

ii. *Effect of sheet metal Type*

❖ *At 0.8mm of aluminium sheet metal energy dissipation is*

$$U_{min=}\frac{1}{2}[\sigma minx\varepsilon min = \frac{1}{2}[-0.699948 * (-0.702)] = 0.24$$

$$U_{max=}\frac{1}{2}[\sigma max\varepsilon max = \frac{1}{2}[0.865889 * (0.0327)] = 0.0141$$

$$U_{spring\ back} = U_{max} - U_{min=}\ 0.0141 - 0.24 = -0.22$$

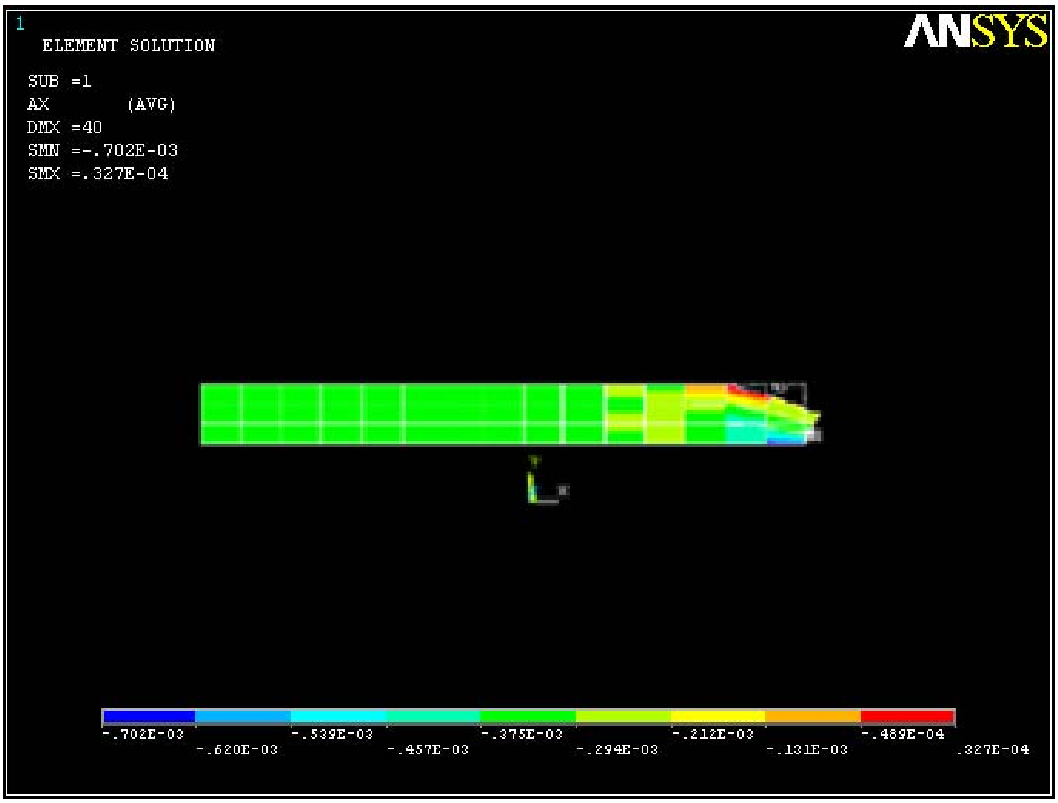
❖ *At 0.8mm of high strength steel sheet metal energy dissipation is*

$$U_{min=}\frac{1}{2}[\sigma min x \varepsilon min = \frac{1}{2}[0.202x10^{-3} * (-0.201x10^{-3})] = -0.0203x10^{-6}$$

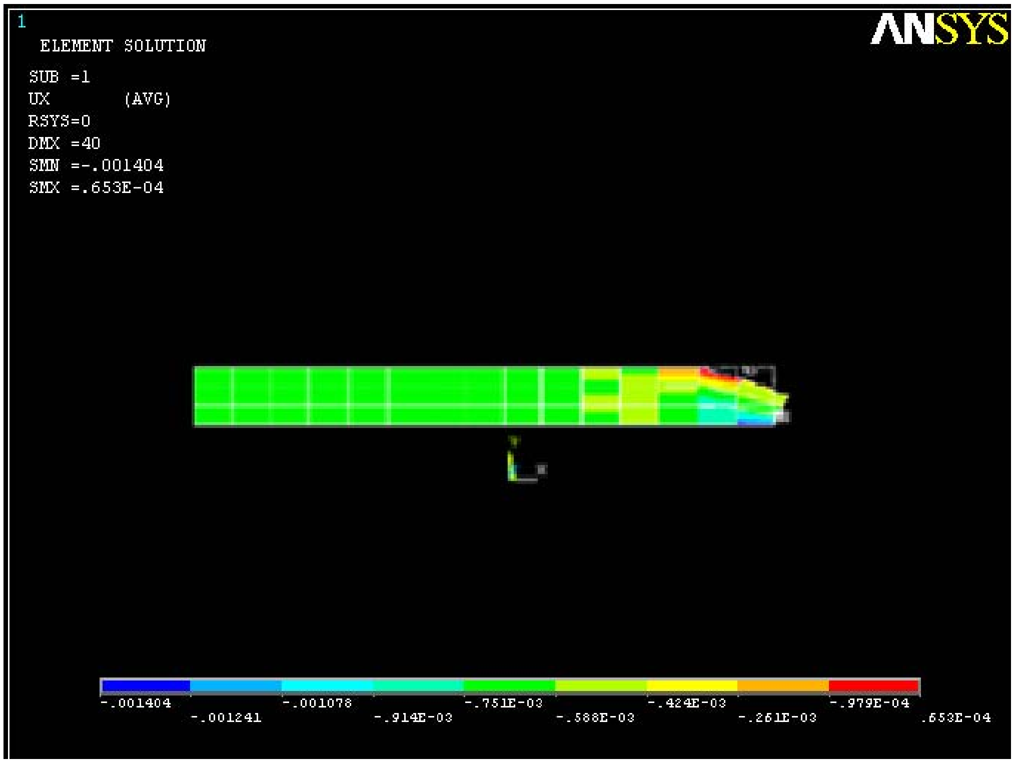
$$U_{max=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[0.433x10^{7} * (0.004196)] = 0.908x10^{4}$$

$$U_{spring\ back}=U_{max}\text{-}U_{min=}\ 0.908x10^{4} - (-0.0203x10^{-6}) = 0.91$$

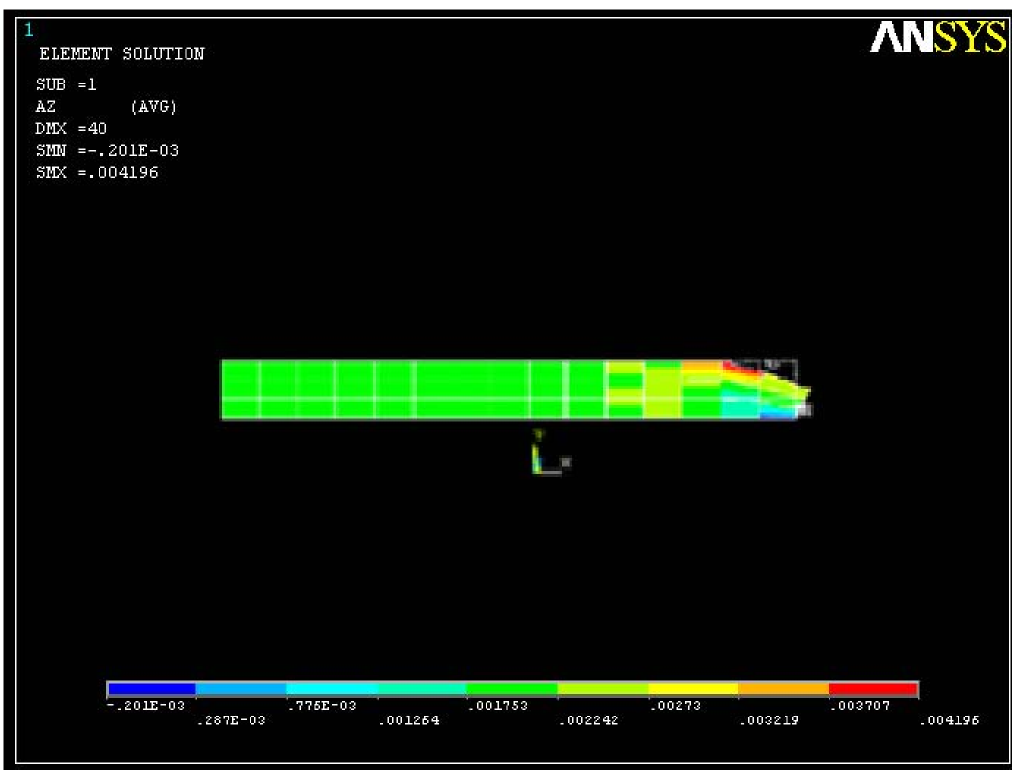
The numerical results of Aluminium, copper, mild steel and high strength steel sheet metal figure.6.6.and figure .6.7 (a-d) shows that for constant sheet metal thickness (0.8mm), the energy dissipation variation is range from -0.22 to 0.91 .Result clearly show that increasing the sheet metal strength (Aluminium to High strength steel) the variation increases. High strength steel needs a considerable higher amount of maximum punch load than the aluminium sheet metal. As we know increasing of sheet metal ultimate strength the punch load is increase. Due to this higher strength, the material is not easily deformed plastically. As a result, the material returns to the original shape and spring back occurs. Hence, the spring back increases from Aluminium to High strength sheet metal.




a) Element solution for Aluminum sheet metal (at 0.8mm)

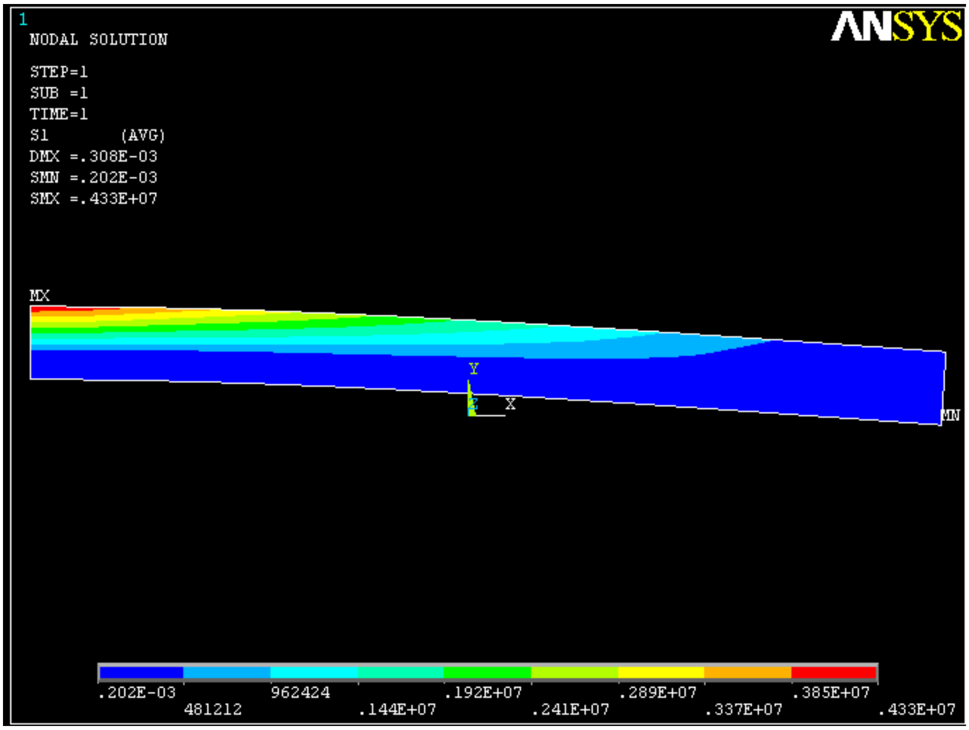



b) Element solution for Copper sheet metal (at 0.8mm)




C) Element solution for High strength steel sheet metal (at 0.8mm)

Global Journal of Researches in Engineering ( A ) Volume XVI Issue IV Version I Year 2016



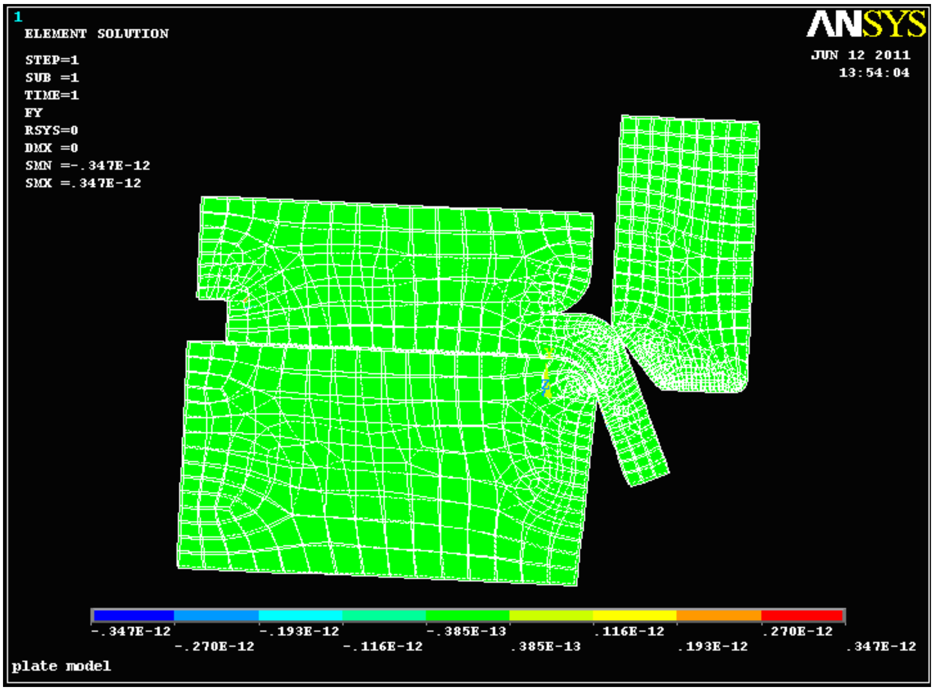

Stress and Nodal solution for High strength steel sheet metal (at 0.8mm)

*Fig. 6.7:* The effect of sheet metal Type

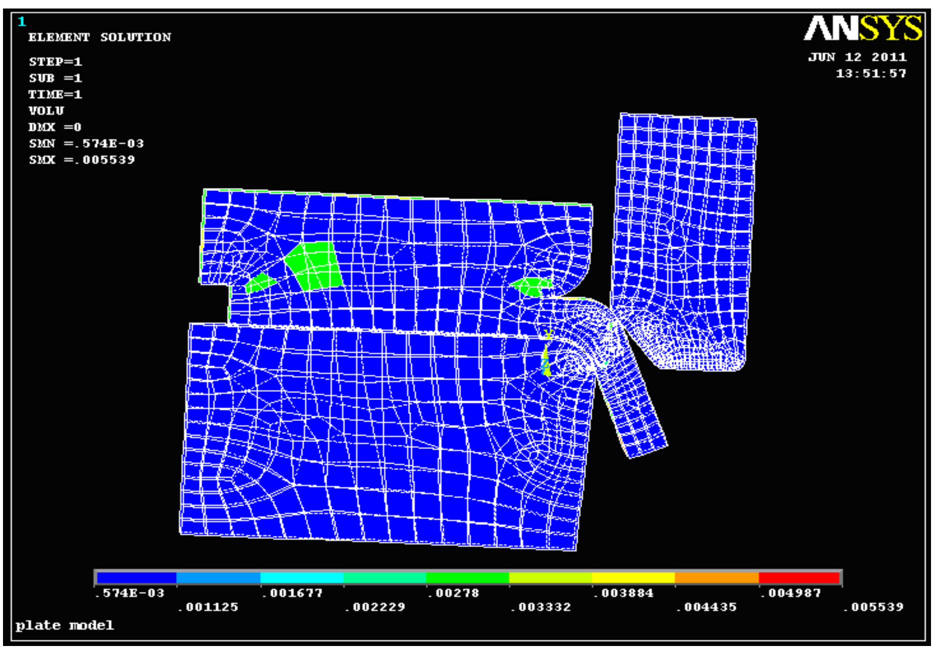
*b) The effect of Tool geometry*

i. *Tool radius (Rp)*

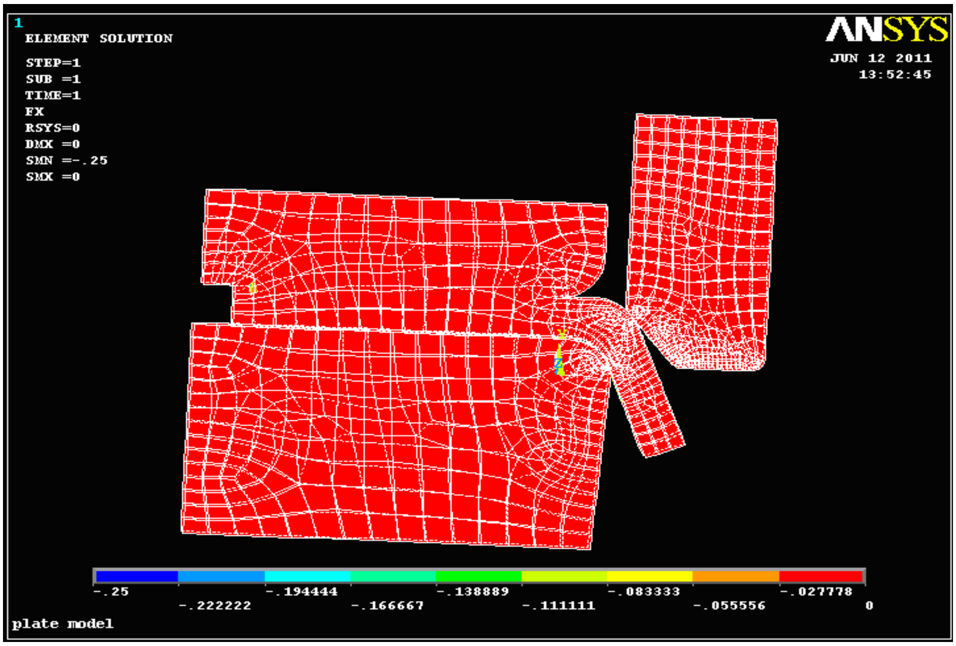
The analysis is to examine the effect of varying the punch radius on spring back. For this purpose the punch is having a different radius Rp, = 10mm, 16mm and 23mm are utilized. The spring back results obtained from numerical analysis in figure6.8 (a-c) shows that Smaller values of the punch radius (Rp=10mm), for the same blank thickness result in smaller spring back values in the deformed sheet metal. From the figure clearly indicates that for reducing of tool radius from23 mm to 10mm the spring back is reduced.




a) Element solution for punch radius (Rp) =10mm




b) Element solution for punch radius (Rp) =16mm

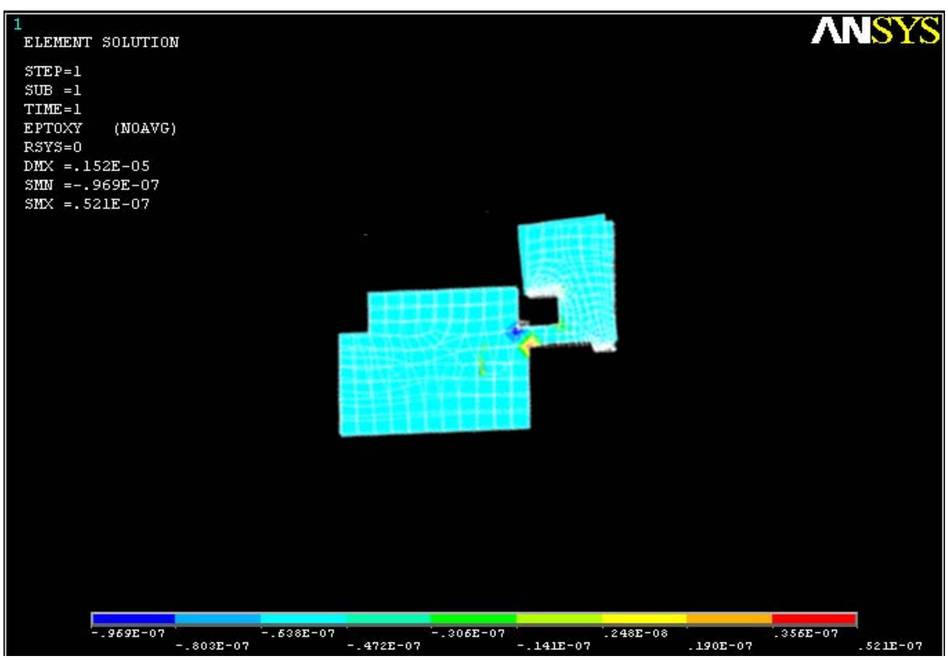



c) Element solution for punch radius (Rp) =23mm

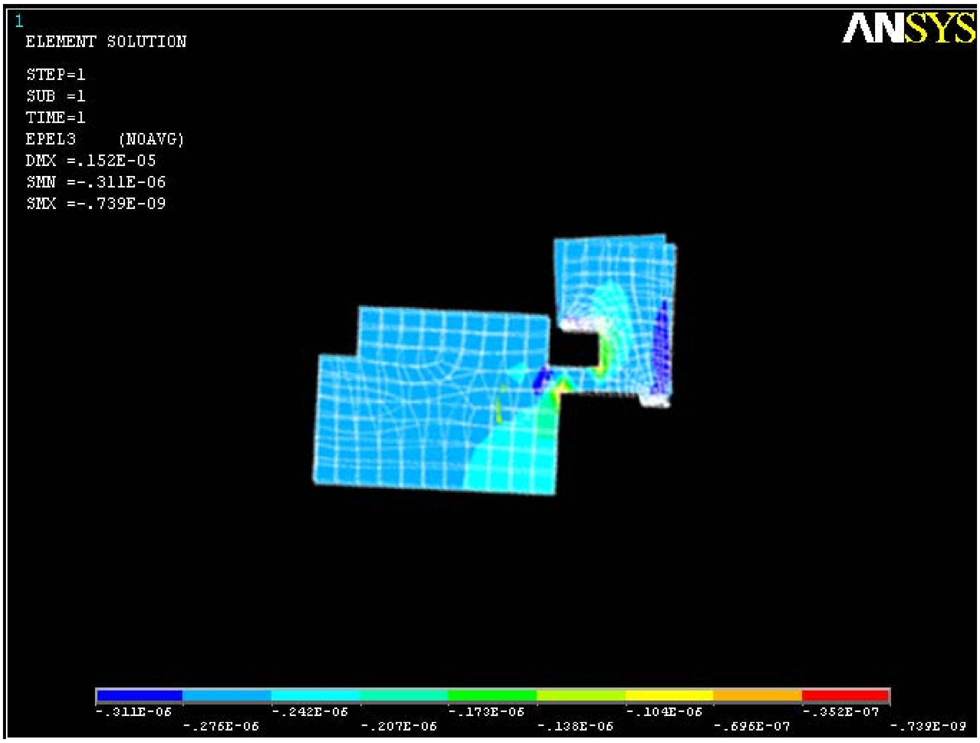
*Fig. 6.8:* The effect of tool radius (Rp)

ii. *Effect of Tool Shape*

In the case of edge bending die observed in fig 6.8 variation of the result range from -0.25to 0.0739 and in the case of differential die the variation ranges from 0.16 to 0.23 .these result shows that in the case deferential die the result close to the maximum value. The reason is in deferential die the pressure is applied in different cross sections of the blank. Due to this the material is deformed plastically. Hence, tool Shape is a significant factor for spring back formation and spring back is highly reduced in the case of differential die bending.




a) Element solution x -component (with 0.8mm thickness Al sheet metal)




b) Element solution y-component (with 0.8mm thickness Al sheet metal)

*Fig. 6.9:* The effect of tool shape

iii. *The effect of friction*

- *At 0.01 friction coefficient the energy dissipation is*

$$U_{min=}\frac{1}{2}[\sigma min x \varepsilon min = \frac{1}{2}[61211 * (0.181x10^{-8})] = 0.26$$

$$U_{max=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[0.433x10^{7} * (0.311x10^{-6})] = 0.67$$

$$U_{spring\ back} = U_{max} - U_{min=}\ 0.67 - 0.26 = 0.19$$

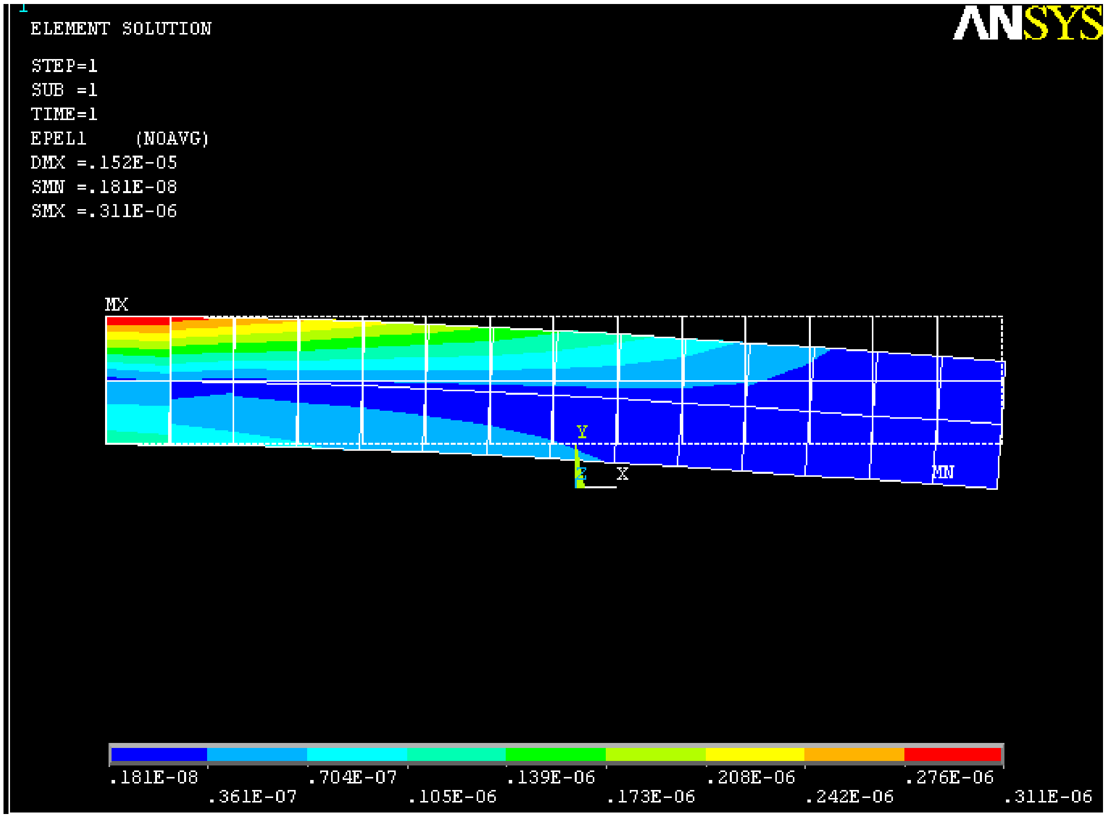
*At 0.50 friction coefficient the energy dissipation is*

$$U_{min=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[-0.433x10^{7} * (-0.122x10^{-6})] = 0.524$$

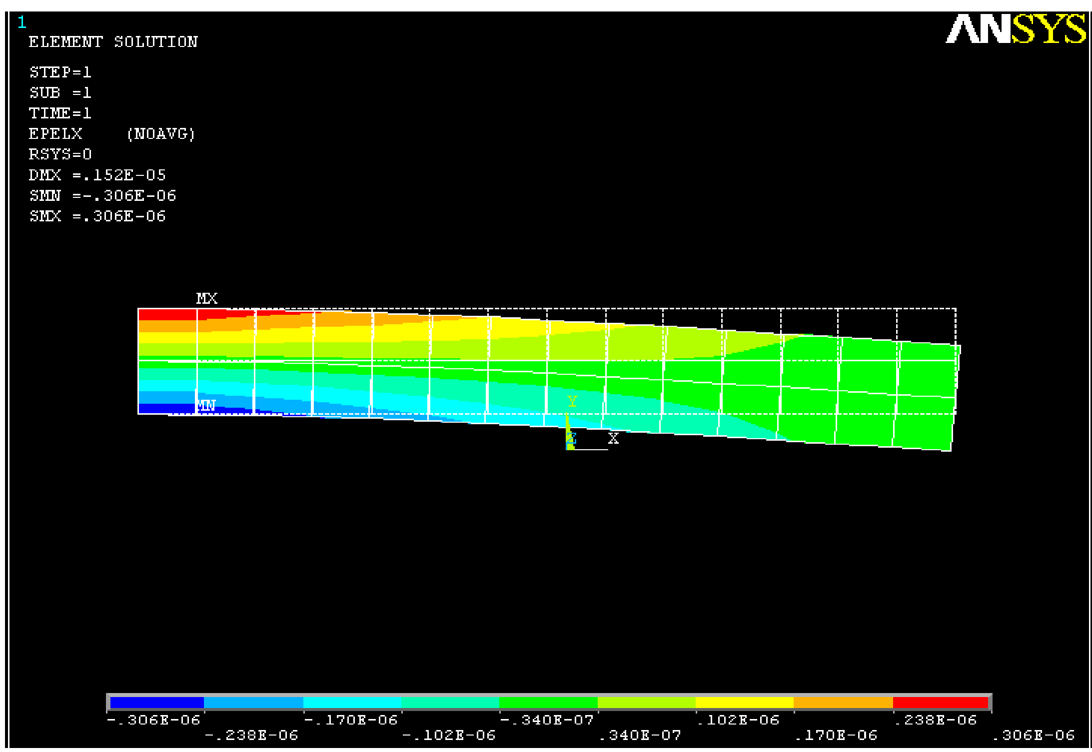
$$U_{max=}\frac{1}{2}[\sigma max \varepsilon max = \frac{1}{2}[-821.995 * (0.122x10^{-6})] = -0.05x10^{-3}$$

$$U_{spring\ back} = U_{max} - U_{min=}\ -0.05x10^{-3} - (0.524) = -0.5205$$

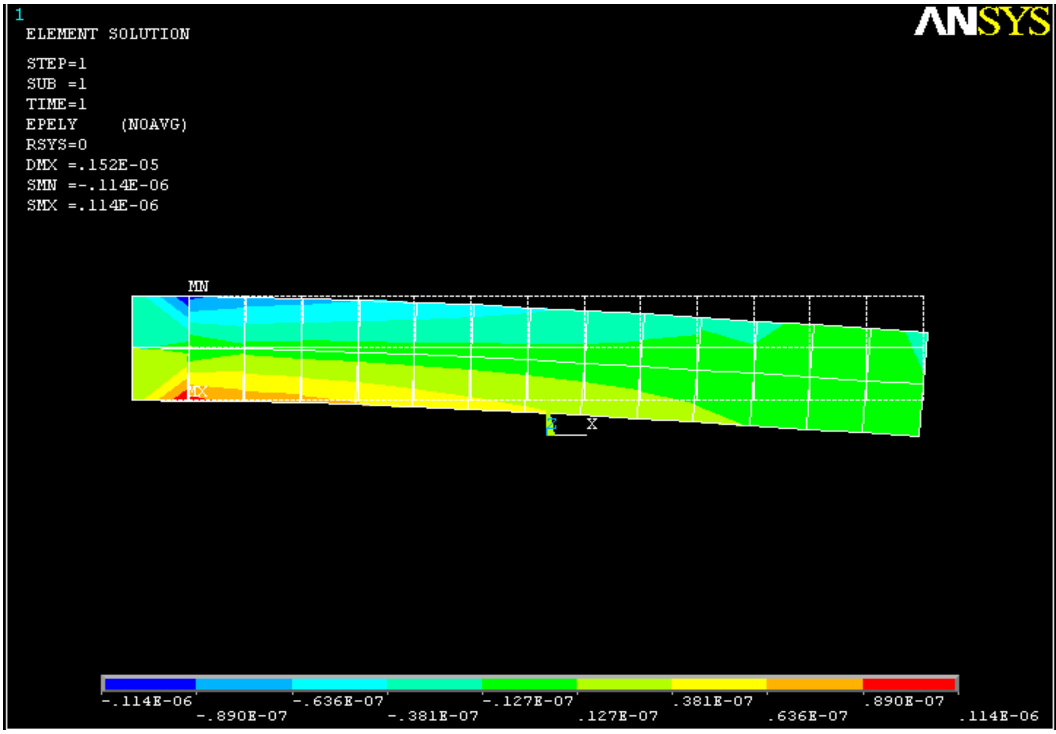
Numerical result conducts that, the coefficient friction varies from $\mu$ = 0.01 to 0.50, with constant dimension and the same sheet metal type. The result increases from 0.19 to 0.52 these needs for maximum bending force. During increasing of the bending force the material will be deformed plastically. But this higher amount force is removing from the material it is highly returned to the original position. Due to this fact the spring back is increased by increasing of friction coefficient for certain limit.



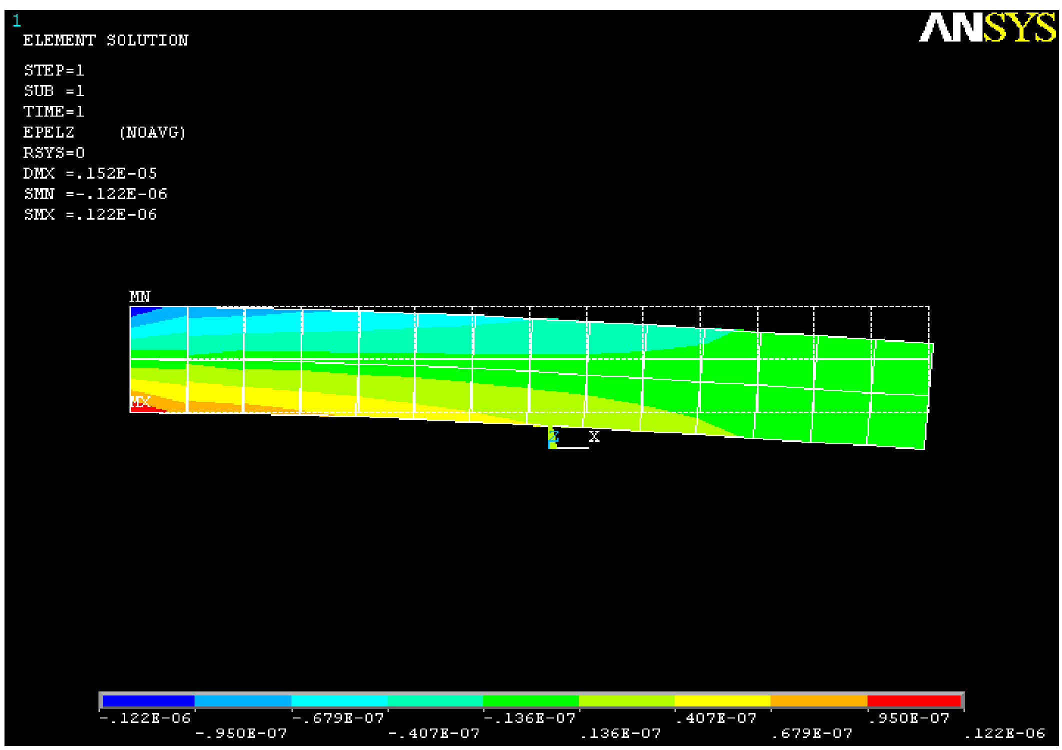

a) Element solution y-component (at μ =0.01)




b) Element solution y-component (at μ =0.05)

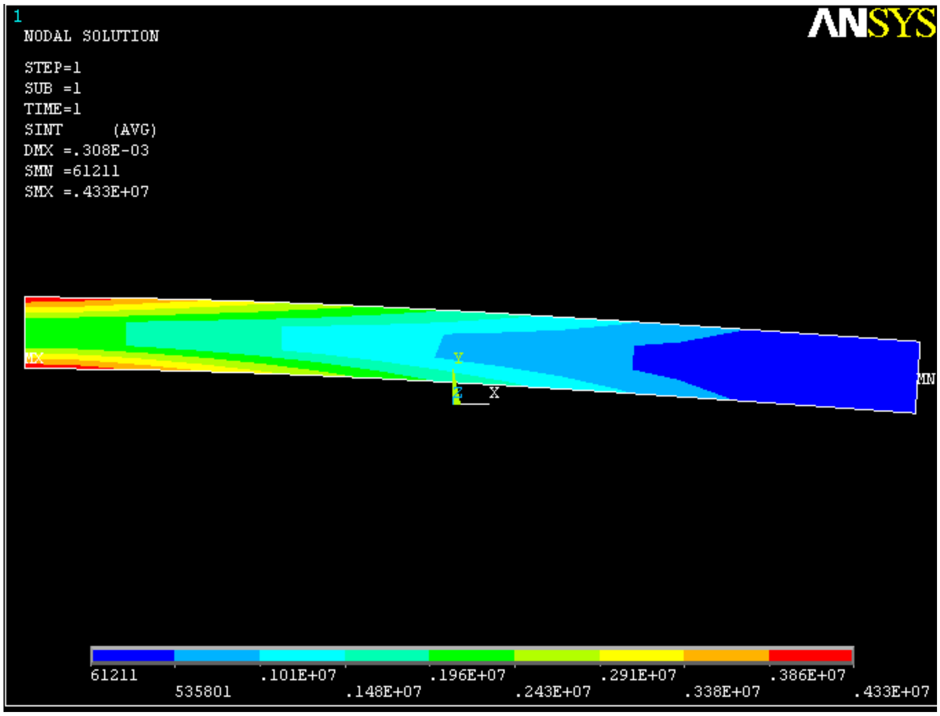



c) Element solution y-component (at $\mu$ =0.15)

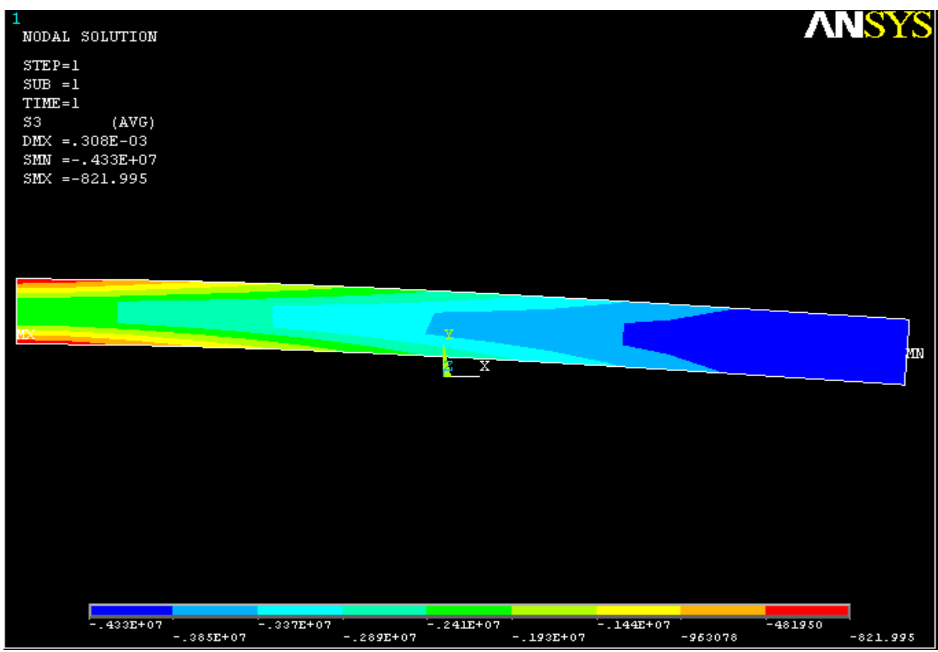



d) Element solution y-component (at $\mu$ =0.50)

Global Journal of Researches in Engineering ( A ) Volume XVI Issue IV Version I Year 2016




e) Stress and Nodal solution y-component (at $\mu$ =0.01)




f) Stress and Nodal solution y-component (at $\mu$ =0.5)

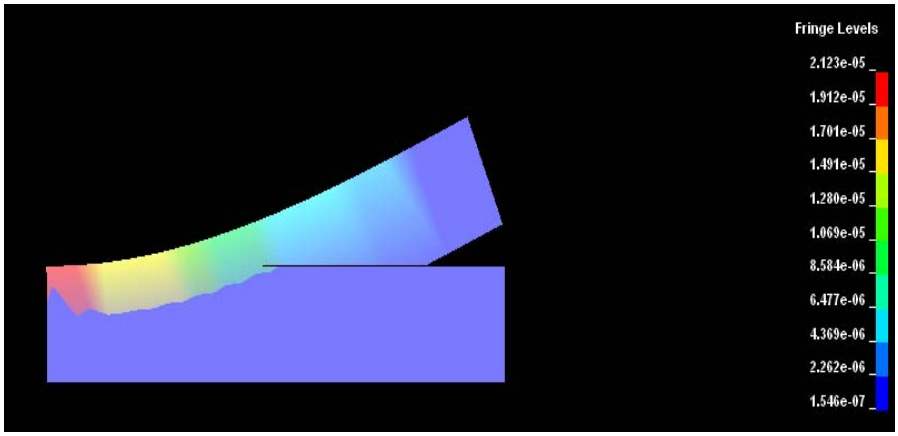
*Fig. 6.10:* The effect of friction

## IV. Implicit Results

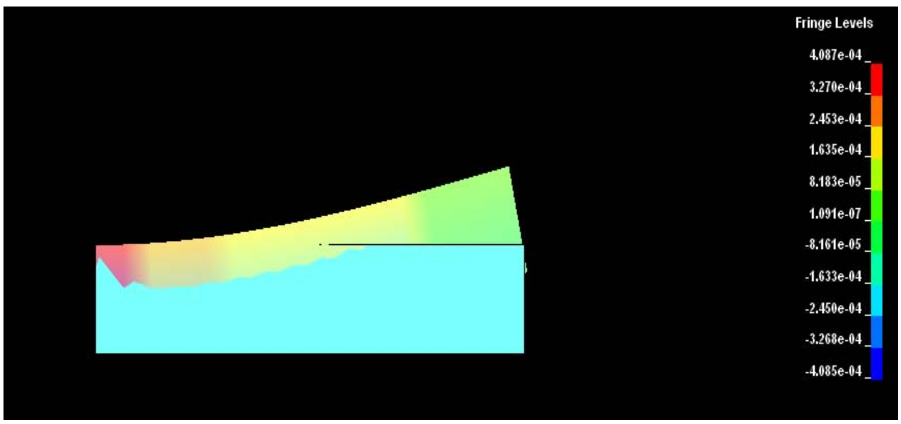
The implicit numerical results have the same effect with explicit result but the difference is the amount of values for the parameters.

*a) The effect of sheet metal thickness*

The implicit result shows in Figure 6.11 with the smaller sheet metal thickness the stress and strain variation are large. But when increasing of sheet thickness from (0.8 mm to 4.5mm) the stress variation is reduced from 2.12 to - 0.0154. This implies that increasing of the thickness from 0.8mm 4.5mm the spring back is reduced.




*a)* Mean strain at (0.8mm thickness)

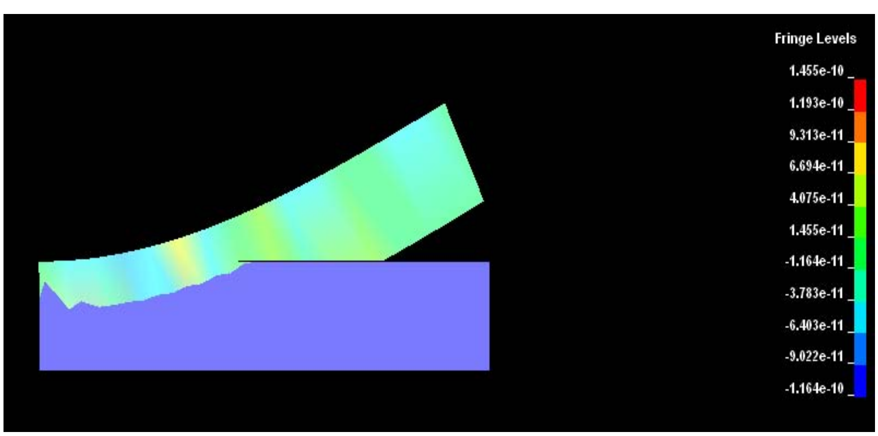



b) Mean strain (4.5 mm thickness)

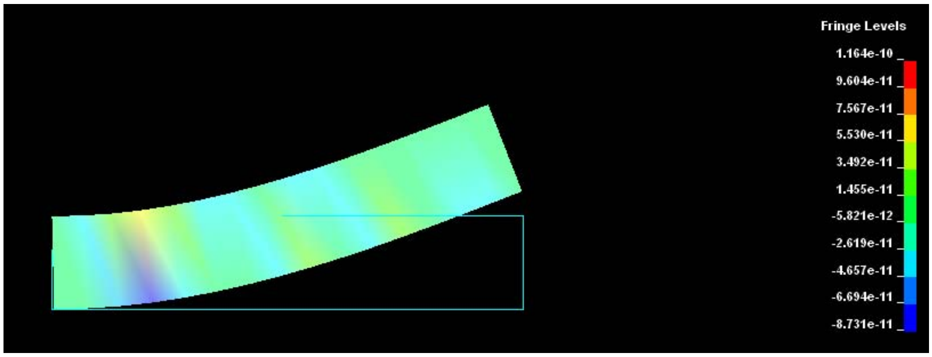
*Fig. 6.11:* the effect of thickness

*b) Material type*

The effect of sheet metal type shows that in figure 6.12 for constant sheet metal thickness, the stress variation is range from - 0.0154 to 0.212. The results clearly show that increasing the sheet metal strength (Aluminium to High strength steel sheet metal) the variation increases. This is due to the yield stress of the sheet metals that is spring back of sheet should be bent, depends on the yield strength of the material. As the materials yield strength increases the spring back after unloading also increases. The spring back will occur where the yield stresses of the material is grater than the stress after Un-loading condition. If the yield stress is equal the stress after deformation, there is no spring back .hence the spring back increases from Aluminium to High strength sheet metal.




a) Mean strain (Aluminum sheet metal)

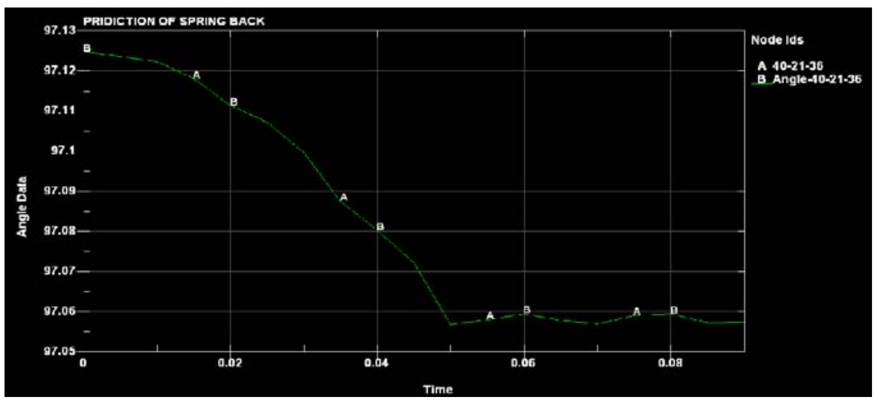



b) Mean strain (High strength steel sheet metal)

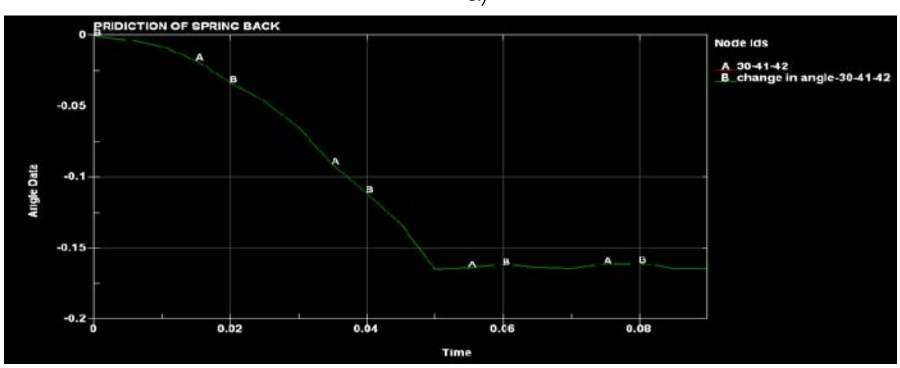
*Fig. 6.12:* the effect of thickness

*c) The effect of angle*

Fig 6.13 shows that the bending angle increases the variation will be reduced, when the variation of spring back angle decrease the spring back also decrees.




a)




b)

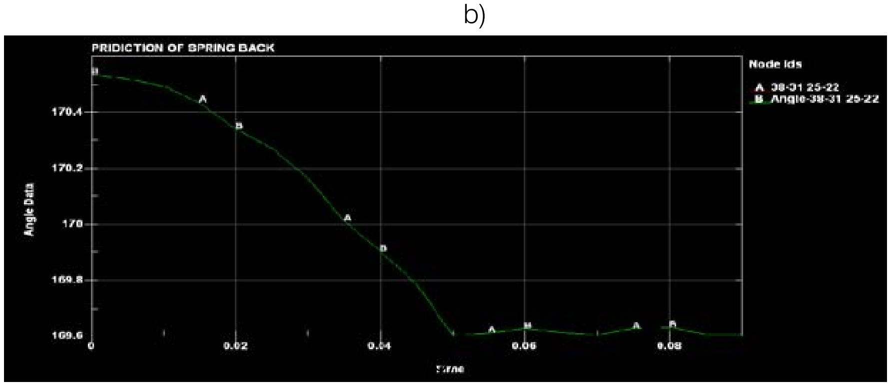
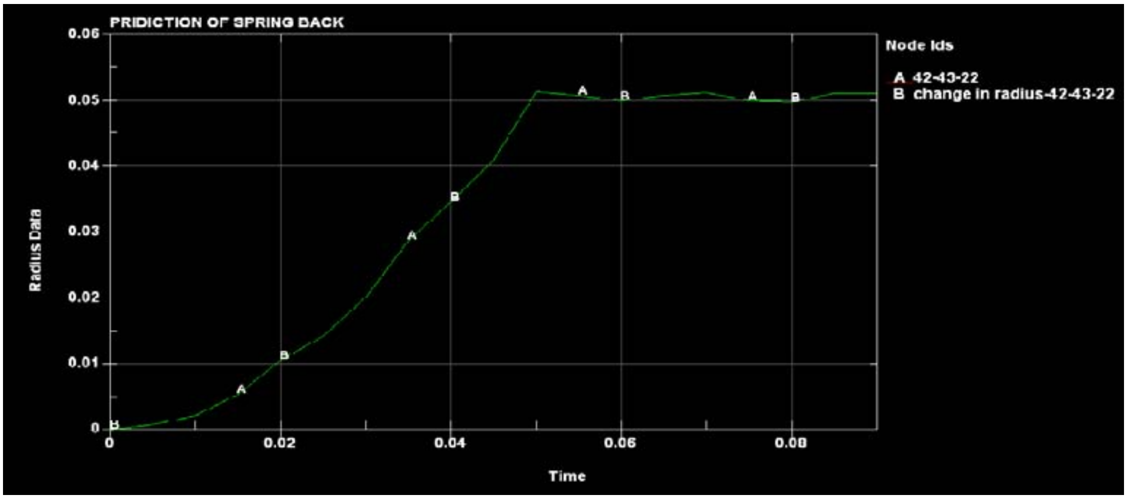


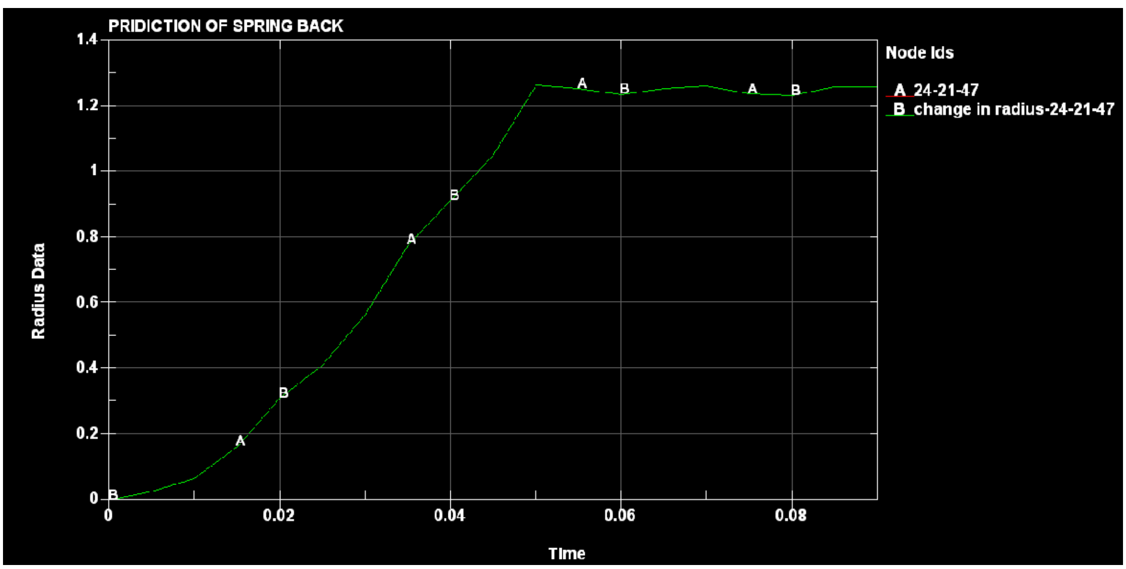

*Fig. 6.13:* Effect of bending angle

*d) The Effect of tool Radius*

The numerical results shows in figure 6.14, For Small punch radius the numerical result have smaller spring back values in the deformed sheet metal. From this result predicts that for increasing of tool radius from 21 to 47 mm the spring back is increase from 0.01 to 1.2.




a)




b)

*Fig. 6.14:* The effect of tool radius

## V. Validation of the Mode

Under this topic Analytical predictions are compared with the previous studies. In the second method, we compare the Analytical investigations with the finite element predictions. It is an effective result in comparing for the validation of the attained results.

*a) Comparison of our investigation with the previous studies*

The Stepped Binder Force Trajectory and Neural Network Control proposed by Jian Cao and Brad Kinsey in order to predict and control spring back in forming process. Regarding the sheet thickness and binder force as possibly the most significant process parameter, the robustness of their control system was tested against variations in the friction coefficient, and excellent results were obtained. However, the effect of material type in the material properties and sheet thickness were not investigated in their work. Therefore, further closed-loop control simulations with these variations were conducted here in order to form a comparison with the neural network control system. The spring back angle values from these neural network control system have wider difference comparing to our result. The resulting spring back angle from the process was calculated within a range of 0.29° to 1.8°. For sheet metal thickness range from 0.8-4.5mm.but in the case of our result within the same thickness range the spring back angle values are 019-0.03. This indicates that the spring back angle of our analysis was considerably less and closer to the original angle. Though the method we have to use and developed are required producing accurate and sufficient results for predicting and controlling of spring back comparing with natural network control method. Recep Kazan (2008) was also conducted to predict spring back in wipe-bending process of sheet metal using artificial neural network (ANN). Here, several parameters were considered to predict spring back. The important parameters they considered for the analysis were sheet thickness and tooling geometry are used. In order to investigate the effect of die radius and blank thickness on the spring back angle of flanging process, models were done with the sheet metal thickness are taken as 0.7mm to 5.0mm and die radius also 0.7 to 5.0mm should considered. However the results with variations in sheet thickness (0.8-4.5mm) spring back angle by artificial neural network were investigated 1.763°. -1.24°.

For constant thickness with different sheet metal type the Variations of radius was investigated 1.2764.-1.89 but in our result the spring back is predicted with 0.08-0.49°.and 0.557-1.333 angle and tool radius respectively. From these analysis our parameter selection and prediction method (analytical and FEM) is better for prediction of spring back and optimization of bending process.

## VI. Conclusions and Recommendation

### a) Conclusion

In this research work a detailed study of the parameters that influencing on spring back was conducted. The conducted literature review revealed that, although similar studies were conducted in the previous developed models were unable to consider simultaneously all the parameters influencing spring back formation. Accordingly this work is an attempt to study spring back by including more parameters at a time in order to study spring back and predict the amount of spring back in sheet deformation process, thereby optimizing the sheet bending process. However a numerical investigation of spring back is conducted using ANSYS™ LS-DYNA™. The developed implicit and explicit numerical models are used for prediction of spring back formation by varying parameters such as: sheet metal material and thickness, coefficient of friction between the die and the material, and tool radius and tool shape .

The results were compared with the previous study results and, the following conclusions were drawn from this study;

- The result shows that increasing sheet metal thickness from 0.8mm to 4.5 mm the spring back is reduced by 20.35 %.
- When increasing of sheet metal strength spring back increases however, in these cases more maximum required punch loads are needed. Aluminium exhibits lower spring back than mild steel and high strength sheet metals. Using Aluminium sheet metal instead of High strength sheet metals spring back is reduced by 56. %
- For decreasing of the tool radius leads to spring back is reduced.
- Modifying tool shape also changes spring back. i.e. using deferential die instead of edge bending die the spring back is reduced by 12 %
- Increasing of friction coefficient from 0.01 to 0.50 the spring back is increase by 52%.
- Hence, an optimum value of sheet metal thickness, material type and tool radius should be chosen for reducing of spring back. Finally utilizing and compensation of tool geometry is considered for optimizing of bending process, when the spring back is reduced, this is also helps to obtain quality sheet metal product manufacturing.

### b) *Recommendation and future works*

Some of the suggestions for further investigations are:

- To verify the spring back prediction through an experiments
- To compensate of spring back in the die design using FE simulations
- Development of spring back prediction is conducted in warm and cold sheet metal conditions are also considered.

## References Références Referencias


1. Xu Jingjing Wang Xiumei Zhang Ping Wu Yimin ,Spring Back Prediction In Sheet Metal Forming Combined Finite Element Method With Date Mining Technique1
2. Hakim S. Sultan Aljibori Finite Element Analysis Of Sheet Metal Forming Process
3. Recep Kazan, Mehmet Firat, Aysun Egrisogut Tiryaki Prediction Of Spring Back In Wipe-Bending Process Of Sheet Metal Using Neural Network
4. Gardiner Ag. The Spring Back Of Metals. Trans Asme J Appl Mech 1957;79:1–9.
5. Waluyo A. Siswanto , Badrul Omar Die Surface Design Optimization Accommodating Spring Back Assisted By An Automatic Surface Generator
6. Pohlak, M.; Küttner, R.; Majak, J.; Karjust, K. & Sutt, A. Simulation Of Incremental Forming Of Sheet Metal Products
7. Himanshu V. Gajjar, Anish H. Gandhi, And Harit K. Raval, Finite Element Analysis Of Sheet Metal Airbending Using Hyperform Ls-Dyna
8. Bradley N. Maker Xinhai Zhu, Input Parameters For Metal Forming Simulation Using Ls-Dyna

9. Steeve Dejardin Finite Element Analysis And Experimental Investigations For Precision Improving In Single Point Incremental Sheet Forming
10. M.H. Parsa Studies The Effect Of Curvature On Spring Back Of Double Curved Steel Sheet Using New Method
11. M. Schikorra1, A. Brosius1, M. Kleiner, Analysis Of A Measurement System For Characterisation Of Spring Back
12. Processhariharasudhan Palaniswamy, Gracious Ngaile, Taylan Altan,(2004), Optimization Of Blank Dimensions To Reduce Spring Back In The flex forming Process
13. Daniel Lepadatu · Ridha Hambli · Abdessamad Kobi· Alain Barreau, Optimisation Of Spring Back In Bending Processes Using Fem Simulation And Response Surface Method
14. Per-Anders Eggertsen1, Kjell Mattiasson, Material Modelling For Accurate Spring Back Prediction
15. Nielen Stander, Mike Burger, Xinhai Zhu And Bradley Make, Spring Back Compensation In Sheet Metal Forming Using A Successive Response Surface Method
16. A.Behrouzi1, M. Shakeri2, B. Mollaei Dariani,Inverse Analysis Of Spring Back In Sheet Metal Forming By Finite Element Method
17. Nan Song1+ Dong Qian1+ Jian Cao1§* Wing Kam Liu1¶Shaofan Li, Effective Models For Prediction Of Spring Back In Flanging.
18. By Fahd Fathi Ahmed Abd El Al1 June, 2000, Finite Element And Experimental Studies Of Springback In Sheet Metal Forming
19. Mohsen Safaeia , Wim De Waelea And Kris Hertschap, Finite Element Analysis Of Influence Of Material Anisotropy On The Spring Back Of Advanced High Strength Steel
20. Peng Chen B, Muammer Koc, Simulation Of Spring Back Variation In Forming Of Advanced High Strength Steels
21. M. Kadkhodayan_, I. Zafarparandeh, An Investigation Into The Influence Of Blank Holder Force On Spring Back In U-Bending
22. Ridha Hambli Æ Ali Mkaddem, (2003) Damage Prediction In L-Bending Processes Using Fem
23. I.A. Burchitz, Improvement Of Spring Back Prediction In Sheet Metal Forming,)
24. F. Ayari A, Parametric Finite Element Analysis Of Square Cup Deep Drawing
25. T. Meindersa ,I.A. Burchitz, Numerical Product Design: Spring Back Prediction, Compensation And Optimization
26. Kyung K. Choi And Nam H. Kim†Design Optimization Of Spring Back In A Deep Drawing Process
27. Hong Seok Kimb, Muammer Koc¸ A,∗ Numerical Investigations On Spring Back Characteristics Of Aluminum Sheet Metal Alloys In Warm Forming Conditions
28. Jeong-Whan Yoona;B;∗, Farhang Pourboghratc, Kwansoo Chungd, Dong-Yol Yang Spring back Prediction For Sheet Metal Forming Process Using A 3d Hybrid Membrane/Shell Method
29. Thaweepat Buranathiti And Jian Cao*, An Effective Analytical Model For Spring back Prediction In Straight Flanging Processes
30. M.C. Oliveira A,*, J.L. Alves B, B.M. Chaparro C, L.F. Menezes A Study On The Influence Of Work-Hardening Modeling In Spring Back Prediction
31. A. Andersson Numerical And Experimental Evaluation Of Spring back In Advanced High Strength Steel
32. Dilip Kumar.K ,Thinning And Spring Back Of Aluminum Sheet Metal During L - Bending Operation
33. Jian Cao And Brad Kinsey, Consistent And Minimal Spring Back Using A Stepped Binder Force Trajectory And Neural Network Control
34. A. Behrouzi1, M. Shakeri2, B. Mollaei Dariani3 Inverse Analysis Of Springback In Sheet Metal Forming By Finite Element Method
35. 2002 S.J. Hu, Z. Marciniak, J.L. Duncan.,Mechanics Of Sheet Metal Forming
36. 2006, By Ivana Suchy ,Hand Book Of Die Design 2nd Ed
37. K. Siegert And S. Wagner,Formability Characteristics Of Aluminum Sheet
38. By Gessessew Likeleh T/YohannesFEM Analysis of Closed Die Forging June 2010 BDU
39. The Finite Element Method 5th Ed Volume 1: the Basis
40. R.M. Cleveland, A.K. Ghosh,(2002) "Inelastic effects on spring back in metals
41. Department of General Engineering at the University of Illinois at Urbana May 200, Tutorial for ANSYS
42. W.P. Carden, L.M. Geng, (2002) "Measurement of spring back.
43. Muammer Koc, (2007), Numerical Investigations on Spring Back Characteristics of Aluminium Sheet Metal Alloys in Warm Forming Conditions
44. Henry Valberg 2010 Applied Metal Forming Including FEM Analysis.
45. Stephen W. Attaway, Ph.D, the Mechanics of Friction in Rope Rescue
46. Rajen subhashchandra Pandya May 2006, Pridiction of variation in dimensional tolerance of holes due to sheet metal hydro forming using Finite Analysis
47. Altair Engineering 2007, HyperMesh 8.0 Tutorials LS-DYNA Solver Interface
48. Livermore Software Technology Corporation 2009, Ls-Pre Post Metal Forming Simulation (Tutorial Manual – Trimming and spring back) David Roy Lance August 23, 2001stress-Strain Curves.

49. Lee Conner Christian May 2005, thru-Thickness Bending Stress Distribution at Elevated Temperatures.

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN: 0975-5861

# Performance of Composite Structures Subjected to High Velocity Impact – Review

By Enock A. Duodu, Jinan Gu, Wei Ding & Shixi Tang
*Jiangsu University*

*Abstract-* In recent years, breakthrough in the development of modelling techniques and impact analysis of composite materials subjected to high velocity has been made. The study methodically reviews the modelling techniques for the structural response of composite materials under high velocity. Although, report gives numerical model as widely used method, yet experimental test is always required to validate both analytical and finite element designs. The assessment shows that all modelling methods are suitable for application based on loading conditions of the composite structure. Lastly, the reference list provides databank for future researchers and engineers on composite structure subjected to high velocity impact.

*Keywords: analytical approach, experimental method, finite element simulation, high velocity impact, composite materials.*

GJRE-A Classification: *FOR Code: 091399*

PERFORMANCEOFCOMPOSITESTRUCTURESSUBJECTEDTOHIGHVELOCITYIMPACTREVIEW

*Strictly as per the compliance and regulations of:*

# Performance of Composite Structures Subjected to High Velocity Impact – Review

Enock A. Duodu α , Jinan Gu σ, Wei Ding ρ & Shixi Tang ω

*Abstract-* In recent years, breakthrough in the development of modelling techniques and impact analysis of composite materials subjected to high velocity has been made. The study methodically reviews the modelling techniques for the structural response of composite materials under high velocity. Although, report gives numerical model as widely used method, yet experimental test is always required to validate both analytical and finite element designs. The assessment shows that all modelling methods are suitable for application based on loading conditions of the composite structure. Lastly, the reference list provides databank for future researchers and engineers on composite structure subjected to high velocity impact.

*Keywords: analytical approach, experimental method, finite element simulation, high velocity impact, composite materials*

## I. Introduction

Carbon fibre-reinforced composites are known for their high weight-specific stiffness and strength properties, which make them a preferred alternative in the material selection for modern lightweight structures in aeronautic and automotive engineering. However, these materials are susceptibility against impact loads. Internal damage formed in composite laminates spreads beyond the impacted area, and significantly reduces the strength and stiffness of the composite [1]. Composite materials response to impact loading and also the dissipation of the incident kinetic energy of the projectile is different when compared to metals. In traditional materials energy is absorb through elastic and plastic deformation which result in permanent structural deformation [2]. However, the capability of the composites to undergo plastic deformation is extremely limited as the resultant energy is frequently absorbed to create large zones for fracture with resultant reductions in both strength and stiffness [3].

Composite materials are extensively used in industrial applications such as aerospace, marine, locomotive and civil engineering structures due to their superior material properties. However, these materials tend to involve many microscopic damages including stiffness reduction due to impact which often leads to catastrophic failure. Currently, the extent of fiber-reinforced composites applied in aircraft structures has become one of the most important targets making the advancement of modern structural design. Nevertheless the applications in aerospace industry, composites are increasingly used in other industries such as civil, sporting equipment, medical fields, automotive, railways and in marine vessels specifically for masts, hulls, desks and propellers. Unlike traditional materials, composites offer an endless array of design variations with flexibility accompanied by complications in modelling and analysis. This performance attracted transportation industries to develop structures replacing metallic material with the lighter structures. However, composite structures are poor to impact resistance owing to cyclic loading conditions, which results in inelastic behavior and poor damage resistance. Composite structures can develop local failures or exhibit local damage such as matrix cracks, fiber breakage, fiber-matrix debonds, and delaminations under normal operating conditions which may contribute to their failure.

High velocity impact is defined as local wave dominated response independent of boundary conditions ranging above 10 m/s, and characterized as dynamic events [4] with high speed and small mass. High velocity impact produces a short duration, steeply rising loading pulse when impacting the structure. It is dominated by inertial forces, wave propagation and changes in material stiffness, strength and fracture energy due to a high strain rate [5]. There are many parameters which influence the response of composite materials under high velocity impact, and these include: type, architectures and volume fraction of the reinforcement, laminate thickness, matrix system, projectile geometry and mass [6]. At high incident impact energies, target perforation may occur and the passage of the impactor naturally results in petalling, cracking and spalling. Although such damage reduce the load-bearing ability of the structure, its effects can generally be predicted using fracture mechanics principles [7].

In a high velocity impact, the response of the structural element is governed by the local behaviour of the material in the neighbourhood of the impacted zone; the impact response of the element being generally independent of its support conditions; and in most cases, impact test is carried out experimentally using a single stage gas gun. In recent years, researchers [8-10] have used sensors and transducers, however, residual velocity is difficult to measure as a result of shear plugs while other researchers have adopted a high-speed

*Author α: School of Mechanical Engineering, Jiangsu University, Zhenjiang, 212013, China. e-mail: enockduodu@ujs.edu.cn*

video cameras [11] due to its consistency and precision. As a result of focus on the impact response, it is important to understand the material's behaviour and the mode of assessment when subjected to impulsive loading.

Nowadays, composites are believed to have superior potential applications as the primary load-bearing structure in many industries, thus, studies on impact behaviour of carbon fibre composite have attracted much attention and become a hot research interest in the discipline of composite materials. This work is a bit of that endurance to establish numerical models capable for structural optimization in diverse engineering applications especially aeronautics and astronautics design. Therefore, the main objective of this paper is to review recent models used to analyze impact response of composite materials subjected to high velocity. Depending on the nature of the structure and the impact threshold, numerous studies have adopted analytical, experimental and numerical methods to analyze the structural behavior. On like metals, composite materials are anisotropic or orthotropic in nature and their mechanical behaviors under impact are complicated to predict, and therefore presents distinctive and demanding task for researchers and engineers to study in order to predict the impact response during static and dynamic loading conditions for safe used. This work endeavor is part of that endurance and aims to review the methodologies capable to predict structural performance in diverse engineering applications.

## II. Methods of Analysis

### *a) Experimental technique*

Lahuerta et al. [12] used an experimental technique to measure the delamination length in mode *I* tests based on video image processing. A non-dimensional formulation of an analytical model proposed in a previous work of García Castillo et al. [13] was redeveloped by [14] based on energy criteria to study the ballistic behaviour of composite plates made from woven laminates of E-glass fibers. This model allows for estimation of the residual velocity of the projectile, the ballistic limit, the energy absorbed by different mechanisms during the penetration of the laminate, and the contact time between the projectile and the laminate. Good agreement was found for residual velocities, contact time and ballistic limit for two geometry ratios.

Hosur et al. [15] conducted experimental study on response of stitched/unstitched woven fabriccarbon/epoxy composite laminates subjected to high velocity impact loading. The ensuing damage is characterized through ultrasonic NDE. Result of the study indicates that the damage is well contained within the stitch grid in the stitched laminates but higher for the unstitched laminates. Their studies also proved that ballistic limit increased with the increase in the thickness of the laminate; however, satin weave laminate exhibited higher ballistic limits in most of the cases.

Garcia-Castillo et al. [16] examined the damage in preloaded glass/vinylester composite panels subjected to high-velocity impacts. In their study, three representative structural cases (no, uniaxial and biaxial loadings) was analyzed. The result shows that the damage area was localized in the center of the panel; and qualitatively the damage area was largest on the non-loaded laminate of impact velocity of 136 m/s followed by 130m/s velocity uniaxial loading with the least being the 98m/s impact loading of the biaxial laminate. The study reveals that the impact energy and damage area was greater in the non-preload laminates than in the uniaxial and biaxial preloaded laminates. This difference occurs due to the increment of effective stiffness in panels subjected to membrane loads, which decreases the displacement of the panels, and accordingly reduces the damage area. This phenomenon is more significant at the perforation-threshold energy, where the bending of the panels is the greatest. High velocity impact response of sandwich structure composite laminated plates, Kevlar-29/epoxy and 60 61-T6 aluminium was experimentally investigated by [17] using a nitrogen gas gun. Adopting the same approach, high velocity projectile impact through different thickness of polyurea coated AA5083-H116 aluminium alloy plates was assessed by [18].

Jabbar et al. [19] presented experimental study to compare the mechanical and ballistic performance of composites reinforced with single-layer and double-layer inter-locked woven fabrics low and high velocity impacts. The energy absorption and mechanical failure behavior of composites during the impact event were found to be strongly affected by the weave design of the reinforcement. The composites reinforced with double-layer interlocked woven fabrics were found to perform better than those comprising single-layer fabrics in terms of impact energy absorption and mechanical failure. Similarly, Sultan [3] prescribed a study to examine the effect of thickness on fiber glass reinforced epoxy matrix subjected to high velocity impact loading. Their results show that the mechanical properties, damage characterization and impact resistance of type C-glass/Epoxy 600 $g/m^2$ possess better toughness, modulus and penetration compared to type C-glass/Epoxy 200 $g/m^2$. Moreover, as the plate thickness increases, the maximum impact load and impact energy increases relatively. The result clearly reveals that impact damage was in the form of perforation, fiber breakage and matrix cracking.

Sabet et al. [20] presented experimental study on high velocity impact performance of glass reinforced polyester (GRP) resin composite plates with different type of reinforcement between the velocity range of 80 to 160 m/s. Result shows higher ballistic limit velocity (velocity at which samples fully penetrated the target plates with zero residual velocity) for 3 mm GRP plates with cross-ply unidirectional reinforcement followed by unidirectional reinforcement and plain weave, the plates with satin weave and chopped strand mat (CSM) reinforcements were almost in same level. The report added that thicker specimens (6 mm), plates with plain weave reinforcement showed better ballistic performance towards sharp tipped conical projectile impact, followed by cross-ply unidirectional, satin weave, unidirectional and CSM reinforced plates. Experimentally, the study reveals that the ballistic limit velocity for all specimens correlate well with estimated ballistic limit values obtained in full perforation tests. Findik et al. [21, 22] have investigated experimental study on impact performance of some polymer-based composites and observed the contact mechanism as well as dynamic response of composite laminates. Pol et al. [23] performed experimental study on the influence of nano-clay Closite 30B on ballistic impact behavior of 2D woven E-glass/epoxy laminated composites.

The standard material characterization under compression and fracture modes was assessed by [24] under experimental study of high velocity impact fracture of ice. The failure of fiber reinforced thermoplastic composites (polypropylene made of hybrid E-glass/PP yarns) was investigated under medium and high velocity impact loading conditions by electromagnetic and acoustic emission signal measurements [25].

Hazell et al. [26] presented experimental study on the response of a bonded carbon–fiber-reinforced plastic composite panel to impact, penetration, and perforation by a high-velocity steel sphere. Hou et al. [27] identified and discussed the ballistic performance, quasi-static and impact perforation of metallic sandwich structures with aluminum foam and studied the effects of several key parameters as impact velocity, skin thickness, thickness, density of foam core, and projectile shapes on the ballistic limit and energy absorption of the panels during perforation of impact loading.

To elucidate the penetration and failure mechanisms, an experimental test using the JH-1 ceramic model of the projectile penetrating into a silicon carbide-faced polycarbonate is implemented in the hydro-code Autodyn-2D [28]. Übeyli et al. [29] have experimentally studied the ballistic behavior of laminated composite having alumina front and dual phase steel backing layers using 7.62 mm armor piercing (AP) projectiles under normal impact. The results showed that utilization of a 6 mm thick alumina front layer which is bonded to dual phase steel enhanced the ballistic resistance of the dual phase steel remarkably.

A study of the high velocity impact response of thick composite plates under tensile preload using a glass sphere projectile and an impact velocity is presented in [30], where less delaminations compared to the unloaded case are obtained under tensile preloads. Ballistic impact tests on thick woven E-glass/vinyl ester plates with compressive preload and variable velocities are performed by [31]. The authors report a detrimental effect on the residual strength of the composite plate.

*b) Analytical study*

Talib et al. [32] formulated analytical model to predict the performance of hybrid composite made of woven fiber Kevlar-29 and $Al_2O_3$ powder/epoxy subjected to high velocity impact. The relationship between the ballistic limit with the thickness and energy absorption with thickness for Kevlar-29 fiber and $Al_2O_3$ powder-reinforced composite materials was established. It was found that the proposed equation is suitable for this type of composite materials after comparing the behavior of the theoretical analyses with the experimental work. The experimental results showed good agreement compared with the theoretical work. The results indicate that the improvements in the performance target for bullet-proof applications are achieved.

Extensive parametric studies were carried-out on woven fabric thick composites and the energy absorption to predict the ballistic impact behavior of thick composites [33, 34]. Also, a normal impact and perforation of conically-tipped hard steel cylinders was done on laminated Kevlar-29/polyester targets and pneumatic and powder guns, with a 12.7 mm barrel diameter are used for dynamic testing where ballistic limits, terminal velocities and perforation are determined on target plates [35, 36].

An analytical formulation by Sheikh et al. [37] to predict the residual velocity of cylindrical projectiles under high velocity impacts on carbon epoxy laminates is investigated. Similarly, Udatha et al. [38] proposed analytical model to predict the performance of 3D woven composites under high velocity impact. For comparison, studies are also presented on the performance of two-dimensional plain weave E-glass/epoxy composites. A good match is observed between the analytical predictions and experimentally obtained limit velocities for complete penetration. It is observed that limit velocity for complete penetration for three-dimensional woven composite is higher than that of two-dimensional plain weave composite.

Mishra et al. [39] formulated mathematical model based on theory of single yarn impact and implemented in MATLAB code to calculate the energy absorption and strain induced in the Kevlar and leather layers composites under high velocity impact. Results of the study shows that the stored energy increases and strain decreases with increase in impact time due to initially high kinetic energy utilizing of impactor for deformation than the absorbed in layers. As the impact time increases, tendency of deformation reduces and energy absorption improves. Again, the strain energy is high at the time of impact inception, due to kinetic energy of impactor is more than the energy absorbing capacity of layers which results in maximum damage of the layers; and the cone area developed in the Kevlar layer is more in comparison to leather layer has absorb more energy than leather layers. The study concludes that outcome of the results may be used as preliminary design tool for an assembly of rigid and semi-rigid materials in an armor system to reduce the experimental cost and time.

Ravi kumar et al. [40] presented analytical method to predict the compressive strength at high strain rate of 5000 $s^{-1}$ loading of a typical woven fabric E-glass/epoxy composite L2R. The result is compared with the experimental tests using compressive split Hopkinson pressure bar apparatus, which observed that the compressive strength is enhanced at high strain rate loading compared with that at quasi-static loading.

Pernas-Sánchez et al. [41] proposed a simplified analytical model of carbon/epoxy tape quasi-isotropic laminates to assess the different energy absorption mechanisms and predict the residual velocity of the projectile subjected to high velocity impacts. The model is validated by experimental test using destructive and non-destructive techniques.

Hossein et al. [42] studied the variation of the ballistic limit with areal density in a woven fabric made from Kevlar fibers. The model allows variation of spacing between laminas in order to study their effect on the ballistic limit. Again, the models based on energy-conservation laws consider that the kinetic energy of the projectile at impact should be consumed during the perforation process by the elastic deformation of the panel, by the failure process of the laminate (which includes several mechanisms), by friction and heating of the laminate, and by accelerating the panel after impact [14].

Garc´ıa-Castillo redeveloped an energy model based on the proposals of Naik, et al. [43] to study laminate plates subjected to ballistic impact with and without in-plane preloads [44, 45]. The authors' model assumes that the plate absorbs the energy by three mechanisms: the elastic deformation of the fibers, the acceleration of the plate, and the generation of damage in the laminate. This damage may be due to the failure of fibers, delamination, and matrix cracking. This model is later used in a non-dimensional formulation to analyze the influence of several ratios in the ballistic behavior of thin laminates [46].

Fatt et al. [47] presented analytical solution to predict the residual velocity of a hemispherical-nose cylindrical projectile impacted on a composite sandwich panel at high velocity range of 75-325m/s. The analytical approach was mechanistic without any detailed account of progressive damage due to delamination and debonding but changes in the load-bearing resistance of the sandwich panel due to failure and complete loss of resistance from the face sheets and core during projectile penetration. The study indicated that the predicted transient deflection and velocity of the projectile and sandwich panel compared fairly well with results from finite element analysis. Again, analytical predictions of the projectile residual velocities were found to be in good agreement with experimental data found in literature.

Using an existing model [48], Feli and Pour [49] presented a new analytical model for perforation process of composite sandwich panels with honeycomb core subjected to high-velocity impact of cylindrical projectile. The redefined model is validated by comparing with [48] experimental tests and numerical model. A good agreement between the residual velocity of projectile in the new analytical model and experiment tests was established.

Mamivand et al. [50] developed analytical technique for the ballistic behaviour of 2-dimensional (2D) woven fabric composites. Similarly, Feli and Asgari [51] have presented analytical approach for perforation of ceramic/multi-layer woven fabric targets by blunt projectiles. This model was used to model back-up woven-fabric material and deformation of yarns during perforation where the kinetic and strain energy of yarns ware determined. Feli et al. [52] developed analytical model and FE simulation based on FE code in LS-DYNA for normal penetration of cylindrical projectiles onto the ceramic-composite targets. Liaghat et al. [53] presented analytical technique to determine the ballistic limit velocity of metallic honeycombs impacted by cylindrical projectiles. This method is based on the assumption that the total kinetic energy of the projectile is dissipated in folding and crushing of honeycomb, tearing of cell walls, forming and shearing of the plug.

López-Puente et al. [54] formulated analytical application to predict residual velocity after the impact onto a thin carbon/epoxy woven laminate. Their model considers three different energy absorption mechanisms for the laminate. The study used experimental impact test to validate the model and the results clearly shows a very good correlation between the results obtained from both experimental and numerical simulations in literature.

A non-dimensional formulation of an analytical model proposed in a previous work of García Castillo et al. [13] was redeveloped by [14] based on energy criteria to study the ballistic behaviour of composite plates made from woven laminates of E-glass fibers.

This model allows for estimation of the residual velocity of the projectile, the ballistic limit, the energy absorbed by different mechanisms during the penetration of the laminate, and the contact time between the projectile and the laminate. Good agreement was found for residual velocities, contact time and ballistic limit for two geometry ratios.

Talib et al. [32] formulated analytical model to predict the performance of hybrid composite made of woven fiber Kevlar-29 and $Al_2O_3$ powder/epoxy subjected to high velocity impact. The relationship between the ballistic limit with the thickness and energy absorption with thickness for Kevlar-29 fiber and $Al_2O_3$ powder-reinforced composite materials was established. It was found that the proposed equation is suitable for this type of composite materials after comparing the behavior of the theoretical analyses with the experimental work. The experimental results showed good agreement compared with the theoretical work. The results indicate that the improvements in the performance target for bullet-proof applications are achieved.

Extensive parametric studies were carried-out on woven fabric thick composites and the energy absorption to predict the ballistic impact behavior of thick composites [33, 34]. Also, a normal impact and perforation of conically-tipped hard steel cylinders was done on laminated Kevlar-29/polyester targets and pneumatic and powder guns, with a 12.7 mm barrel diameter are used for dynamic testing where ballistic limits, terminal velocities and perforation are determined on target plates [35, 36].

An analytical formulation by Sheikh et al. [37] to predict the residual velocity of cylindrical projectiles under high velocity impacts on carbon epoxy laminates is investigated. Similarly, Udatha et al. [38] proposed analytical model to predict the performance of 3D woven composites under high velocity impact. For comparison, studies are also presented on the performance of two-dimensional plain weave E-glass/epoxy composites. A good match is observed between the analytical predictions and experimentally obtained limit velocities for complete penetration. It is observed that limit velocity for complete penetration for three-dimensional woven composite is higher than that of two-dimensional plain weave composite.

Mishra et al. [39] formulated mathematical model based on theory of single yarn impact and implemented in MATLAB code to calculate the energy absorption and strain induced in the Kevlar and leather layers composites under high velocity impact. Results of the study shows that the stored energy increases and strain decreases with increase in impact time due to initially high kinetic energy utilizing of impactor for deformation than the absorbed in layers. As the impact time increases, tendency of deformation reduces and energy absorption improves. Again, the strain energy is high at the time of impact inception, due to kinetic energy of impactor is more than the energy absorbing capacity of layers which results in maximum damage of the layers; and the cone area developed in the Kevlar layer is more in comparison to leather layer has absorb more energy than leather layers. The study concludes that outcome of the results may be used as preliminary design tool for an assembly of rigid and semi-rigid materials in an armor system to reduce the experimental cost and time.

Ravi kumar et al. [40] presented analytical method to predict the compressive strength at high strain rate of 5000 $s^{-1}$ loading of a typical woven fabric E-glass/epoxy composite L2R. The result is compared with the experimental tests using compressive split Hopkinson pressure bar apparatus, which observed that the compressive strength is enhanced at high strain rate loading compared with that at quasi-static loading.

Pernas-Sánchez et al. [41] proposed a simplified analytical model of carbon/epoxy tape quasi-isotropic laminates to assess the different energy absorption mechanisms and predict the residual velocity of the projectile subjected to high velocity impacts. The model is validated by experimental test using destructive and non-destructive techniques.

Hossein et al. [42] studied the variation of the ballistic limit with areal density in a woven fabric made from Kevlar fibers. The model allows variation of spacing between laminas in order to study their effect on the ballistic limit. Again, the models based on energy-conservation laws consider that the kinetic energy of the projectile at impact should be consumed during the perforation process by the elastic deformation of the panel, by the failure process of the laminate (which includes several mechanisms), by friction and heating of the laminate, and by accelerating the panel after impact [14].

Garc´ıa-Castillo redeveloped an energy model based on the proposals of Naik, et al. [43] to study laminate plates subjected to ballistic impact with and without in-plane preloads [44, 45]. The authors' model assumes that the plate absorbs the energy by three mechanisms: the elastic deformation of the fibers, the acceleration of the plate, and the generation of damage in the laminate. This damage may be due to the failure of fibers, delamination, and matrix cracking. This model is later used in a non-dimensional formulation to analyze the influence of several ratios in the ballistic behavior of thin laminates [46].

Fatt et al. [47] presented analytical solution to predict the residual velocity of a hemispherical-nose cylindrical projectile impacted on a composite sandwich panel at high velocity range of 75-325m/s. The analytical approach was mechanistic without any detailed account of progressive damage due to delamination and debonding but changes in the load-bearing resistance of the sandwich panel due to failure and complete loss of resistance from the face sheets and core during projectile penetration. The study indicated that the predicted transient deflection and velocity of the projectile and sandwich panel compared fairly well with results from finite element analysis. Again, analytical predictions of the projectile residual velocities were found to be in good agreement with experimental data found in literature.

Using previously developed model of Buitrago et al. [48], Feli and Pour [49] presented a new analytical model for perforation process of composite sandwich panels with honeycomb core subjected to high-velocity impact of cylindrical projectile. The redefined model is validated by comparing with [48] experimental tests and numerical model. A good agreement between the residual velocity of projectile in the new analytical model and experiment tests was established.

Mamivand et al. [50] developed analytical technique for the ballistic behaviour of 2-dimensional (2D) woven fabric composites. Similarly, Feli and Asgari[51] have presented analytical approach for perforation of ceramic/multi-layer woven fabric targets by blunt projectiles. This model was used to model back-up woven-fabric material and deformation of yarns during perforation where the kinetic and strain energy of yarns ware determined. Feli et al. [52] developed analytical model and FE simulation based on FE code in LS-DYNA for normal penetration of cylindrical projectiles onto the ceramic-composite targets. Liaghat et al. [53] presented analytical technique to determine the ballistic limit velocity of metallic honeycombs impacted by cylindrical projectiles. This method is based on the assumption that the total kinetic energy of the projectile is dissipated in folding and crushing of honeycomb, tearing of cell walls, forming and shearing of the plug.

López-Puente et al. [54] formulated analytical application to predict residual velocity after the impact onto a thin carbon/epoxy woven laminate. Their model considers three different energy absorption mechanisms for the laminate. The study used experimental impact test to validate the model and the results clearly shows a very good correlation between the results obtained from both experimental and numerical simulations in literature.

*c) Finite element method*

A numerical model with appropriate erosion criteria for impact analysis of hybrid-fiber engineered cementitious composites (ECC) panels using LS-DYNA commercial software under high velocity is investigated by [55]. The study shows that the tensile stress-strain relationship of the developed numerical model compared with the experimental test in reference [56] is in good agreement.

Prakash et al. [57] developed FE model to study the influence of adhesive thickness on high velocity impact (HVI) performance of ceramic ($Al_2O_3$-99.5)/aluminum (Al5083 H116) composite laminate through a detailed numerical investigation using the AUTODYN software platform. The result of the study discloses that interface layer plays a significant role in the impact performance. The result is validated by experimental analysis for optimum designs of the target plates. Park et al. [58] performed numerical analysis using the commercial software tool LS-DYNA on high velocity impact of shear thickening fluids (STF) impregnated Kevlar fabric. The simulation results are in good agreement with empirical data obtained. The empirical and numerical study on the energy absorption characteristics of neat Kevlar and STF impregnated Kevlar fabrics suggest a positive effect by the STF impregnation on the energy absorption.

Pernas-Sánchez et al. [59] developed finite element model to predict the behavior of composite unidirectional laminates under high velocity impact. The numerical model is validated by C-Scan images which exhibit very good correlation with reference to penetration and the damaged area. Wang et al. [60] conducted FE analysis on CFRP laminates subjected to high velocity impact. The predicted numerical results are validated by experimental measurement; and the study shows that thin CFRP laminates have higher energy absorbing efficiency (EAE) under higher velocity (energy) while thick CFRP laminates have higher EAE under lower velocity (energy) impact. The energy absorbing efficiency comparison shows that impact velocity range of EAE-CFRP laminates is higher than that of stainless-steel. Therefore, CFRP laminates are seen as a potential advantage to substitute the metal plates in higher velocity impact resistance structures.

Ivañez et al. [61] formulated a user material VUMAT subroutine and implemented into ABAQUS/Explicit finite element platform to predict the high-velocity impact response of sandwich plates. The accuracy of the finite-element model is determined by comparing experimental data with numerical predictions in terms of ballistic limit and residual velocity. Satisfactory agreement with the experimental results was established. The comparison of the damaged area in sandwich and spaced plates revealed that the suppression of the foam core in the sandwich structure affects the size of the damaged area. Buitrago et al. [48] formulated a model and implemented into ABAQUS/Explicit through user-written VUMAT subroutines finite element to predict the behaviour of sandwich panels made of carbon/epoxy laminate skins with aluminum honeycomb core under high-velocity impacts. The model is validated with experimental tests by comparing numerical and experimental residual velocity, ballistic limit and contact time.

Heimbs et al. [62] have carried out an experimental and numerical study of the influence of tensile and compressive preloading impact on the performance of carbon/epoxy plates at high velocity.

Ultrasonic C-scans and micrographs are used for the post-test damage inspection, where matrix cracking and delaminations are observed as the major impact damage modes. Tensile preloading is found to reduce the extent of delaminations, while compressive preload increased the extent of delaminations resulting from a higher bending deflection of the impact plate. The study shows that preloading has an influence on the impact response of laminated composite plates and is relevant in the structural design analyses.

Silva et al. [63] presented experimental and numerical application to predict the ballistic impact on composite laminated plates reinforced with Kevlar-29/Vinylester. The analysis is performed using a commercial code based on finite difference hydrocode AUTODYN and values obtained are compared with the experimental data to evaluate the performance of the simulation. Good correlation between numerical simulation and experimental results is achieved for deformation and damage of the laminates. Tham et al. [64] conducted a combined experimental and 3D dynamic nonlinear finite element (FE) approach to study damage in composite beams subject to ballistic impact. The influence of tensile and compressive preloads on the soft body impact behaviour of composite laminates has been studied experimentally and numerically in [65], where the researchers used gelatine projectile as a substitute material.

Bürger et al. [66] formulated a model based on Lagrangian and implemented into an explicit solver in the commercial FEA software ABAQUS/Explicit to simulate the ballistic impact of an armor-piercing projectile in hybrid ceramic/fiber reinforced composite armor. The ballistic limit prediction velocity shows that global damage and residual velocity are very accurate when experimentally compared. Sastry et al. [67] developed numerical model and implemented into the commercial software ABAQUS/Explicit to study the effect of ballistic impact on the composite plate made-up of woven fabric CFRP, the E-glass/epoxy and the Kevlar/epoxy for different ply stacking sequences. The result indicates that the Kevlar/epoxy absorbs a maximum kinetic energy of energy compared to the other the two materials. The numerical simulation provides quick estimation with good accuracy and reliability as compared to experimental results.

Sevkat et al. [68] presented a combined experimental and numerical approach to study the ballistic impact response of S2-glass fiber toughened epoxy composite beams using a high speed gas gun. Again, a hybrid particle finite element algorithm for high velocity impact based on the Generalized Particle Algorithm (GPA) is formulated [69-71] and compared to the other computation algorithm.

Mohotti et al. [72] formulated a bird strike-like projectile simulation using explicit finite element code in LS-DYNA to investigate the behaviour of multi-layered composite plate coated with polyurea and aluminium alloys under high velocity impact. The study shows that the application of polyurea coatings resulted in a higher residual velocity reduction per unit areal density than aluminium alloys. This indicates the feasibility of polyurea to be utilised in layered composite armour systems in mitigating ballistic threats.

Kumar et al. [73] have numerically study the effect of impactor and laminate parameters on the impact response and impact-induced damages in graphite/epoxy laminated cylindrical shells using 3D finite element formulation. The numerical results compared with experimental data showed good correlation. Zhao and Cho [74] investigated the impact-induced damage initiation and propagation in the laminated composite shell under low-velocity impact. The study employed a three dimensional eight-node non-conforming element with Taylor's modification scheme to analysis the interlaminar stress distribution and damage propagation.

Ghosh and Sinha [75] developed a finite element model to predict the initiation and propagation of damage laminated composite plates under forced vibration and impact loads. Tarfaoui et al. [76] presented a FEA of static and dynamic tests on thick filament wound glass/epoxy tubes. The material characteristics of the models are validated to predict the static and dynamic elastic behavior. Kim et al. [77] have numerically proposed a damage model based on continuum damage mechanics for the progressive damage analysis of a composite structure. The damage model is implemented in the user material subroutine of the ABAQUS/Explicit program. The impact response and damage from the numerical analysis are comparable with results obtained through experimental test.

## III. Concluding Remarks

This paper reviews the modelling techniques to analysis the impact response of composite structures subjected to high velocity. Three approaches; experimental, analytical and numerical methods were successfully employed to predict the impact behaviour. The report shows that numerous researchers assessed the impact behaviour of composite edifice through experimental method due to the simplification of use and does not need detail parameter on actual damage mechanisms. But, this method is costly and difficult to extend towards more general loading conditions, where multi-axial stress conditions are imposed. Finite element simulations have been applied to structural analysis under high velocity impact loadings for accurate estimation of results under both static and dynamic conditions. On the other hand, computational cost is very high, which requires high performance computers to model complex impact events. Again, numerous researchers and engineers have applied analytical models due to low computational cost and time, and capable to define the physical behaviour of the composite materials. Noticeably, analytical formulations are only applicable to simple models. The report shows that all methods for analysis are suitable for application based on loading conditions of the composite material. Nonetheless, numerical simulation offers the most detailed information on the spatial and temporal distribution of damage during impact which is more flexible and powerful alternative and widely used compare to analytical formulations and experimental tests.

## References Références Referencias


1. Kaw AK. Mechanics of composite materials: CRC press; 2005.
2. Razali N, Sultan MTH, Mustapha F, Yidris N, Ishak MR. Impact Damage on Composite Structures–A Review.
3. Sultan MTH, Basri S, Rafie ASM, Mustapha F, Majid DL, Ajir MR. High velocity impact damage analysis for glass epoxy-Laminated plates. Trans Tech Publ. p. 2318-28.
4. Poe C, Jackson WC. The use of impact force as a scale parameter for the impact response of composite laminates. Journal of Composites, Technology and Research. 1993;15:282-9.
5. Fatt MSH, Palla L, Sirivolu D. Modeling Blast and High-Velocity Impact of Composite Sandwich Panels. Major Accomplishments in Composite Materials and Sandwich Structures: Springer; 2010. p. 661-90.
6. Abrate S. Modeling of impacts on composite structures. Composite structures. 2001;51:129-38.
7. Alves M, Chaves C, Birch RS. Impact on aircraft.
8. García-Castillo SK, Sánchez-Sáez S, Santiuste C, Navarro C, Barbero E. Perforation of Composite Laminate Subjected to Dynamic Loads. Dynamic Failure of Composite and Sandwich Structures: Springer; 2013. p. 291-337.
9. Zee RH, Wang CJ, Mount A, Jang BZ, Hsieh CY. Ballistic response of polymer composites. Polymer composites. 1991;12:196-202.
10. Wisnom M. Modelling discrete failures in composites with interface elements. Composites Part A: Applied Science and Manufacturing. 2010;41:795-805.
11. Varas D, Zaera R, López-Puente J. Experimental study of CFRP fluid-filled tubes subjected to high-velocity impact. Composite Structures. 2011;93:2598-609.
12. Lahuerta F, Westphal T, Nijssen RPL, van der Meer FP, Sluys LJ. Measuring the delamination length in static and fatigue mode I tests using video image processing. Composites Part B: Engineering. 2014;63:1-7.
13. García-Castillo SK, Sánchez-Sáez S, Barbero E. Influence of areal density on the energy absorbed by thin composite plates subjected to high-velocity impacts. The Journal of Strain Analysis for Engineering Design. 2012:0309324712454996.
14. García-Castillo SK, Sánchez-Sáez S, Barbero E. Nondimensional analysis of ballistic impact on thin woven laminate plates. International Journal of Impact Engineering. 2012;39:8-15.
15. Hosur MV, Vaidya UK, Ulven C, Jeelani S. Performance of stitched/unstitched woven carbon/epoxy composites under high velocity impact loading. Composite Structures. 2004;64:455-66.
16. Garcia-Castillo SK, Navarro C, Barbero E. Damage in preloaded glass/vinylester composite panels subjected to high-velocity impacts. Mechanics Research Communications. 2014;55:66-71.
17. Ramadhan AA, Talib ARA, Rafie ASM, Zahari R. High velocity impact response of Kevlar-29/epoxy and 6061-T6 aluminum laminated panels. Materials & Design. 2013;43:307-21.
18. Wan H, Bai S, Li S, Mo J, Zhao S, Song Z. Shielding performances of the designed hybrid laminates impacted by hypervelocity flyer. Materials & Design. 2013;52:422-8.
19. Jabbar A, Hasan Malik M, Hussain T, Zulifqar A, Tausif M. Comparison of mechanical and ballistic performance of composite laminates produced from single-layer and double-layer interlocked woven structures. Polymer Composites. 2014;35:1583-91.
20. Sabet A, Fagih N, Beheshty MH. Effect of reinforcement type on high velocity impact response of GRP plates using a sharp tip projectile. International Journal of Impact Engineering. 2011;38:715-22.
21. Tarim N, Findik F, Uzun H. Ballistic impact performance of composite structures. Composite Structures. 2002;56:13-20.
22. Findik F, Tarim N. Ballistic impact efficiency of polymer composites. Composite structures. 2003;61:187-92.
23. Pol MH, Liaghat GH, Mazdak S. Effect of nanoclay particles on the ballistic behavior of glass/epoxy composites-experimental investigation. Journal Modares Mechanical Engineerimg. 2013;13:98-104.
24. Combescure A, Chuzel-Marmot Y, Fabis J. Experimental study of high-velocity impact and fracture of ice. International Journal of Solids and Structures. 2011;48:2779-90.
25. Astanin VV, Shchegel GO, Hufenbach W, Hornig A, Langkamp A. Characterising failure in textile-reinforced thermoplastic composites by electromagnetic emission measurements under medium and high velocity impact loading. International Journal of Impact Engineering. 2012;49:22-30.

26. Hazell PJ, Appleby-Thomas GJ, Kister G. Impact, penetration, and perforation of a bonded carbon-fibre-reinforced plastic composite panel by a high-velocity steel sphere: an experimental study. The Journal of Strain Analysis for Engineering Design. 2010;45:439-50.
27. Hou W, Zhu F, Lu G, Fang D-N. Ballistic impact experiments of metallic sandwich panels with aluminium foam core. International journal of impact engineering. 2010;37:1045-55.
28. Zhang XF, Li YC. On the comparison of the ballistic performance of 10% zirconia toughened alumina and 95% alumina ceramic target. Materials & Design. 2010;31:1945-52.
29. Übeyli M, Deniz H, Demir T, Ögel B, Gürel B, Keleş Ö. Ballistic impact performance of an armor material consisting of alumina and dual phase steel layers. Materials & Design. 2011;32:1565-70.
30. Schueler D, Toso-Pentecôte N, Voggenreiter H. Modeling of High Velocity Impact on Preloaded Composite Panels. 2011.
31. Vaidya UK, Shafiq B. Dynamic response of navy relevant laminated and sandwich composites subjected to complex impact loads. p. 39-44.
32. Talib ARA, Abbud LH, Ali A, Mustapha F. Ballistic impact performance of Kevlar-29 and Al 2 O 3 powder/epoxy targets under high velocity impact. Materials & Design. 2012;35:12-9.
33. Naik NK, Kumar S, Ratnaveer D, Joshi M, Akella K. An energy-based model for ballistic impact analysis of ceramic-composite armors. International Journal of Damage Mechanics. 2012:1056789511435346.
34. Nair NS, Kumar CVS, Naik NK. Ballistic impact performance of composite targets. Materials & Design. 2013;51:833-46.
35. Patel BP, Bhola SK, Ganapathi M, Makhecha DP. Penetration of projectiles in composite laminates. Defence Science Journal. 2004;54:151-9.
36. Ali A, Abbud LH, Talib ARA, Mustapha F. Impact Resistance of Armor Composite Made of Kevlar29 and Al2O3 Powder. Materials Testing. 2012;54:169-74.
37. Sheikh AH, Bull PH, Kepler JA. Behaviour of multiple composite plates subjected to ballistic impact. Composites Science and Technology. 2009;69:704-10.
38. [38] Udatha P, Kumar CVS, Nair NS, Naik NK. High velocity impact performance of three-dimensional woven composites. The Journal of Strain Analysis For Engineering Design. 2012:0309324712448578.
39. Mishra RR, Kumar ANV, Rajesha S. High Velocity Impact Analysis of Kevlar Composite by MATLAB. Indian Journal of Advances in Chemical Science. 2014;2:68-71.
40. Ravikumar G, Pothnis JR, Joshi M, Akella K, Kumar S, Naik NK. Analytical and experimental studies on mechanical behavior of composites under high strain rate compressive loading. Materials &Design. 2013;44:246-55.
41. Pernas-Sánchez J, Artero-Guerrero JA, Varas D, López-Puente J. Experimental analysis of normal and oblique high velocity impacts on carbon/epoxy tape laminates. Composites Part A: Applied Science and Manufacturing. 2014;60:24-31.
42. Pol MH, Liaghat GH, Hajiarazi F. Effect of nanoclay on ballistic behavior of woven fabric composites: Experimental investigation. Journal of Composite Materials. 2012:0021998312449768.
43. Naik NK, Doshi AV. Ballistic impact behaviour of thick composites: Parametric studies. Composite structures. 2008;82:447-64.
44. García-Castillo SK, Sánchez-Sáez S, Barbero E, Navarro C. Response of pre-loaded laminate composite plates subject to high velocity impact. EDP sciences. p. 1257-63.
45. García-Castillo SK, Sánchez-Sáez S, López-Puente J, Barbero E, Navarro C. Impact behaviour of preloaded glass/polyester woven plates. Composites Science and Technology. 2009;69:711-7.
46. Zhou J, Guan ZW, Cantwell WJ. The perforation resistance of sandwich structures subjected to low velocity projectile impact loading. Aeronautical Journal. 2012;116:1247.
47. Fatt MSH, Sirivolu D. A wave propagation model for the high velocity impact response of a composite sandwich panel. International journal of impact engineering. 2010;37:117-30.
48. Buitrago BL, Santiuste C, Sánchez-Sáez S, Barbero E, Navarro C. Modelling of composite sandwich structures with honeycomb core subjected to high-velocity impact. Composite structures. 2010;92:2090-6.
49. Feli S, Pour MHN. An analytical model for composite sandwich panels with honeycomb core subjected to high-velocity impact. Composites Part B: Engineering. 2012;43:2439-47.
50. Mamivand M, Liaghat GH. A model for ballistic impact on multi-layer fabric targets. International Journal of Impact Engineering. 2010;37:806-12.
51. Feli S, Asgari MR. Finite element simulation of ceramic/composite armor under ballistic impact. Composites Part B: Engineering. 2011;42:771-80.
52. Feli S, Yas MH, Asgari MR. An analytical model for perforation of ceramic/multi-layered planar woven fabric targets by blunt projectiles. Composite Structures. 2011;93:548-56.
53. Liaghat GH, Nia AA, Daghyani HR, Sadighi M. Ballistic limit evaluation for impact of cylindrical projectiles on honeycomb panels. Thin-Walled Structures. 2010;48:55-61.
54. López-Puente J, Zaera R, Navarro C. An analytical model for high velocity impacts on thin CFRPs

woven laminated plates. International Journal of solids and structures. 2007;44:2837-51.
55. Li J, Zhang YX. Evolution and calibration of a numerical model for modelling of hybrid-fibre ECC panels under high-velocity impact. Composite Structures. 2011;93:2714-22.
56. Maalej M, Quek ST, Zhang J. Behavior of hybrid-fiber engineered cementitious composites subjected to dynamic tensile loading and projectile impact. Journal of Materials in Civil Engineering. 2005;17:143-52.
57. Prakash A, Rajasankar J, Anandavalli N, Verma M, Iyer NR. Influence of adhesive thickness on high velocity impact performance of ceramic/metal composite targets. International Journal of Adhesion and Adhesives. 2013;41:186-97.
58. Park Y, Kim Y, Baluch AH, Kim C-G. Numerical simulation and empirical comparison of the high velocity impact of STF impregnated Kevlar fabric using friction effects. Composite Structures. 2015;125:520-9.
59. Pernas-Sánchez J, Artero-Guerrero JA, Viñuela JZ, Varas D, López-Puente J. Numerical analysis of high velocity impacts on unidirectional laminates. Composite Structures. 2014;107:629-34.
60. Wang B, Xiong J, Wang X, Ma L, Zhang G-Q, Wu L-Z, et al. Energy absorption efficiency of carbon fiber reinforced polymer laminates under high velocity impact. Materials & Design. 2013;50:140-8.
61. Ivañez I, Santiuste C, Barbero E, Sánchez-Sáez S. Numerical modelling of foam-cored sandwich plates under high-velocity impact. Composite structures. 2011;93:2392-9.
62. Heimbs S, Bergmann T, Schueler D, Toso-Pentecôte N. High velocity impact on preloaded composite plates. Composite Structures. 2014;111:158-68.
63. Silva MAG, Cismaşiu C, Chiorean CG. Numerical simulation of ballistic impact on composite laminates. International Journal of Impact Engineering. 2005;31:289-306.
64. Tham CY, Tan VBC, Lee HP. Ballistic impact of a KEVLAR® helmet: Experiment and simulations. International Journal of Impact Engineering. 2008;35:304-18.
65. Heimbs S, Bergmann T. High-velocity impact behaviour of prestressed composite plates under bird strike loading. International Journal of Aerospace Engineering. 2012;2012.
66. Bürger D, De Faria AR, De Almeida SFM, De Melo FCL, Donadon MV. Ballistic impact simulation of an armour-piercing projectile on hybrid ceramic/fiber reinforced composite armours. International Journal of Impact Engineering. 2012;43:63-77.
67. Sastry YBS, Budarapu PR, Krishna Y, Devaraj S. Studies on ballistic impact of the composite panels. Theoretical and Applied Fracture Mechanics. 2014;72:2-12.
68. Sevkat E, Liaw B, Delale F, Raju BB. A combined experimental and numerical approach to study ballistic impact response of S2-glass fiber/toughened epoxy composite beams. Composites Science and Technology. 2009;69:965-82.
69. Johnson G, Beissel S, Gerlach C. A combined particle-element method for high-velocity impact computations. Procedia Engineering. 2013;58:269-78.
70. Johnson G, Beissel S, Gerlach C. Another approach to a hybrid particle-finite element algorithm for high-velocity impact. International journal of impact engineering. 2011;38:397-405.
71. Johnson G, Beissel S, Gerlach C. A 3D combined particle-element method for intense impulsive loading computations involving severe distortions. International Journal of Impact Engineering. 2015;84:171-80.
72. Mohotti D, Ngo T, Mendis P, Raman SN. Polyurea coated composite aluminium plates subjected to high velocity projectile impact. Materials & Design. 2013;52:1-16.
73. Kumar S, Rao BN, Pradhan B. Effect of impactor parameters and laminate characteristics on impact response and damage in curved composite laminates. Journal of Reinforced Plastics and Composites. 2007;26:1273-90.
74. Zhao G, Cho C. On impact damage of composite shells by a low-velocity projectile. Journal of composite materials. 2004;38:1231-54.
75. Ghosh A, Sinha PK. Dynamic and impact response of damaged laminated composite plates. Aircraft Engineering and Aerospace Technology. 2004;76:29-37.
76. Tarfaoui M, Gning PB, Hamitouche L. Dynamic response and damage modeling of glass/epoxy tubular structures: Numerical investigation. Composites Part A: Applied Science and Manufacturing. 2008;39:1-12.
77. Kim E-H, Rim M-S, Lee I, Hwang T-K. Composite damage model based on continuum damage mechanics and low velocity impact analysis of composite plates. Composite Structures. 2013;95:123-34.

Global Journal of Researches in Engineering: A
Mechanical and Mechanics Engineering
Volume 16 Issue 4 Version 1.0 Year 2016
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 Print ISSN: 0975-5861

# Characterization and Simplified Modeling of the Failure Behavior of Spot Welds from Extra-High Strength Steels for Crash Simulation

By Sachin Patil & Hamid Lankarani
*Wichita State University*

*Abstract-* Vehicle collision characteristics significantly influenced by spot welded joints in vehicle steel body components. In engineering practice, spot welds are normally not modeled in detail, but as connection elements which transfer forces and moments. Therefore a proper methodology for the development detailed weld model to study structural response of the weld when the applied load range is beyond the yield strength discussed in this paper. Three-dimensional finite element (FE) models of spot welded joints are developed using LS-Dyna. Simple spot weld models are developed based on the detailed model behavior developed earlier. In order to generate testing data, virtual tensile testing simulations are carried out with mesh sensitivity in the necking zone.

*Keywords: finite element; spot weld; weld characterization; EHSS steel; T section specimen; B-PILLAR component IIHS testing.*

GJRE-A Classification: FOR Code: 091399

CHARACTERIZATIONANDSIMPLIFIEDMODELINGOFTHEFAILUREBEHAVIOROFSPOTWELDSFROMEXTRAHIGHSTRENGTHSTEELSFORCRASHSIMULATION

*Strictly as per the compliance and regulations of:*

# Characterization and Simplified Modeling of the Failure Behavior of Spot Welds from Extra-High Strength Steels for Crash Simulation

Sachin Patil [α] & Hamid Lankarani [σ]

*Abstract-* Vehicle collision characteristics significantly influenced by spot welded joints in vehicle steel body components. In engineering practice, spot welds are normally not modeled in detail, but as connection elements which transfer forces and moments. Therefore a proper methodology for the development detailed weld model to study structural response of the weld when the applied load range is beyond the yield strength discussed in this paper. Three-dimensional finite element (FE) models of spot welded joints are developed using LS-Dyna. Simple spot weld models are developed based on the detailed model behavior developed earlier. In order to generate testing data, virtual tensile testing simulations are carried out with mesh sensitivity in the necking zone. This high mesh resolution around necking zone is required to capture the steep gradients in the pressure and stress tri-axility, etc. Once the stress strain curve are generated in the simulations examined damage function and evolution to represent failure. Various EHSS steels grades used in this study. The results from this study shows reasonable agreement between the simulations and the test results. Hence, spot weld model obtained should be considered for crash analysis applications to understand behaviors of structural parts.

*Keywords: finite element; spot weld; weld characterization; EHSS steel; T section specimen; B-PILLAR component IIHS testing.*

## I. Introduction

Spot welding is the primary joining method used for the construction of the automotive body structure made of steel. A major challenge in the crash simulation today is the lack of a simple yet reliable modeling approach to characterize spot weld separation. Various approaches for Numerical simulation of spot welding has been discussed by [1, 2, 3, 4]. A study of a spot weld for numerical analysis of automotive applications under crash loading conditions using validation model 3 point- bend test were studied by Sebastian et al [5].Hardness in the heat-affected zone and stresses are studied [6,7,8,9] that exhibit sharp hardness change adds to brittleness and notch sensitivity. Lee et al [10] and Chao [11] have studied the ultimate tensile strength of resistance spot welds in mild steel subjected to combined loading tension and shear loads. Detailed solid element simulations of local spot weld deformation under various loads provide rationale for the experimental observations and model simplifications discussed in paper by Deng et al [12]. Schweizerhof K et al [13] has discussed mesh sensitivity in spot weld modeling. Failure model parameters are derived from Finite element method (FEM) test simulations [14] since it's difficult to measure of local properties in spot welds.

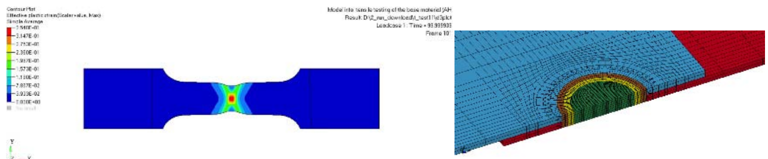
The present work deals with a complete study on identification and modeling of spot weld connections. Relatively few studies have been conducted on the failure model of a spot weld under impact loading conditions whereas quasi-static cases are found more often. Most of studies are based on AHSS, DP 600 material as spot-weld and those sources do not show that EHSS steel materials sheet metal spot welding. In this study, the mechanical properties and spot weld-ability of newly developed EHSS steels are discussed which are widely used in automotive crash area with high energy intake e.g., front rails, sill, crash box, etc. The separation criteria are implemented into a commercially available explicit finite element code. This work is further focuses on acceptance of a B-pillarrail components subjected to axial impact. B-pillar commonly used hat section rails spot welded from end to end to integrate side structure. The key methodological evolution on the spot weld behavior is combined with a study on weld of Hat beam specimen of a prototypical B-pillar system.Thus improving crash safety through virtual prototyping is best approach to lessen cost and time.

## II. Finite Element Modeling, Parameter Identification

Reliable modelling of deformation and damage behavior are necessary for the assessment of weld failure in automobile components. In this study, the mechanical properties and spot weld-ability of newly developed steels are discussed [15]. All of the specimens are made of high-strength steel (EHSS) sheet metal of the same thickness of 1.2 mm. This steel is having a yield strength 368 Mpa close to Dual phase

*Author α: Doctoral student in Mechanical Engineering at Wichita State University. e-mail: sapatil1@shockers.wichita.edu*
*Author σ: Professor, Department of Mechanical Engineering, Wichita State University.*

DP600 but lower tensile strength. The high-strength steel materials HSLA340 showed a mutually comparable strength at quasi-static loading [16].Uniaxial tensile tests and shear tests were made and studied to evaluate the mechanical properties of the material. In order to generate testing data, virtual tensile testing simulations were carried out with mesh sensitivity (30636 nodes and 30151 elements) in necking zone, as shown in Fig 1(a). This high mesh resolution around necking zone is required to capture the steep gradients in pressure and stress tri-axility, etc. A yield curve is defined to consider effect of strain rate due to dynamic event and to consider the deformation mechanism.



(a) (b)

*Fig.1:* (a) FE simulations of tensile tests on smooth flat specimens, (b) Detail meshing of weld zone

The deformation of spot weld in HSS steel were numerically investigated under the relevant loads tension, shearing and bending specimens to develop reference model for validation and to avoid high costs for experimentation. Different properties are needed to consider for different zones to predict plastic flow localization and failure in steel spot weld. Failure strain are scaled to maintain the same strain energy to fail in various regions [17]. The spot welds are modeled by using fine solid mesh, as shown in Fig 1(b), to analyze the localized deformation. Fine solid mesh allows one to consider spot weld geometry and hardness gradient of its material [18]. This approach is also suitable for the spot welds rupture, which will be modelled in the crash analysis by element elimination. Safer car with improved spot weld rupture definition will provide realistic results compared to physical situation. Brittle fracture produces disastrous consequences as it occurs without warning. This necessitates that we propose a proper failure damage model in this study.

To demonstrate the proposed approach, simulation results of Extra High Strength Steels (EHSS) for lap-shear and coach peel specimens were used, [19, 20]. Characterization and deformation relevant to weld specimen loading were analyzed for the assessment of weld failure. The failure loads were used as the reference loads to determine the loads applied for other tests such as the fatigue tests, torsion test, etc. Von-mises stress and plastic strain experienced by the weld as well as strain rate corresponding to materials defined in various regions of weld were validated in terms of output result. This suggests that the predicted material constitutive laws using the inverse FE modelling for different zones is accurate. The deformation and failure behavior of weld joints were investigated on small scale specimens under tension and shear loading and KS-2 loading [21]. Spot weld models are developed in FE code LS-Dyna and its parameters identified. Detailed description about the modeling can be referred from [22-23].Damage in weld initiated is the function of failure function defined in the FE program Ls-Dyna. Identification of the material parameters for the elastic-plastic region including damage and failure is an iterative process to follow physical testing.

*Table 1:* Spot Weld Material Parameters EHSS Steel Material

| *MAT_SPOTWELD_DAMAGE-FAILURE_TITLE ( MAT_100_DA ) | | | | | | | |
|---|---|---|---|---|---|---|---|
| mid | ro | e | pr | sigy | et | dt | tfail |
| 1 | 7.80E-09 | 2.00E+05 | 0.3 | 368 | 784 | 1e 6 | 0 |
| $$ Failure Parameter EHSS steel grade | | | | | | | |
| efail | nrr | nrs | nrt | mrr | mss | mtt | nf |
| 0 | 11030 | 25033 | 25033 | 16547 | 37548 | 37548 | 0 |
| rs | opt | fval | true_t | beta | | | |
| 0 | 0 | 5 | 1e-6 | 0 | 0 | | |
| *DEFINE_SPOTWELD_FAILURE_RESULTANTS | | | | | | | |
| id | dsn | dss | dlcidsn | dlcidss | | | |
| 1 | 0.9E+02, | 1.80E+02 | 1.00E+04 | 1.00E+04 | | | |

*MAT_SPOTWELD_DAMAGE-FAILURE predicted the accurate weld failure patterns consistent with all three experimental test modes[24]. Potential issues could happen if the material properties are not properly treated in the spot weld material card.

## III. Validation of Automotive Components

In order to model vehicles involved in automotive crashes, the structural components of these vehicles may need to be modeled in detail. Square beam parts are very common in automotive systems for absorbing energy during impact events like front and rear rails, cross members in the B-pillar structure, bumpers and B and C pillar reinforcements. Structural integrity of these welded structures are generally controlled by the strength of the spot welds which commonly fail under combined loading. Component level analyses and tests were conducted to establish the material properties of the spot weld.

### *a) T-Section Specimen Analysis*

The T-joint specimens were used for the stress in the transverse direction also under load speeds simulating of 1 m/s. For this purpose also identified a slide mass in the amount of 192 kg to realize the failure of spot welds as shown in figure 2(a).

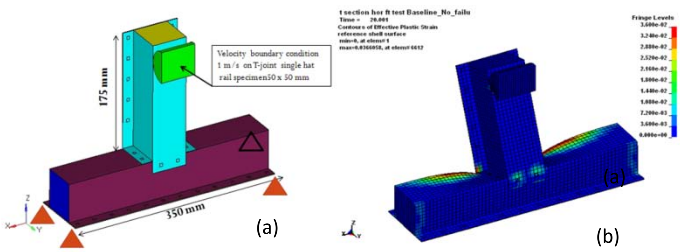



*Fig. 2:* (a) Simulation setup of T-joint specimen, (b) Baseline spot weld model behavior

In baseline, artificial nature of contact forces disturbs the internal spot weld forces and stresses. Strain plots for critical welds are shown below. This is done to check for possibility of weld tearing. There is failure of shell elements due to high localized strain without any failure of spot welds causing unphysical deformation. Validation of simulation model was done as described in the following section. The simulations were compared out with new spot weld parameters as shown in Figure 3.

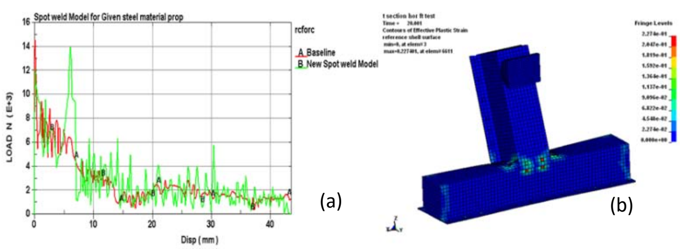



*Fig. 3:* (a) Force response of simulation loading (Baseline and New spot weld), (b) New spot weld post deformation

Comparing with baseline, the main failure mode encountered for weld on front and side of vertical rail. The force amplitude for these welds is between 2 kN and 12 kN, which avoid tearing of sheet metal with tail formation of these spot weld (Figure 9).Also high strain observed in this region of weld. This is more realistic deformation when compared to physical test. Overall weld force level changed slightly from baseline. Based on this information, it can be conclude that given EHSS steel are comparable with test specified HL340 steel results as referenced below figure 4 .Many simulations were carried out changing the weld material parameters and mesh sensitivity to improve the performance.

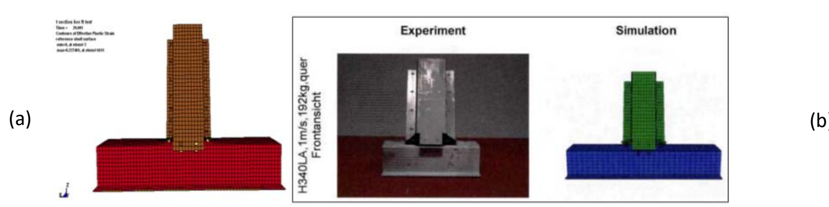



*Fig. 4:* Comparison of post deformation (a)New spot weld simulation loading (b)Experimental loading [25]

Also the representation of the local spot weld forces from the simulation under a loading rate of 1m/s and a slide mass of 192 kg are shown in Figure 5 below.

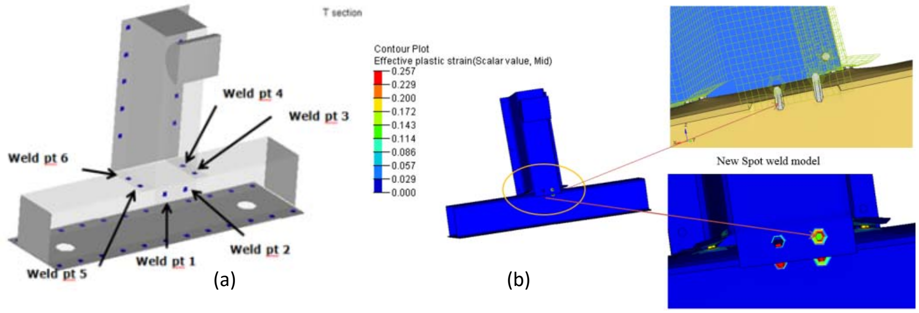



*Fig. 5:* (a) Location of spot weld on specimen, (b) weld failure captured from the simulation

*Table 2:* T-section specimen weld deformation for 30 milli-sec

| Spot weld ID | Deformation mode | Max force kN | Time in Max (ms) |
|---|---|---|---|
| 1 | fails | 13 | 27 |
| 2 | fails | 12.8 | 28 |
| 3 | partial failure | 11.6 | 24 |
| 4 | partial failure | 10.8 | 23 |
| 5 | OK | 10.1 | 29 |
| 6 | OK | 9.5 | 27 |

T-section specimen weld deformation for 30milli-sec observed and result shown in table 2. Two partial damage spot weld, two ruptured and two without damage. All weld forces for no tearing mode are below allowable force level 12596N ,however weld ID 1 and 2 observed complete failure due to exceeding allowable force level.At macroscopic scale, the mechanical performances of this new steel configuration spot weld are excellent in term of energy absorption. The final total internal energy of the T- joint rail component with new spot weld model is 127 kJ which is greater than baseline 116.7 kJ. Initial lower peak load implies a better performance of the energy collapsible structure in terms of safety design. The oscillations in the calculated force curve occur .These oscillations are caused by the immediate removal of the hexahedron is reached caused the failure criterion, since the elimination of the stored elastic energy at the Area around the spot weld is suddenly released. It is clear that the behavior of the force - time curves from simulation and experiment approach lesser peaks after the first force peaks. The force levels vary little from each other. This suggests that on a good set of failure criteria close. The performance, can be grown in individual spot weld forces, with mechanical properties comparable to experimental investigation carried out by literature even though the material involving spot weld differs. Figure 5 shows the post deformation of specimen in this simulation study as well as experimental loading [25]. It can be seen that the deformation pattern is comparable to the experiment on similar grade steel. A considerable amount of experiments have been performed to investigate the failure behavior of spot weld in similar setup [22]. In general, new spot weld model prediction is on conservative side and these spot weld model has been well characterized by this component model. The material data for the vehicle spot weld simulation can be adjusted to fit the results from this component simulation.

## IV. B-pillar IIHS Component Testing

The automotive industry continues to face the challenge of developing efficient side body structures that meet the performance requirements for multiple crashworthiness test modes. B-pillar, Roof and Side sill are the key structural members that help reduce the risk of injury to the occupants during a side impact crash event. Insurance Institute for Highway Safety (IIHS) evaluates a vehicle's crashworthiness with the help of Side impact test. Protecting people in side crashes is challenging because the sides of vehicles have relatively little space to absorb energy and shield occupants. The side crushing deformation is crucial to maintain space integrity in the occupant compartment. Thus structural performance of weld need special attention. Side impact crash tests consist of a stationary test vehicle struck on the driver’s side by a crash cart fitted with an IIHS deformable barrier element. The 1,500 kg moving deformable barrier (MDB) has an impact velocity of 50 km/h (31.1 mi/h) and strikes the vehicle on the driver’s side at a 90-degree angle [26]. The longitudinal impact point of the barrier on the side of the test vehicle is dependent on the vehicle's wheelbase. The impact reference distance (IRD) is defined as the distance rearward from the test vehicle's front axle to the closest edge of the deformable barrier when it first contacts the vehicle (Figure 6). Middle plane of barrier is in-line with front row dummy seat reference plane

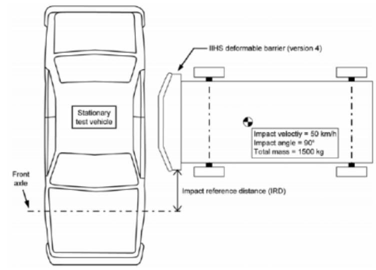
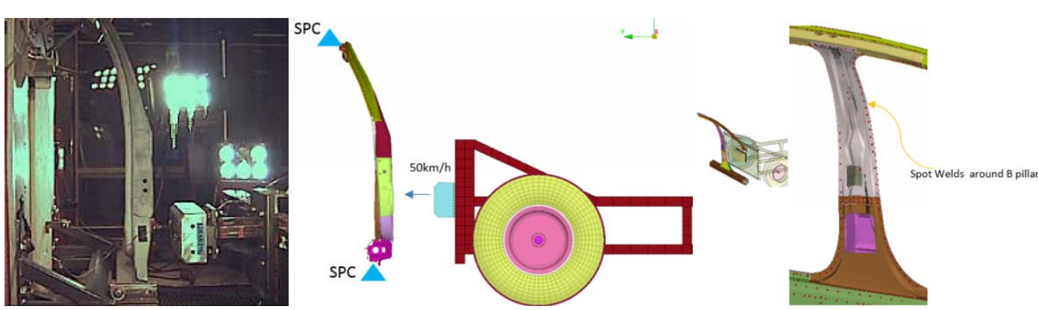



*Fig.6:* Moving deformable barrier alignment with test vehicle [26]

The MDB is accelerated by the propulsion system until it reaches the test speed (50 km/h) and then is released from the propulsion system 25 cm before the point of impact with the test vehicle. The impact point tolerance is ± 2.5 cm of the target in the horizontal and vertical axes. The impact speed tolerance is 50 ± 1 km/h. The MDB alignment calculation was configured to maximize loading to the occupant compartment.

One of the leading automotive OEM client was interested in B- pillar correlation with new weld methodology. B-pillar subsystem level test is best way to study of weld performance in Impact Analysis (Figure 7). The crash event between the MDB and the target vehicle is shortened by this approach. IIHS Side Impact barrier mounted on wagon fixture base for sled test. Barrier engages B-pillar only in component level resulting in single load path for energy management. Thus developing component testing to confirm performance prior to full-vehicle testing is best strategy. A laboratory experiment was designed at Wichita State University's National Institute for Aviation Research to test the B-Pillar spot weld welded structures [27]. Wichita State University's National Institute for Aviation Research utilizing state-of-the-art testing, measurement and data collection equipment along with advanced software and techniques to perform crash sled test analyses. This Crash dynamics lab performs various component level crash tests. NIAR research center wagon fixture base used for this subsystem level test. The test conditions are equivalent to full vehicle test as per IIHS test protocol, especially confirmation of impact point is same as used in full vehicle test setup. The results of B-Pillar Component test were used to improve the spot weld finite element model developed at Wichita State University, simulating the crash events at NIAR sled test facility with a higher degree of correlation.

An area of focus in this study is the deformation mode capture. This component level setup not captures door to occupant interaction. To understand the effects of the spot weld, two FE models have been developed. The first model is MAT 100 SW to provide a baseline test and understanding of side impact crash at a basic level. The second door model is a new spot weld in terms of spot weld parameters which is representative of weld failure. [Studies have been performed by modeling the components of the door including the trim, inner panel, outer panel, Hinge pillar and Rocker material. The CAE model is followed latest procedure per Side Safety regulation using 4 mm mesh.Two pieces for b pillar are layered & weldedafter the blanking process &before hot stamping, Spot weld modeled with new paramter applied for high strength steel parts as indicated in picture.




wagon fixture base for barrrier mouting

*Fig.7:* Test setup for B-Pillar spot weld welded structures [28]

The idea was to make the wagon accelerate like in the full-scale test by LINCAP, to validate the new spot weld model. These sled tests are referred to as *correlation tests*. The sled tests were done to evaluate how well the spot weld perform and what could be improved to meet the customer needs. Based on physical test findings, a procedure was developed for spot weld failure in order to correlate properly in Ls-Dyna simulations. In simulation model, B-pillar is impacted by a moving rigid impactor plate. The impacting mass is modeled using a mass element of 1500 kg and is attached to the impactor plate by a reference point located on RBE3. A SPC boundary condition is imposed at upper and lower end of B-pillar using *Boundary_SPC constrained to zero in all three direction.B-Pillar spot weld design had significant strength gradient at joint between upper and lower B-pillar components. B-pillar Lower material changed from HSS to EHSS steel grade characterized in earlier section. EHSS steel grade provides increased elongation for event. This side impact model was then used to investigate the effects of spot weld failure. Spot welds commonly fail under combined loads during impact scenario. Spot weld lines around B pillar are shown in figure 7.

BLUE: Baseline RED: New SW Model

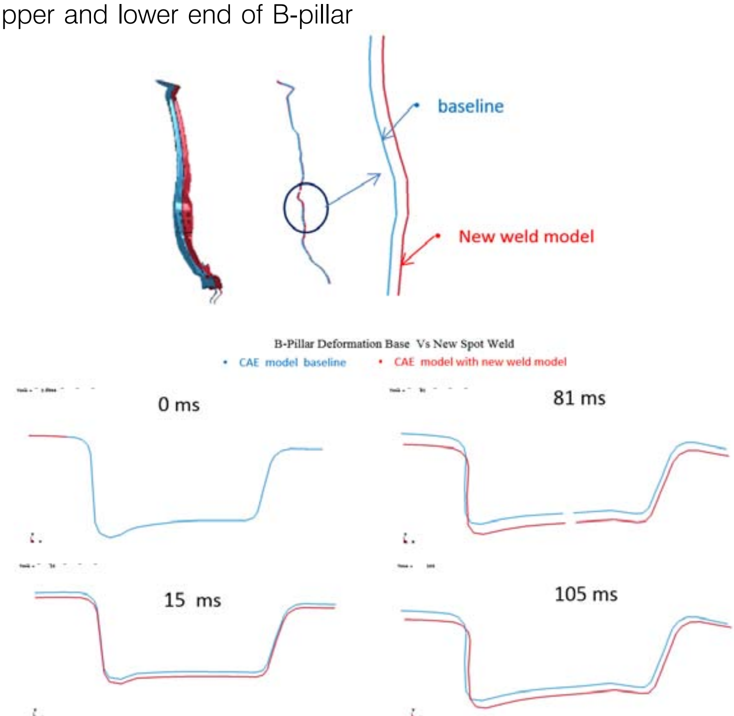



*Fig.8:* Post-crash deformation of the B-Pillar spot weld welded structures

The load balance between underbody and upper body has changed in new spot weld Design and caused the lower body intrusion. The B-pillar side impact simulation shows the comparison of side sill deformation mode between baseline and new spot weld model(Figure 8).Baseline CAE model softer than the test predicting moredeformation than the test.

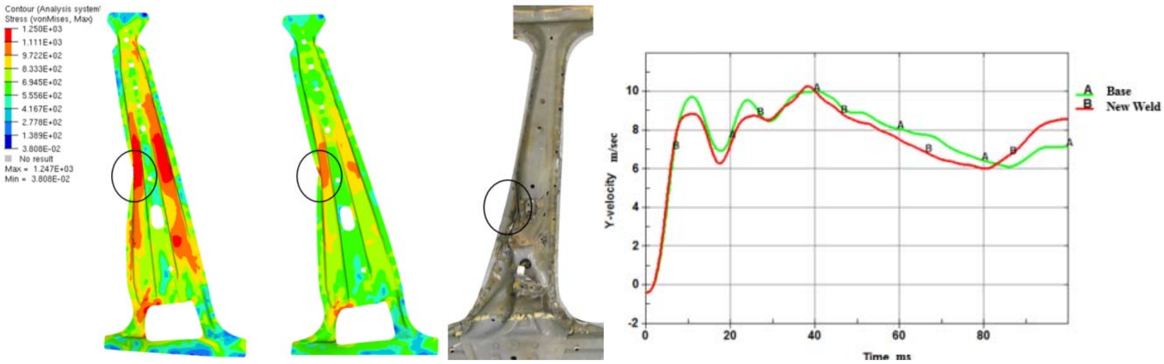



*Fig. 9:* (a)Comparison of Stress contour of the B-Pillar spot weld welded structures LH side view,(b) Test Deformation of the B-Pillar[27] RH side view, (c)B-pillar velocity comparison

Post deformation of test vs simulation compared in figure 9. Baseline FE model having MAT 100 spot weld material model displayed undesirable structural performance as per stress contour. This model had insufficient Strength/elongation combination. New Spot WeldB-pillar Modelimproved CAE correlation for deformation modes as shown in figure 9. It is observed that internal energy of B-pillar reinf parts is 6 % more for New Spot Weld Model compared to baseline. Also result were compared with side impact crash test data found in Lightweight BIW Structure project by the Auto/Steel Partnership (A/SP), 2009[29].

Component test correlates well with B pillar simulation when spot welds failure defined as per MAT_100_DAMAGE model. This focused on the need to define spot weld failure for side impact testing to evaluate the risk of injuries and then finding countermeasure to diminish it.

*Table 4:* Result Summary for B-Pillar IIHS Component Testing /Side Impact statistics

| Load case | Measuring Points | Target | Baseline | New Spot Weld Model |
|---|---|---|---|---|
| IIHS | B pillar velocity (at beltline) (m/sec) | 10 | 10.2 | 10 |
| | B pillar residual intrusion (at beltline) (mm) | 70 | 123 | 94 |

WSU sled tests are simplified cases which do not account forintrusion and occupant to door spacing. Hence above table compare simulation study for baseline and new spot weld model. New Spot Weld Model analysis catches well velocity &crush modes. Overall New Spot Weld Model show lower velocity. Not a big difference in B-pillar beltline velocity however B-pillar residual space cut down by 60 mm. The baseline simulation shows less survival space as compared to New spot weld model.Reducing B-pillar intrusion vis structural upgrading of the body side weld failure model. Failure in the weld diminish momentum exchange between door and dummy and thus it delay force by more energy absorption. This is compliant for occupant cushioning. Failure of weld at bottom concentrating the impact load on the occupant in the lower pelvis region. A more desirable crush pattern for the B-pillar/door is to remain upright during side impact for a more evenly distributed impact loading on the occupant.

## V. Conclusion

To establish modelling procedure for weld failure in this paper, simulation model was built and correlated with the Baseline test specification. A failure spot weld analysis performed in this work could he extremely relevant from the vehic1e design stand point. The weld model includes failure criteria based on a critical plastic failure strain, as well as on a force envelope. Depending on the materials, a greater number of different specimen tests will be needed to identify the parameters for the damage model. Two examples were provided to demonstrate the implementations of this procedure and to show the improvement of the results through the use of new spot weld model. In the first example, axial load was applied on a hat shape rail to observe crush deformation mode. In the second example, T section specimen impacted to see weld failure in joint region, the weld failure significantly improved. Both of the examples proved the proposed spot welding procedure was correct. Then, investigations based on the simple models were performed to identify the B-pillar velocity in side impact simulations. National Institute for Aviation Research did this project to show their capability to capture this correlations The system integrated FEM has proven to be a valuable and effective predictive tool that can account for spot weld interactions for Structural integrity of B-Pillar welded structures. Through computational simulations results, this study provide essential information to match performance of weld and to study the stiffness of the b-pillar sub-structure.

## VI. Acknowledgments

The authors would like to acknowledge participants of the research project coordinated by the Auto/Steel Partnership (AS/P) and FOSTA.

## References Références Referencias


1. Heubrandtner, T., Rangger, G., and Scherjau, D., "Advanced spotweld failure modelling based on Trefftz formulation," 4th LS-DYNA Anwenderforum, Bamberg, Germany, 2005.
2. Seeger F, Feucht M, Frank T, Keding B, Haufe A. An Investigation on Spot Weld Modelling for Crash Simulation with LS-DYNA. 4 th LS-DYNA Forum. Bamberg, Germany; 2004.
3. E. Nakayama, M. Fukumoto, M. Miyahara, K. Okamura, H. Fujimoto and K. Fukui" Fatigue Strength Prediction of Spot-Welded Joints Using Small Specimen Testing "Corporate Research & Development Laboratories, Sumitomo Metal Industries, Ltd.,1-8, Fuso-Cho, Amagasaki, Hyogo 660-0891, Japan
4. Wang, J., Xia, Y., Zhou, Q., Zhang, J., "Simulation of Spot Weld Pullout by Modeling Failure around Nugget," SAE Technical Paper, 2006-01-0532.
5. Sebastian, B., Sommer, S., .Characterization and modeling of fracture behavior of spot welded joints.11 thLs-dynaForum,Ulm 2012
6. Ha JW, Song JH, Huh H, Lim JH, Park SH. Dynamic material properties of the heat-affected zone (haz) in resistance spot welding. 2008. p. 5800-5806.
7. Zhang SC. Stress intensities derived from stresses around a spot weld. International Journal of Fracture. 1999;99(4):239-257.
8. Nakayama E, Okamura K, Miyahara M, Yoshida M, Fukui K, Fujimoto H. Prediction of Strength of Spot-Welded Joints By Measurements of Local Mechanical Properties. SAE Technical Paper. 2003(2003-01-2830).
9. Lee, YL ,Wehner, TJ ,Lu, M-W ,Morrissett, TW, Pakalnins, E .Ultimate Strength ofResistance Spot Welds Subjected to Combined Tension and Shear Journal of Testing and Evaluation, Volume 26, Issue 3 (May 1998),pages 213-219
10. Yuh J. Chao,"Ultimate Strength and Failure Mechanism of Resistance Spot Weld Subjected to Tensile, Shear,or Combined Tensile/Shear Loads" Journal of Engineering Materials and Technology APRIL 2003,
11. Deng X, Chen W, Shi G. Three-dimensional finite element analysis of the mechanical behavior of spot welds. Finite Elements in Analysis and Design. 2000;35(1):17-39.
12. Schweizerhof K, Schmid W, Klamser H. Improved Simulation of Spotwelds in Comparison to Experiments using LS-DYNA. 18th CAD-FEM Users' Meeting International Congress on FEM Technology. Friedrichshafen (Lake Constance), Germany; 2000.
13. Wang J, Xia Y, Zhou Q, Zhang J. Simulation of Spot Weld Pullout by Modeling Failure Around Nugget. SAE Technical Paper. 2006(2006-01-0532).
14. Advanced High Strength Steel (AHSS) application guidelines, International Iron & Steel Institute, committee on automotive applications, March 2005. Web site:www.worldautosteel.org .
15. High Strength Low Alloy (HSLA) Steel, The U. S. Steel Automotive Group Grade and Product Reference. United States Steel Corporation, 2005. .
16. ZhiliFeng, SrdjanSimunovic, "Impact Modeling and Characterization of Spot Welds" ORNL and Auto/Steel Partnership report.
17. J. H. Song, H. Huh, H. G. Kim And S. H. Park " Evaluation of The Finite Element Modeling of A Spot Welded Region For Crash Analysis" International Journal of Automotive Technology, Vol. 7, No. 3, pp. 329−336 (2006)
18. Nguyen, N. T., Kim, D. Y., Song, J. H., Kim, K. H., Lee, I. H., and Kim, H. Y., "Numerical Prediction of Various Failure Modes in Spotwelded Metals" International Journal of Automotive Technology, 13(3), 459-467, 2012.
19. Oh, C.S., Kim, N.H., Kim, Y. J., Baek, J.H., Kim, Y.P., and Kim, W.S., "A Finite Element Ductile Failure Simulation Method using Stress-Modified Fracture Strain Model," Engineering Fracture Mechanics,78, 124–137, 2011.
20. HAHN, O., WIßLING, M. and Klokkers, F.: Determination of true Characteristic values for bolted and riveted sheet metal stamping compounds under impulsive load. In: (2009) EFB Research Report No. 297
21. SachinPatil.," Modeling and Characterization of Spot WeldMaterial Configurations for Crash Analysis" Phd Dissertation ,Wichita State Univ,2014
22. Patil, S.A., and Lankarani, H.M., "Characterization and Modeling of the Strength of Spot Weld Steel for Automotive Joints," 2nd International Conference and Exhibition on Mechanical & Aerospace Engineering, MechAero-2014, Philadelphia, USA, Sep 2014.
23. DYNA3D, Livermore Software Technology Corporation, http://www.lstc.com [cited 2016].
24. Michael Oeter, Kenan Özdem, Dr.-Ing.Ortwin Hahn, "Experimental determination of Structural behavior of spot welded Components made of sheet steel

connections" AVIF A172, 17 05 63-60079 Frankfurt , Germany
25. Federal Motor Vehicle Safety Standards; Side Impact Protection; Side Impact Phase-In Reporting Requirements; Proposed Rule, Federal Register, Part IV, Department of Transportation 49 CFR Parts 571 and 598, Docket No. NHTSA-2004-17694
26. National Institute for Aviation Research (NIAR) Corporation, Wichita State University1845 Fairmount St.Wichita, KS 67260-0093 36.
27. NHTSA Website, 2007, http://www-nrd.nhtsa.dot. gov/departments/nrd-11/FEA_models. html
28. Lightweight BIW Structure project by the Auto/Steel Partnership (A/SP), 2009

Global Journals Inc. (US) Guidelines Handbook 2016

www.GlobalJournals.org

# Fellows

## FELLOW OF ASSOCIATION OF RESEARCH SOCIETY IN ENGINEERING (FARSE)

Global Journals Incorporate (USA) is accredited by Open Association of Research Society (OARS), U.S.A and in turn, awards “FARSE ” title to individuals. The 'FARSE' title is accorded to a selected professional after the approval of the Editor-in-Chief /Editorial Board Members/Dean.

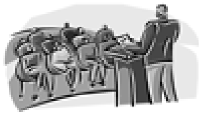
- The “FARSE” is a dignified title which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., FARSE or William Walldroff, M.S., FARSE.

FARSE accrediting is an honor. It authenticates your research activities. After recognition as FARSE, you can add 'FARSE' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, and Visiting Card etc.

*The following benefits can be availed by you only for next three years from the date of certification:*

FARSE designated members are entitled to avail a 40% discount while publishing their research papers (of a single author) with Global Journals Incorporation (USA), if the same is accepted by Editorial Board/Peer Reviewers. If you are a main author or co-author in case of multiple authors, you will be entitled to avail discount of 10%.

Once FARSE title is accorded, the Fellow is authorized to organize a symposium/seminar/conference on behalf of Global Journal Incorporation (USA).The Fellow can also participate in conference/seminar/symposium organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent.

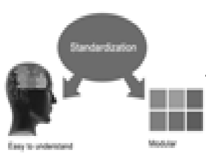


You may join as member of the Editorial Board of Global Journals Incorporation (USA) after successful completion of three years as Fellow and as Peer Reviewer. In addition, it is also desirable that you should organize seminar/symposium/conference at least once.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

The FARSE can go through standards of OARS. You can also play vital role if you have any suggestions so that proper amendment can take place to improve the same for the benefit of entire research community.

As FARSE, you will be given a renowned, secure and free professional email address with 100 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.




The FARSE will be eligible for a free application of standardization of their researches. Standardization of research will be subject to acceptability within stipulated norms as the next step after publishing in a journal. We shall depute a team of specialized research professionals who will render their services for elevating your researches to next higher level, which is worldwide open standardization.

The FARSE member can apply for grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A. Once you are designated as FARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria. After certification of all your credentials by OARS, they will be published on your Fellow Profile link on website https://associationofresearch.org which will be helpful to upgrade the dignity.


The FARSE members can avail the benefits of free research podcasting in Global Research Radio with their research documents. After publishing the work, (including published elsewhere worldwide with proper authorization) you can upload your research paper with your recorded voice or you can utilize chargeable services of our professional RJs to record your paper in their voice on request.

The FARSE member also entitled to get the benefits of free research podcasting of their research documents through video clips. We can also streamline your conference videos and display your slides/ online slides and online research video clips at reasonable charges, on request.

The FARSE is eligible to earn from sales proceeds of his/her researches/reference/review Books or literature, while publishing with Global Journals. The FARSE can decide whether he/she would like to publish his/her research in a closed manner. In this case, whenever readers purchase that individual research paper for reading, maximum 60% of its profit earned as royalty by Global Journals, will be credited to his/her bank account. The entire entitled amount will be credited to his/her bank account exceeding limit of minimum fixed balance. There is no minimum time limit for collection. The FARSE member can decide its price and we can help in making the right decision.

The FARSE member is eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get remuneration of 15% of author fees, taken from the author of a respective paper. After reviewing 5 or more papers you can request to transfer the amount to your bank account.

## MEMBER OF ASSOCIATION OF RESEARCH SOCIETY IN ENGINEERING (MARSE)

The ' MARSE ' title is accorded to a selected professional after the approval of the Editor-in-Chief / Editorial Board Members/Dean.

The “MARSE” is a dignified ornament which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., MARSE or William Walldroff, M.S., MARSE.

MARSE accrediting is an honor. It authenticates your research activities. After becoming MARSE, you can add 'MARSE' title with your name as you use this recognition as additional suffix to your status. This will definitely enhance and add more value and repute to your name. You may use it on your professional Counseling Materials such as CV, Resume, Visiting Card and Name Plate etc.

*The following benefitscan be availed by you only for next three years from the date of certification.*

MARSE designated members are entitled to avail a 25% discount while publishing their research papers (of a single author) in Global Journals Inc., if the same is accepted by our Editorial Board and Peer Reviewers. If you are a main author or co-author of a group of authors, you will get discount of 10%.

As MARSE, you will be given a renowned, secure and free professional email address with 30 GB of space e.g. johnhall@globaljournals.org. This will include Webmail, Spam Assassin, Email Forwarders,Auto-Responders, Email Delivery Route tracing, etc.


We shall provide you intimation regarding launching of e-version of journal of your stream time to time.This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.


The MARSE member can apply for approval, grading and certification of standards of their educational and Institutional Degrees to Open Association of Research, Society U.S.A.

Once you are designated as MARSE, you may send us a scanned copy of all of your credentials. OARS will verify, grade and certify them. This will be based on your academic records, quality of research papers published by you, and some more criteria.

It is mandatory to read all terms and conditions carefully.

# Auxiliary Memberships

## Institutional Fellow of Open Association of Research Society (USA)-OARS (USA)

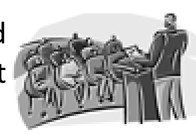
Global Journals Incorporation (USA) is accredited by Open Association of Research Society, U.S.A (OARS) and in turn, affiliates research institutions as "Institutional Fellow of Open Association of Research Society" (IFOARS).

The "FARSC" is a dignified title which is accorded to a person's name viz. Dr. John E. Hall, Ph.D., FARSC or William Walldroff, M.S., FARSC.

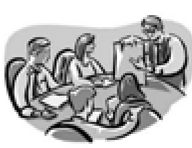
The IFOARS institution is entitled to form a Board comprised of one Chairperson and three to five board members preferably from different streams. The Board will be recognized as "Institutional Board of Open Association of Research Society"-(IBOARS).

*The Institute will be entitled to following benefits:*

The IBOARS can initially review research papers of their institute and recommend them to publish with respective journal of Global Journals. It can also review the papers of other institutions after obtaining our consent. The second review will be done by peer reviewer of Global Journals Incorporation (USA)
The Board is at liberty to appoint a peer reviewer with the approval of chairperson after consulting us.
The author fees of such paper may be waived off up to 40%.



The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.

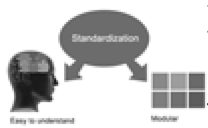


The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.


The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of "Open Association of Research Society, U.S.A (OARS)" so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.




After nomination of your institution as "Institutional Fellow" and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.
The board can also take up the additional allied activities for betterment after our consultation.

**The following entitlements are applicable to individual Fellows:**

Open Association of Research Society, U.S.A (OARS) By-laws states that an individual Fellow may use the designations as applicable, or the corresponding initials. The Credentials of individual Fellow and Associate designations signify that the individual has gained knowledge of the fundamental concepts. One is magnanimous and proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice.


Open Association of Research Society (US)/ Global Journals Incorporation (USA), as described in Corporate Statements, are educational, research publishing and professional membership organizations. Achieving our individual Fellow or Associate status is based mainly on meeting stated educational research requirements.

Disbursement of 40% Royalty earned through Global Journals : Researcher = 50%, Peer Reviewer = 37.50%, Institution = 12.50% E.g. Out of 40%, the 20% benefit should be passed on to researcher, 15 % benefit towards remuneration should be given to a reviewer and remaining 5% is to be retained by the institution.

We shall provide print version of 12 issues of any three journals [as per your requirement] out of our 38 journals worth $ 2376 USD.

**Other:**

**The individual Fellow and Associate designations accredited by Open Association of Research Society (US) credentials signify guarantees following achievements:**

- The professional accredited with Fellow honor, is entitled to various benefits viz. name, fame, honor, regular flow of income, secured bright future, social status etc.

- In addition to above, if one is single author, then entitled to 40% discount on publishing research paper and can get 10%discount if one is co-author or main author among group of authors.
- The Fellow can organize symposium/seminar/conference on behalf of Global Journals Incorporation (USA) and he/she can also attend the same organized by other institutes on behalf of Global Journals.
- The Fellow can become member of Editorial Board Member after completing 3yrs.
- The Fellow can earn 60% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.
- Fellow can also join as paid peer reviewer and earn 15% remuneration of author charges and can also get an opportunity to join as member of the Editorial Board of Global Journals Incorporation (USA)
- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

**Note :**

"

- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone.

"

# Process of submission of Research Paper

The Area or field of specialization may or may not be of any category as mentioned in 'Scope of Journal' menu of the GlobalJournals.org website. There are 37 Research Journal categorized with Six parental Journals GJCST, GJMR, GJRE, GJMBR, GJSFR, GJHSS. For Authors should prefer the mentioned categories. There are three widely used systems UDC, DDC and LCC. The details are available as 'Knowledge Abstract' at Home page. The major advantage of this coding is that, the research work will be exposed to and shared with all over the world as we are being abstracted and indexed worldwide.

The paper should be in proper format. The format can be downloaded from first page of 'Author Guideline' Menu. The Author is expected to follow the general rules as mentioned in this menu. The paper should be written in MS-Word Format (*.DOC,*.DOCX).

The Author can submit the paper either online or offline. The authors should prefer online submission.Online Submission: There are three ways to submit your paper:

**(A) (I) First, register yourself using top right corner of Home page then Login. If you are already registered, then login using your username and password.**

**(II) Choose corresponding Journal.**

**(III) Click 'Submit Manuscript'. Fill required information and Upload the paper.**

**(B) If you are using Internet Explorer, then Direct Submission through Homepage is also available.**

**(C) If these two are not conveninet , and then email the paper directly to dean@globaljournals.org.**

Offline Submission: Author can send the typed form of paper by Post. However, online submission should be preferred.

# Preferred Author Guidelines

**MANUSCRIPT STYLE INSTRUCTION** **<u>(Must be strictly followed)</u>**

Page Size: 8.27" X 11'"

- Left Margin: 0.65
- Right Margin: 0.65
- Top Margin: 0.75
- Bottom Margin: 0.75
- Font type of all text should be Swis 721 Lt BT.
- Paper Title should be of Font Size 24 with one Column section.
- Author Name in Font Size of 11 with one column as of Title.
- Abstract Font size of 9 Bold, “Abstract” word in Italic Bold.
- Main Text: Font size 10 with justified two columns section
- Two Column with Equal Column with of 3.38 and Gaping of .2
- First Character must be three lines Drop capped.
- Paragraph before Spacing of 1 pt and After of 0 pt.
- Line Spacing of 1 pt
- Large Images must be in One Column
- Numbering of First Main Headings (Heading 1) must be in Roman Letters, Capital Letter, and Font Size of 10.
- Numbering of Second Main Headings (Heading 2) must be in Alphabets, Italic, and Font Size of 10.

**You can use your own standard format also.**
**Author Guidelines:**

1. General,

2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript’s Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

**1. GENERAL**

Before submitting your research paper, one is advised to go through the details as mentioned in following heads. It will be beneficial, while peer reviewer justify your paper for publication.

**Scope**

The Global Journals Inc. (US) welcome the submission of original paper, review paper, survey article relevant to the all the streams of Philosophy and knowledge. The Global Journals Inc. (US) is parental platform for Global Journal of Computer Science and Technology, Researches in Engineering, Medical Research, Science Frontier Research, Human Social Science, Management, and Business organization. The choice of specific field can be done otherwise as following in Abstracting and Indexing Page on this Website. As the all Global

Journals Inc. (US) are being abstracted and indexed (in process) by most of the reputed organizations. Topics of only narrow interest will not be accepted unless they have wider potential or consequences.

**2. ETHICAL GUIDELINES**

Authors should follow the ethical guidelines as mentioned below for publication of research paper and research activities.

Papers are accepted on strict understanding that the material in whole or in part has not been, nor is being, considered for publication elsewhere. If the paper once accepted by Global Journals Inc. (US) and Editorial Board, will become the copyright of the Global Journals Inc. (US).

**Authorship: The authors and coauthors should have active contribution to conception design, analysis and interpretation of findings. They should critically review the contents and drafting of the paper. All should approve the final version of the paper before submission**

The Global Journals Inc. (US) follows the definition of authorship set up by the Global Academy of Research and Development. According to the Global Academy of R&D authorship, criteria must be based on:

1) Substantial contributions to conception and acquisition of data, analysis and interpretation of the findings.

2) Drafting the paper and revising it critically regarding important academic content.

3) Final approval of the version of the paper to be published.

All authors should have been credited according to their appropriate contribution in research activity and preparing paper. Contributors who do not match the criteria as authors may be mentioned under Acknowledgement.

Acknowledgements: Contributors to the research other than authors credited should be mentioned under acknowledgement. The specifications of the source of funding for the research if appropriate can be included. Suppliers of resources may be mentioned along with address.

**Appeal of Decision: The Editorial Board's decision on publication of the paper is final and cannot be appealed elsewhere.**

**Permissions: It is the author's responsibility to have prior permission if all or parts of earlier published illustrations are used in this paper.**

Please mention proper reference and appropriate acknowledgements wherever expected.

If all or parts of previously published illustrations are used, permission must be taken from the copyright holder concerned. It is the author's responsibility to take these in writing.

Approval for reproduction/modification of any information (including figures and tables) published elsewhere must be obtained by the authors/copyright holders before submission of the manuscript. Contributors (Authors) are responsible for any copyright fee involved.

**3. SUBMISSION OF MANUSCRIPTS**

Manuscripts should be uploaded via this online submission page. The online submission is most efficient method for submission of papers, as it enables rapid distribution of manuscripts and consequently speeds up the review procedure. It also enables authors to know the status of their own manuscripts by emailing us. Complete instructions for submitting a paper is available below.

Manuscript submission is a systematic procedure and little preparation is required beyond having all parts of your manuscript in a given format and a computer with an Internet connection and a Web browser. Full help and instructions are provided on-screen. As an author, you will be prompted for login and manuscript details as Field of Paper and then to upload your manuscript file(s) according to the instructions.

To avoid postal delays, all transaction is preferred by e-mail. A finished manuscript submission is confirmed by e-mail immediately and your paper enters the editorial process with no postal delays. When a conclusion is made about the publication of your paper by our Editorial Board, revisions can be submitted online with the same procedure, with an occasion to view and respond to all comments.

Complete support for both authors and co-author is provided.

**4. MANUSCRIPT'S CATEGORY**

Based on potential and nature, the manuscript can be categorized under the following heads:

Original research paper: Such papers are reports of high-level significant original research work.

Review papers: These are concise, significant but helpful and decisive topics for young researchers.

Research articles: These are handled with small investigation and applications

Research letters: The letters are small and concise comments on previously published matters.

**5.STRUCTURE AND FORMAT OF MANUSCRIPT**

The recommended size of original research paper is less than seven thousand words, review papers fewer than seven thousands words also.Preparation of research paper or how to write research paper, are major hurdle, while writing manuscript. The research articles and research letters should be fewer than three thousand words, the structure original research paper; sometime review paper should be as follows:

**Papers**: These are reports of significant research (typically less than 7000 words equivalent, including tables, figures, references), and comprise:

(a)Title should be relevant and commensurate with the theme of the paper.

(b) A brief Summary, "Abstract" (less than 150 words) containing the major results and conclusions.

(c) Up to ten keywords, that precisely identifies the paper's subject, purpose, and focus.

(d) An Introduction, giving necessary background excluding subheadings; objectives must be clearly declared.

(e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition; sources of information must be given and numerical methods must be specified by reference, unless non-standard.

(f) Results should be presented concisely, by well-designed tables and/or figures; the same data may not be used in both; suitable statistical data should be given. All data must be obtained with attention to numerical detail in the planning stage. As reproduced design has been recognized to be important to experiments for a considerable time, the Editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned un-refereed;

(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

(h) Brief Acknowledgements.

(i) References in the proper form.

Authors should very cautiously consider the preparation of papers to ensure that they communicate efficiently. Papers are much more likely to be accepted, if they are cautiously designed and laid out, contain few or no errors, are summarizing, and be conventional to the approach and instructions. They will in addition, be published with much less delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and to make suggestions to improve briefness.

It is vital, that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

**Format**

*Language: The language of publication is UK English. Authors, for whom English is a second language, must have their manuscript efficiently edited by an English-speaking person before submission to make sure that, the English is of high excellence. It is preferable, that manuscripts should be professionally edited.*

Standard Usage, Abbreviations, and Units: Spelling and hyphenation should be conventional to The Concise Oxford English Dictionary. Statistics and measurements should at all times be given in figures, e.g. 16 min, except for when the number begins a sentence. When the number does not refer to a unit of measurement it should be spelt in full unless, it is 160 or greater.

Abbreviations supposed to be used carefully. The abbreviated name or expression is supposed to be cited in full at first usage, followed by the conventional abbreviation in parentheses.

Metric SI units are supposed to generally be used excluding where they conflict with current practice or are confusing. For illustration, 1.4 l rather than 1.4 × 10-3 m3, or 4 mm somewhat than 4 × 10-3 m. Chemical formula and solutions must identify the form used, e.g. anhydrous or hydrated, and the concentration must be in clearly defined units. Common species names should be followed by underlines at the first mention. For following use the generic name should be constricted to a single letter, if it is clear.

**Structure**

All manuscripts submitted to Global Journals Inc. (US), ought to include:

Title: The title page must carry an instructive title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) wherever the work was carried out. The full postal address in addition with the e-mail address of related author must be given. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining and indexing.

*Abstract, used in Original Papers and Reviews:*

Optimizing Abstract for Search Engines

Many researchers searching for information online will use search engines such as Google, Yahoo or similar. By optimizing your paper for search engines, you will amplify the chance of someone finding it. This in turn will make it more likely to be viewed and/or cited in a further work. Global Journals Inc. (US) have compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Key Words

A major linchpin in research work for the writing research paper is the keyword search, which one will employ to find both library and Internet resources.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy and planning a list of possible keywords and phrases to try.

Search engines for most searches, use Boolean searching, which is somewhat different from Internet searches. The Boolean search uses "operators," words (and, or, not, and near) that enable you to expand or narrow your affords. Tips for research paper while preparing research paper are very helpful guideline of research paper.

Choice of key words is first tool of tips to write research paper. Research paper writing is an art.A few tips for deciding as strategically as possible about keyword search:

- One should start brainstorming lists of possible keywords before even begin searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in research paper?" Then consider synonyms for the important words.
- It may take the discovery of only one relevant paper to let steer in the right keyword direction because in most databases, the keywords under which a research paper is abstracted are listed with the paper.
- One should avoid outdated words.

Keywords are the key that opens a door to research work sources. Keyword searching is an art in which researcher's skills are bound to improve with experience and time.

Numerical Methods: Numerical methods used should be clear and, where appropriate, supported by references.

*Acknowledgements: Please make these as concise as possible.*

References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

References to information on the World Wide Web can be given, but only if the information is available without charge to readers on an official site. Wikipedia and Similar websites are not allowed where anyone can change the information. Authors will be asked to make available electronic copies of the cited information for inclusion on the Global Journals Inc. (US) homepage at the judgment of the Editorial Board.

The Editorial Board and Global Journals Inc. (US) recommend that, citation of online-published papers and other material should be done via a DOI (digital object identifier). If an author cites anything, which does not have a DOI, they run the risk of the cited material not being noticeable.

The Editorial Board and Global Journals Inc. (US) recommend the use of a tool such as Reference Manager for reference management and formatting.

Tables, Figures and Figure Legends

*Tables: Tables should be few in number, cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g. Table 4, a self-explanatory caption and be on a separate sheet. Vertical lines should not be used.*

*Figures: Figures are supposed to be submitted as separate files. Always take in a citation in the text for each figure using Arabic numbers, e.g. Fig. 4. Artwork must be submitted online in electronic form by e-mailing them.*

Preparation of Electronic Figures for Publication

Even though low quality images are sufficient for review purposes, print publication requires high quality images to prevent the final product being blurred or fuzzy. Submit (or e-mail) EPS (line art) or TIFF (halftone/photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Do not use pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings) in relation to the imitation size. Please give the data for figures in black and white or submit a Color Work Agreement Form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution (at final image size) ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs) : >350 dpi; figures containing both halftone and line images: >650 dpi.

*Figure Legends: Self-explanatory legends of all figures should be incorporated separately under the heading 'Legends to Figures'. In the full-text online edition of the journal, figure legends may possibly be truncated in abbreviated links to the full screen version. Therefore, the first 100 characters of any legend should notify the reader, about the key aspects of the figure.*

**6. AFTER ACCEPTANCE**

Upon approval of a paper for publication, the manuscript will be forwarded to the dean, who is responsible for the publication of the Global Journals Inc. (US).

**6.1 Proof Corrections**

The corresponding author will receive an e-mail alert containing a link to a website or will be attached. A working e-mail address must therefore be provided for the related author.

Acrobat Reader will be required in order to read this file. This software can be downloaded

(Free of charge) from the following website:

www.adobe.com/products/acrobat/readstep2.html. This will facilitate the file to be opened, read on screen, and printed out in order for any corrections to be added. Further instructions will be sent with the proof.

Proofs must be returned to the dean at dean@globaljournals.org within three days of receipt.

As changes to proofs are costly, we inquire that you only correct typesetting errors. All illustrations are retained by the publisher. Please note that the authors are responsible for all statements made in their work, including changes made by the copy editor.

**6.2 Early View of Global Journals Inc. (US) (Publication Prior to Print)**

The Global Journals Inc. (US) are enclosed by our publishing's Early View service. Early View articles are complete full-text articles sent in advance of their publication. Early View articles are absolute and final. They have been completely reviewed, revised and edited for publication, and the authors' final corrections have been incorporated. Because they are in final form, no changes can be made after sending them. The nature of Early View articles means that they do not yet have volume, issue or page numbers, so Early View articles cannot be cited in the conventional way.

**6.3 Author Services**

Online production tracking is available for your article through Author Services. Author Services enables authors to track their article - once it has been accepted - through the production process to publication online and in print. Authors can check the status of their articles online and choose to receive automated e-mails at key stages of production. The authors will receive an e-mail with a unique link that enables them to register and have their article automatically added to the system. Please ensure that a complete e-mail address is provided when submitting the manuscript.

**6.4 Author Material Archive Policy**

Please note that if not specifically requested, publisher will dispose off hardcopy & electronic information submitted, after the two months of publication. If you require the return of any information submitted, please inform the Editorial Board or dean as soon as possible.

**6.5 Offprint and Extra Copies**

A PDF offprint of the online-published article will be provided free of charge to the related author, and may be distributed according to the Publisher's terms and conditions. Additional paper offprint may be ordered by emailing us at: editor@globaljournals.org .

You must strictly follow above Author Guidelines before submitting your paper or else we will not at all be responsible for any corrections in future in any of the way.

Before start writing a good quality Computer Science Research Paper, let us first understand what is Computer Science Research Paper? So, Computer Science Research Paper is the paper which is written by professionals or scientists who are associated to Computer Science and Information Technology, or doing research study in these areas. If you are novel to this field then you can consult about this field from your supervisor or guide.

## TECHNIQUES FOR WRITING A GOOD QUALITY RESEARCH PAPER:

**1. Choosing the topic:** In most cases, the topic is searched by the interest of author but it can be also suggested by the guides. You can have several topics and then you can judge that in which topic or subject you are finding yourself most comfortable. This can be done by asking several questions to yourself, like Will I be able to carry our search in this area? Will I find all necessary recourses to accomplish the search? Will I be able to find all information in this field area? If the answer of these types of questions will be "Yes" then you can choose that topic. In most of the cases, you may have to conduct the surveys and have to visit several places because this field is related to Computer Science and Information Technology. Also, you may have to do a lot of work to find all rise and falls regarding the various data of that subject. Sometimes, detailed information plays a vital role, instead of short information.

**2. Evaluators are human:** First thing to remember that evaluators are also human being. They are not only meant for rejecting a paper. They are here to evaluate your paper. So, present your Best.

**3. Think Like Evaluators:** If you are in a confusion or getting demotivated that your paper will be accepted by evaluators or not, then think and try to evaluate your paper like an Evaluator. Try to understand that what an evaluator wants in your research paper and automatically you will have your answer.

**4. Make blueprints of paper:** The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

**5. Ask your Guides:** If you are having any difficulty in your research, then do not hesitate to share your difficulty to your guide (if you have any). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work then ask the supervisor to help you with the alternative. He might also provide you the list of essential readings.

**6. Use of computer is recommended:** As you are doing research in the field of Computer Science, then this point is quite obvious.

**7. Use right software:** Always use good quality software packages. If you are not capable to judge good software then you can lose quality of your paper unknowingly. There are various software programs available to help you, which you can get through Internet.

**8. Use the Internet for help:** An excellent start for your paper can be by using the Google. It is an excellent search engine, where you can have your doubts resolved. You may also read some answers for the frequent question how to write my research paper or find model research paper. From the internet library you can download books. If you have all required books make important reading selecting and analyzing the specified information. Then put together research paper sketch out.

**9. Use and get big pictures:** Always use encyclopedias, Wikipedia to get pictures so that you can go into the depth.

**10. Bookmarks are useful:** When you read any book or magazine, you generally use bookmarks, right! It is a good habit, which helps to not to lose your continuity. You should always use bookmarks while searching on Internet also, which will make your search easier.

**11. Revise what you wrote:** When you write anything, always read it, summarize it and then finalize it.

**12. Make all efforts:** Make all efforts to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in introduction, that what is the need of a particular research paper. Polish your work by good skill of writing and always give an evaluator, what he wants.

**13. Have backups:** When you are going to do any important thing like making research paper, you should always have backup copies of it either in your computer or in paper. This will help you to not to lose any of your important.

**14. Produce good diagrams of your own:** Always try to include good charts or diagrams in your paper to improve quality. Using several and unnecessary diagrams will degrade the quality of your paper by creating "hotchpotch." So always, try to make and include those diagrams, which are made by your own to improve readability and understandability of your paper.

**15. Use of direct quotes:** When you do research relevant to literature, history or current affairs then use of quotes become essential but if study is relevant to science then use of quotes is not preferable.

**16. Use proper verb tense:** Use proper verb tenses in your paper. Use past tense, to present those events that happened. Use present tense to indicate events that are going on. Use future tense to indicate future happening events. Use of improper and wrong tenses will confuse the evaluator. Avoid the sentences that are incomplete.

**17. Never use online paper:** If you are getting any paper on Internet, then never use it as your research paper because it might be possible that evaluator has already seen it or maybe it is outdated version.

**18. Pick a good study spot:** To do your research studies always try to pick a spot, which is quiet. Every spot is not for studies. Spot that suits you choose it and proceed further.

**19. Know what you know:** Always try to know, what you know by making objectives. Else, you will be confused and cannot achieve your target.

**20. Use good quality grammar:** Always use a good quality grammar and use words that will throw positive impact on evaluator. Use of good quality grammar does not mean to use tough words, that for each word the evaluator has to go through dictionary. Do not start sentence with a conjunction. Do not fragment sentences. Eliminate one-word sentences. Ignore passive voice. Do not ever use a big word when a diminutive one would suffice. Verbs have to be in agreement with their subjects. Prepositions are not expressions to finish sentences with. It is incorrect to ever divide an infinitive. Avoid clichés like the disease. Also, always shun irritating alliteration. Use language that is simple and straight forward. put together a neat summary.

**21. Arrangement of information:** Each section of the main body should start with an opening sentence and there should be a changeover at the end of the section. Give only valid and powerful arguments to your topic. You may also maintain your arguments with records.

**22. Never start in last minute:** Always start at right time and give enough time to research work. Leaving everything to the last minute will degrade your paper and spoil your work.

**23. Multitasking in research is not good:** Doing several things at the same time proves bad habit in case of research activity. Research is an area, where everything has a particular time slot. Divide your research work in parts and do particular part in particular time slot.

**24. Never copy others' work:** Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

**25. Take proper rest and food:** No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

**26. Go for seminars:** Attend seminars if the topic is relevant to your research area. Utilize all your resources.

**27. Refresh your mind after intervals:** Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

**28. Make colleagues:** Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

**29. Think technically:** Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

**30. Think and then print:** When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

**31. Adding unnecessary information:** Do not add unnecessary information, like, I have used MS Excel to draw graph. Do not add irrelevant and inappropriate material. These all will create superfluous. Foreign terminology and phrases are not apropos. One should NEVER take a broad view. Analogy in script is like feathers on a snake. Not at all use a large word when a very small one would be sufficient. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Amplification is a billion times of inferior quality than sarcasm.

**32. Never oversimplify everything:** To add material in your research paper, never go for oversimplification. This will definitely irritate the evaluator. Be more or less specific. Also too, by no means, ever use rhythmic redundancies. Contractions aren't essential and shouldn't be there used. Comparisons are as terrible as clichés. Give up ampersands and abbreviations, and so on. Remove commas, that are, not necessary. Parenthetical words however should be together with this in commas. Understatement is all the time the complete best way to put onward earth-shaking thoughts. Give a detailed literary review.

**33. Report concluded results:** Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

**34. After conclusion:** Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print to the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects in your research.

## Informal Guidelines of Research Paper Writing

**Key points to remember:**

- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

**Final Points:**

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

**General style:**

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

**Title Page:**

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

**Abstract:**

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

**Introduction:**

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

**Procedures (Methods and Materials):**

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

**Results:**

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

**Discussion:**

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

Please carefully note down following rules and regulation before submitting your Research Paper to Global Journals Inc. (US):

**Segment Draft and Final Research Paper:** You have to strictly follow the template of research paper. If it is not done your paper may get rejected.

- The **major constraint** is that you must independently make all content, tables, graphs, and facts that are offered in the paper. You must write each part of the paper wholly on your own. The Peer-reviewers need to identify your own perceptive of the concepts in your own terms. NEVER extract straight from any foundation, and never rephrase someone else's analysis.

- Do not give permission to anyone else to "PROOFREAD" your manuscript.

- Methods to avoid Plagiarism is applied by us on every paper, if found guilty, you will be blacklisted by all of our collaborated research groups, your institution will be informed for this and strict legal actions will be taken immediately.)
- To guard yourself and others from possible illegal use please do not permit anyone right to use to your paper and files.

## Criterion for Grading a Research Paper (Compilation) by Global Journals Inc. (US)

**Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals Inc. (US).**

| Topics | Grades | | |
|---|---|---|---|
| | **A-B** | **C-D** | **E-F** |
| ***Abstract*** | Clear and concise with appropriate content, Correct format. 200 words or below | Unclear summary and no specific data, Incorrect form<br><br>Above 200 words | No specific data with ambiguous information<br><br>Above 250 words |
| ***Introduction*** | Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited | Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter | Out of place depth and content, hazy format |
| ***Methods and Procedures*** | Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads | Difficult to comprehend with embarrassed text, too much explanation but completed | Incorrect and unorganized structure with hazy meaning |
| ***Result*** | Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake | Complete and embarrassed text, difficult to comprehend | Irregular format with wrong facts and figures |
| ***Discussion*** | Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited | Wordy, unclear conclusion, spurious | Conclusion is not cited, unorganized, difficult to comprehend |
| ***References*** | Complete and correct format, well organized | Beside the point, Incomplete | Wrong format and structuring |

# Index

### *C*



### *H*



### *L*



### *O*



### *P*



### *S*

save our planet

# Global Journal of Researches in Engineering

Visit us on the Web at www.GlobalJournals.org | www.EngineeringResearch.org
or email us at helpdesk@globaljournals.org

ISSN 9755861