Fatigue Strain based Approach for Damage Evolution Model of Concrete

Indra Narayan Yadav[1] and Dr. Kamal Bahadur Thapa[2]

[1] Tribhuvan University

Received: 13 December 2018 Accepted: 2 January 2019 Published: 15 January 2019

Abstract

Fatigue Strain-based Approach to the Damage evolution Modeling plays a very important role in the evaluation of the material properties of concrete utilizing strain analysis methods, the nonlinear fatigue strain evolution model is proposed , evolution model of fatigue modulus is established and the hypothesis of fatigue modulus inversely related fatigue strain amplitude causes formation of cracks and microcracks, anisotropic in nature, damage the chemistry and orientation of composed structural elements of concrete materials resulting reduction in stiffness and inelastic deformations. This paper presents Fatigue Strain and Damage evolution Model of concrete, developed, in strain life approach, by using damage principle of continuum thermodynamics. Due to the formation of nucleation and microcracks by continuous fatigue loading and unloading result in stiffness reduction and inelastic deformation, and hence the phenomenon is termed as damaged. The fatigue strain, fatigue modulus evolution curves have three stages, namely, variation phase, linear change stage, and convergence stage.

Index terms**—** fatigue strain based approach; damage; evolution model; concrete fatigue modulus; thermodynamics; fatigue modulus; inelastic, strength reduction.

1 Introduction

n recent times, concrete has become the bedrock of infrastructural civilization in the world. Statistics have shown that over 75% of the infrastructures in the world have to do with concrete. Therefore, it is necessary to study regarding the behavior of concrete in every aspect from the production, transportation, placing and eventually maintenance of concrete.

Concrete today has a very wide range of applications. Virtually every civil engineering work in Nepal today is directly or indirectly involving the use of concrete. The use of concrete in civil engineering works includes: construction of residential houses, industrial warehouses, roads pavement construction, Shore Protection works, piles, domes, bridges, culverts, drainages, canals, dams etc. (Shetty, 2005;Neville, 2011;Edward and David, 2009;Duggal, 2009;Gambhir, 2005). In recent practice, the cases of failure of structures and roads (concretely related failure) occur on a yearly basis.

Variation of material internal as well as external deformation of concrete materials due to fatigue loading to the failure is reflected by fatigue strain. For, qualitative understanding of the failure fatigue strain, the detailed study of the evolution curve is essential. Longitudinal and residual deformations in three stage namely rapid, stable and ultimate growth stage which is generally used in all types of concrete as well as all types of fatigue failure i.e. compression, tension, bending, uniaxial, biaxial or multiaxial fatigue (Chen. Et. Al), which is in the form of cubical polynomial fitting curve, resulting in the correlation coefficients is more than 0.937. According to Cachim et. Al., in a constant order of magnitude, the stress in the different level of concrete have different coefficients used in logarithmic form regarding the curve obtained from the maximum strain versus the number of cycles graph at the second phases of concrete. The linear nature of curve obtained from graphs regarding maximum strain versus the number of cycles to the failure according to Xie. Et. Al. who had also given the well-developed experienced formula for fatigue strain in second phases of the concrete matrix. Data regarding fatigue strain in a similar stage was nonlinear in nature given by Wang et. Al.

At the low accuracy, three staged fatigue evolution equations are described in a simpler way in different literature. Strictly speaking, it became complicated to develop nonlinear equations of high precision based on the relation between fatigue strain and the number of cycles at different amplitude. At low fatigue stress with the comparison to the ultimate stress of concrete material but greater than ultimate value, very few research has been done yet. Without considering the initial strain, for three-stage fatigue strain and curve regarding strain to the number of cycles to the failure is obtained which caused alter fittings of curves coefficient fittings parameters. Therefore endurance limit for For the production of concrete, except cement, all materials are locally available i.e. sand, aggregate, and water. So, it is very much popular in the list of construction material is construction engineering. Concrete is a heterogeneous matrix related to the composition i.e. cement, sand, aggregate and water among them cement is the weakest part compared to the remaining ingredients. At the initial stage of production, water and air are inside the matrix of the composition of structure slowly released from that matrix during an initial setting time to final setting time creating microvoids at the original place of air and water made alteration of the chemistry of the matrix. When the cyclic load which is lower than ultimate load but higher than threshold limit is applied to the concrete then due to alteration i.e. separation of the matrix in composition, alters the ingredient from each other by creating microvoids continuously increasing up to microvoids and finally break up which is called fracture. Force applied until fracture appears is usually lesser than ultimate monotonic loads phenomenon which deals about the chemistry of fracture is called fatigue mainly caused by progressive cyclic loading tends to change the [2] permanent internal structure resulting microcracks until macrocracks creating the permanent damage in the concrete matrix.

Based on the concept of dual nature of fatigue damage, the model for ordinary concrete has been documented through the number of investigations presented in the different researches. It is very much essential to predict the progressive creep damage model based on cyclic dependent and time-dependent damage at constant and variable amplitude. [3] Damage in the concrete pavement was carried out through the accelerated pavement testing results. As per Minor hypothesis, one cannot predict the cumulative fatigue damage in concrete accurately. The theoretical model for the prediction of cumulative fatigue model in compression, compression-tension, tension-tension, flexural, torsional, uniaxial, bi-axial, tri-axial under monotonic and cyclic loading using different approaches such as bounding surface approach with using the energy released rate by constructing damage effective tensor poorly described in different past research papers and articles also. The need for validation of such models in inelastic flow and microcracking related to plasticity theories and voids caused degradation of elastic moduli through energy dissipations. The experimental work of [4] described that the increase of damage in the concrete material takes place is about last 20% of its probable fatigue life. [5] Presented a theoretical model to describe the fatigue process of concrete material in alternate tensioncompression fatigue loading utilizing double bounding surface approach with strain-energy release rate by evaluating damage-effective tensor. A number of damage constitutive models regarding failure fatigue life of concrete have been published for capturing the model regarding mechanical behavior of concrete under monotonic and cyclic loading ([6], [7], [8], [9], and [10]), which have done in the past.

This paper presents the physical meanings, the ranges, and the impact on the shape of the curve of parameters in the nonlinear strain evolution model are all discussed. The evolution model of fatigue modulus was established under constant amplitude bending fatigue loading based on the fatigue strain evolution model and the hypothesis of fatigue modulus inversely related fatigue strain amplitude. A class of damage mechanics theory to model the fatigue damage and failure of concrete caused by the multitude of cracks and microcracks whereby anisotropic damaging behavior is captured through the use of proper response function involving damage parameter in material stiffness tensor is also developed. The increment of damage parameter is obtained from consistency equation in cycle dependent damage surface in strain space. The model is also capable of capturing the inelastic deformations that may arise due to misfits of crack surfaces and development of sizable crack tip process zone. Moreover, the whole process is validated by the experimental data II.

2 Formulation

According to the continuum damage mechanics approach to describe the constitutive relation for the concrete matrix relate to fatigue loading at low frequency by neglecting thermal effects. Considering, the isothermal process, small deformations and rate independent behavior, the Helmholtz Free Energy (HFE) per unit volume can be written from [1] is given below :( ) ( ) k k i 2 1 A k) , A(+ ? = ? : ? ? E ? ? i ? : : (1)

Where, E (k) = fourth-order elastic stiffness tensor, ? = strain tensor, i ? = stress tensor. ?? ?? (??)= surface energy of microcracks [2], and k = cumulative fatigue damage parameter. The colon (:) indicates the tensor contraction operation. For inelastic fatigue damage, a constitutive relation between the fatigue stress and fatigue strain tensors shall be established by fourth order material's stiffness tensor such as ( ) ( )k k A i ? ? : E ? ? ? = ? ? = (2)

The rate of change of Eqn (2) with respect to cyclic number N is given by ( ) ( ) ( ) ( ) k k k k k i D e ? ? ? ? ? : E ? : E ? ? ? ? ? ? ? ? ? + + = ? + = i (3)

Where e ? ? , = stress increment, D ? ? = rate of stress-relaxation, and ( )k i ? ?

= rate of stress tensor For small deformation, the following matrix of the fourth-order stiffness tensor, E, when adopted ( ) ( )k k A D E E E ? ? + = = ? ? ? 0 2**(4)**

Where M ? L E D k and k ? ? ? ? = ? = i (5)

Where L and M are, fourth and second-order response tensors which determine the directions of the elastic and inelastic fatigue damage processes. Following the Clausius-Duhem inequality equations, applying the standard thermodynamic discussions [13] and a potential function by assuming unloading is in an elastic process( ) ( ) 0 , , 2 2 1 2 1 = ? ? = ? k p k ? ? : M ? : L : ? ? (6)

In Eqn (6), ( )k p , ? = damage function which is given as ( ) ( ) ? ? ? ? ? ? ? ? ? + = k A k h k p i , 2 , 2 2 ? ? (7) Which is for some scalar-valued function( ) k h , 2 ? .

It should be noted that as long as the function( ) k p , 2 ?

is well defined, the right-hand side of Eqn (7) need not be identified.

For specific forms of response tensors, L and M shall be specified. Since fatigue damage is highly directional, so, directionality response tensors should be developed. For the development of response tensor, the strain tensor is divided into positive and negative cones. The positive and negative cones of the fatigue strain tensor completely hold the corresponding positive and negative eigenvalue of the system, i.e., ? ? ? + = as positive and negative cones of the strain tensor, respectively. Based on the fact of experimental observations for concrete materials, the damage is assumed to arrive in the cleavage mode of cracking as per Figure1. For the mode of cleavage cracking, the terms of response tensors are postulated for L and M+ + + + ? = ? : ? ? ? L (8) + = ? M ? (9)

Substituting the response tensors L and M from Eqns (8) and (**??**) into Eqn (6) gives the final form of the fatigue cracked damaged surface( ) ( )**(**

)) (0 ,) 2 1 (= 0 , , 2 2 1 2 1 2 2 1 2 1 10b k p k p k = ? ? = ? ? = ? + + + + + + ? ? : ? ? ? : ? ? : ? ? ? ?

Damage function p(k) is obtained from an experimental test of uniaxial tensile loading, then the equation can be written as( ) ? ? ? ? ? ? ? ? ? ? = k E E ? p 0 0 u ln k (11)

When, ?? = 0in the inelastic damage surface, the limit damage surface reduces to( ) u ? p = k (**12**)

Where u ? = strain corresponding to the uniaxial tensile strength of concrete, For describing the three-stage fatigue damage law, we have?? ?? = ?? 0 +? (?? ??? ?? ???? ? 1) 1/??**(13)**

Where, ?? 0 = initial strain and ?? ?? = fatigue strain, ?? = cycle times of fatigue loads. ??ð ??"ð ??" = fatigue in life. ??, ??, and ?? were the parameter regarding fatigue. The equation of damage surface for uniaxial tensile loading Eqns (10a) is rewritten as III.

3 Fatigue Damage Model

In fact, progressive permanent structural changes in the form of cracks due to fatigue loading flows material fails at lower stress than the ultimate tensile strength of the material which has a higher value than the threshold limit. Damage surface of the material within the given prescribed strain, fatigue loading (reloading and unloading process) increases the growth of microcracks which leads inelastic deformation tends to reduce the ultimate overall strength of the concrete material. Therefore, for modified damage surface, fatigue damage with respect to the number of cycles i.e.

4 ( )

k , ? ? is obtained from ( ) ( ) 0 ,) 2 1 (2 2 1 2 1 = ? ? + + k p N X ? ? : ? ? (14)

Where, X (N) = function that depends on the number of loading cycles. Propose a power function for X (N) as( ) A N N X =**(15)**

Here, N = number of loading cycles, and A = material parameter. From, Eqns (**??**1) and (**??**4), we can obtain the cumulative fatigue parameter k as under( ) ? = + + u 0 ? 2 1 1 1 ? : ? A N exp E k ? (16)

Differentiating Eqns (15) with respect to N, an increment of damage in one cycle can be obtained as Finally, the rate of damage parameter k ? can be used in the simple constitutive relation in Eqn (14) for uniaxial tensile stress state to get inelastic deformation, stiffness reduction and strength reduction due to fatigue cycles to the failure. Substituting all related parameters, we can get, ( )? ? ? ? ? ? ? ? + ? ? = + + + + + ? ? : ? : ? ? ? ? : E ? ? k k ? ? ? (18)

When ?? = 0Eqn (17) can be treated for uniaxial tension-tension fatigue loading then the process is classified as elastic-damaging, in which stress-strain curve returns to original conditions upon unloading of the material. In fact, damage incurred in concrete shall not be considered perfectly elastic. The tired unloaded material shows some residual strains due to the development of sizable crack tip process zone at the surface and misfits of the crack surfaces.

At the condition of uniaxial tension, Eqn (18) can be written as( ) ( ) + + + + + ? + ? = ? ? ? ? ? ? ? : E ? 2 0 1 2 : 2 1 : u A u A N exp E AN ? ? ? ? ? ? ? (19)

Where,? 2 1 ? ? = IV.

5 Fatigue Strain Evolution Model

Depending upon the different stress types, three-stage variation law of fatigue evolution model was proposed. Moreover, some valuable physical parameters like initial strain, instability speed of the third stage as a form of acceleration directly proportional to the total fatigue life of concrete. Mathematically, the model could be obtained as below.?? ?? = ?? ?? +? (?? ??? ?? ?? ?? ? ??) ??/??**(20)**

In formula (20), ?? 0 = initial strain and ?? ?? = atigue strain, ?? = cycle times of fatigue loads, ??ð ??”ð ??” = fatigue life. ??, ??, and ?? were damage parameters.

If ?? ?? max or ?? ?? res was interpreted in the form of ?? ?? , formula (20) can be modified. if the initial maximum ?? 0 max or initial residual strain ?? 0 res is regarded as the value of ?? 0 , formula (21 and 22) should be obtained.?? ?????? ?? = ?? ?????? ?? +? (?? ??? ?? ?? ?? ? ??) ??/?? (**21**)?? ð ??”ð ??”ð ??”ð ??”ð ??”ð ??” ?? = ?? ð ??”ð ??”ð ??”ð ??”ð ??”ð ??” ?? +? (?? ??? ?? ?? ?? ? ??) ??/?? (22)

Equation (21) is a formula for maximum strain and equation (22) is the formula for the residual strain.

On the basis of the elastic proportional limit, if the upper limit of fatigue stress is large then fatigue strain increases fastly. The slope of the curve regarding this increment will be large and became vertical that causes the degeneration of the three-stage curve. When the upper limit of fatigue does not exceed the threshold **??**)) / 2 1 : (2 2 1 : 2 0 1 2 u A u A N exp E AN dN dk k ? ? ? ? ? ? ? = = + + + + ? ? ? ? ? ? (17)

strain value, the elastic strain should be added to the initial strain and value became unchanged, shows similarity in curve formulation. By the experiment, it can be shown that the value of most stresses falls in between the value of threshold and upper limit.

Being the maximum and minimum value of stress and strain in fatigue test, two types of the curve regarding maximum strain i.e. ?? 0 max and residual strain i.e. ?? 0 res with respect to the cyclic number are obtained. The main causes for obtaining these two types of the curve are due to defects in materials and preloading conditions also. It is very much difficult to differentiate these two maximum and residual value, so experiment regarding fatigue test is essential.

Therefore, at that condition of fatigue loading reaches to the upper limit then, the corresponding ?? 1 max and residual strain ?? 1 res are obtained and adopted in this paper. For comparison, strain obtained the formula of ?? 1 max and ?? 1 res compared to the actual experimental data i.e. ?? 1 res = 0.25 (?? 1 max /?? unstable) 2 . In this formula, ?? unstable is a total strain of concrete in an unstable state.

For the study of fatigue strain parameters ??, ?? and ??, on the basis of evolution law of fatigue strain curves, divided by fatigue strain in both side of formulas (21) and (**??**2

Formula (**??**3) and (24) are the normalized fatigue strain evolution model. Where, ?? ð ??”ð ??” max = limited maximum fatigue strain and ?? ð ??”ð ??” res = limited fatigue residual strain. ?? = destabilizing factor the value of which depends on ?? and ??. If ??/??ð ??”ð ??” (Circulation ratio) is equal to 1, the coordinate point (1, 1) will be adopted in formulas (23) and (24), thus obtained the values of ?? as formula (25) and 26, which is the maximum fatigue strain and the residual fatigue strain.?? 1 = ? ?1? ?? ?????? ?? ?? ?????? ?? ? ? ? ?? ?????? ?? ? ? ??? + 1 (25) ?? 2 = ? ?1? ?? ð ??”ð ??”ð ??”ð ??”ð ??”ð ??” ?? ?? ð ??”ð ??”ð ??”ð ??”ð ??”ð ??” ?? ? ? ? ?? ð ??”ð ??”ð ??”ð ??”ð ??”ð ??” ?? ? ? ??? + 1(**26)**

From equation (**??**3) impacts of ?? and ?? on the fatigue, strain evolution curve can be calculated. Firstly, the impact of ?? was analyzed i.e. ?? 0 max /?? ð ??”ð ??” max and ??/?? ð ??”ð ??” max . After that, combined with ?? and ?? 0 max /?? ð ??”ð ??” max , the impact of ?? was further calculated. The curve regarding the impact of ?? and ?? were shown in Figures. It is obviously shown that according to the rate of convergence speed of p, influences the convergence speed of curve in S nonlinear model. The third stage of the curve will grow faster when the faster increment of P which is also called instability speed factor. Therefore the factor p should be located in the curve.

The parameter ?? values on the curve shall also affect the curve in the sense of total fatigue life of the material which shall be shown in the third stage of the nonlinear curve. After increasing of ??, the part of acceleration shall become shorter. ??/??ð ??”ð ??”max is located corresponding to (0, 1? ?? 0 max /?? ð ??”ð ??” max), whereas, ?? was placed in the comparison of (0, ?? ð ??”ð ??” max ??? 0 max). The obtained value of the parameters ??, ?? and p are mainly aimed which is found in b-type curves having three stages of evolutions. Therefore, it can be imagined that the values for both type curve are not limited by the literature. By modeling, S-shaped curves contents various parameters including different kinds of fatigue strain evolutions at the different stages for the concrete material.

V.

6 Numerical Examples

The proposed model contains two material parameters, first is A which is a factor related to materials intermolecular microcracks and the second one is ? which is called damage factor related to kinematic phenomena of the particle i.e. crack surface close perfectly after unloading. Damage parameter i.e. k, indicates the reduction in stiffness, is obtained by measuring stiffness at different three stages of the fatigue loading cycle. The kinematic parameter, ?, is obtained by obtaining the permanent deformation during one of the fatigue cyclic loadings. Due to the scarcity of reliable experimental data from the different researches for obtaining the fatigue damage parameters in performing numerical simulation, analyst's judgments to obtain numerical results. Table **??** **??**) are prescribed in this paper for sample calculation which gives the clear idea of fatigue strain behaviour.

The model formulation for obtaining modulus reduction with an increment at t the number of fatigue maximum strain and (**??** 4) and (**??**) shows the increase in damage with increasing loading cycles. The experimental work of Figure [11] is also shown for comparison. Theoretical model which is also shown well captures the similar nature of increment of damage with respect to fatigue cyclic loading as observed in the experiment [11]. For numerical simulation, the following constant were used, A = 0.10 and ?? = 0.15 and 0.00 in two cases, Parameter A is estimated by comparing predicted results and experimental results over a range of applied strains.

Figures (6) and (**??**) depict the theoretical cyclical stress-strain behavior of concrete material in tension. In Figure (6), no permanent deformations are found on the condition of fatigue unloading of concrete material but progressive damage is accumulated in each fatigue loading cycle due to the reduction of elastic modulus. In fact, it is an ideal case for elasticperfectly damaging behavior in damage mechanics which can be obtained by letting ?? = 0with assuming that crack surfaces i.e. microcracks, macrocracks, etc. shall close perfectly upon unloading. As the concrete material is heterogeneous, therefore it falls on permanent deformations after fatigue loading and unloading. Figure **??** shows the versatile behavior of the model where the stiffness degradation and permanent deformation are illustrated simultaneously.

7 b) Ordinary Concrete Fatigue Strain Evolution Model

The model curve regarding maximum fatigue strain and fatigue residual strain under different strain and stress levels using the model formulas (21) to (22) are described in Figures. Coefficients of different damage parameters regarding the evolutionary model are shown in Table **??** The data in the figure for the Strain Family Curve are the average of each group. From Figures (12), (13), (14) and Table of Fatigue Strain evolutionary Model, fatigue strain evolution equations (21) and (**??**2) can be a good fit to the experimental data. Correlation coefficients are above 0.98. The evolution in the sense of fatigue damage parameter regarding maximum fatigue strain and fatigue residual strain has been plotted which clearly shows the similar threephase variation at the different intermediate stage close to the linear change in their behavior. When the cycle ratio is exceeded by 0.90 then the curve converged rapidly. The level-S shaped curve of strain evolution is from the lower left corner to the upper right corner in the plotting of graph. This is due to experimenting measured of initial maximum strain and lacking measurement of initial residual strain, the strain evolution curve regarding maximum strain starts from the initial value, but the strain evolution curve of fatigue residual strain starts from zero. This is due to the defect in the material structure and de-orientation of molecules of the concrete. Based on the Model formation on the basis of (0, ?? ð ??"ð ??" max ??? 0 max). ?? fall in these the prescribed ranges while fitting of the curve is done surrounding its prescribed boundary conditions.

8 Authors' contributions

All authors read and approved the final manuscript.

frequency is presented by utilizing the framework of continuum thermodynamics of Continuum Mechanics by taking two material fatigue damage parameter i.e. A=fatigue damage Parameter regarding energy microcracks of the material particle and another is ?=kinematic damage Parameter (phenomena of material crack surface close perfectly after unloading). For the production of concrete, except cement, all materials are locally available i.e. sand, aggregate, and water. So, it is very much popular in the list of construction material is construction engineering. Concrete is a heterogeneous matrix related to the composition i.e. cement, sand, aggregate and water among them cement is the weakest part compared to the remaining ingredients. So, fatigue damage in concrete in the fatigue process is obviously due to the development of internal micro-cracks, microvoids, macrocracks, a cycle-dependent damage surface is obtained in the formulation of the model. Fatigue damage evolution law regarding functions of damage response were obtained and used in the developing the constitutive relation to demonstrating the capacity for validation of the model for further diagnosis of concrete material, relate to stiffness degradation including inelastic deformations, under tension-tension, tensioncompression fatigue loading by finding out the cumulative fatigue damage parameter i.e. K. The curve regarding fatigue response at A =0.10 and ? =0.15 and 0.00 is calculated firstly by the modeling and after that this generated model curve is compared to the Curve obtained from the experimental data of Peiyin Lu. Et al (2004) which shows similar tread of generation of fatigue curve. This shows the good relationship between VI.

9 Conclusion a) Concrete

10 Fatigue Evoluation Model

Table **??**: Influence of fatigue strain Parameter "P" on Fatigue strain Curve by Putting the value of (i) P=2.00, ?=1.25

(ii) P=3.00, ?=. [1] [2]

[1] Year 2019 E © 2019 Global Journals

[2] © 2019 Global Journals

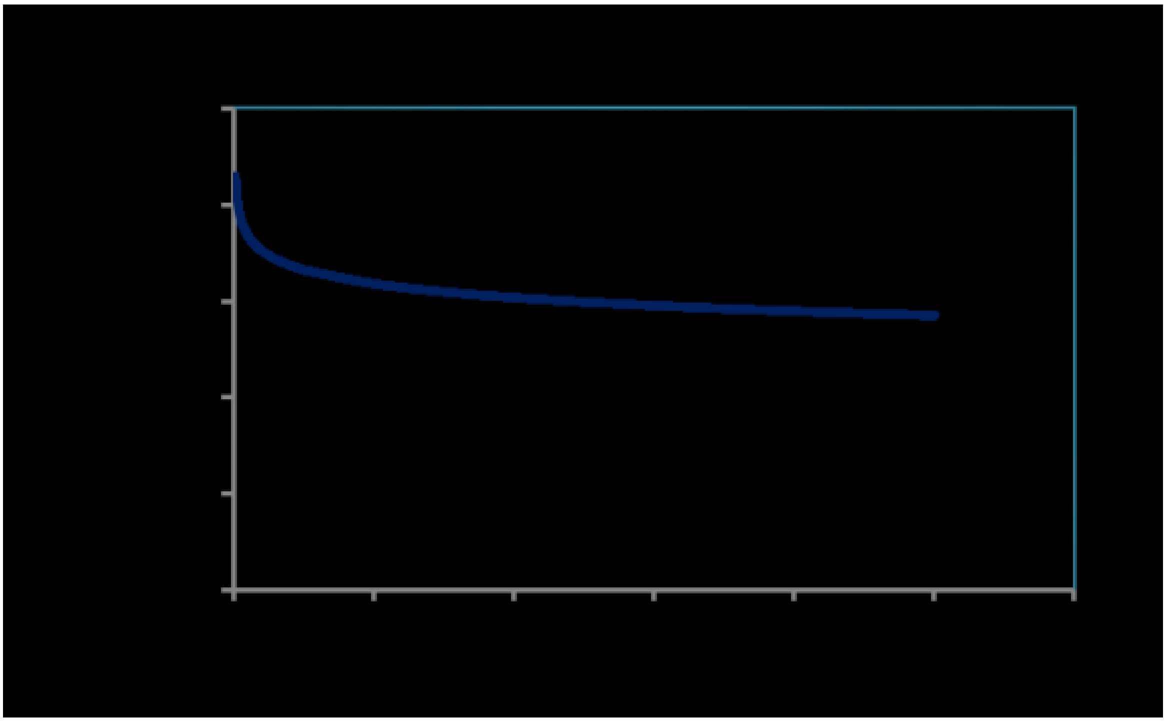


Figure 1: Fatigue

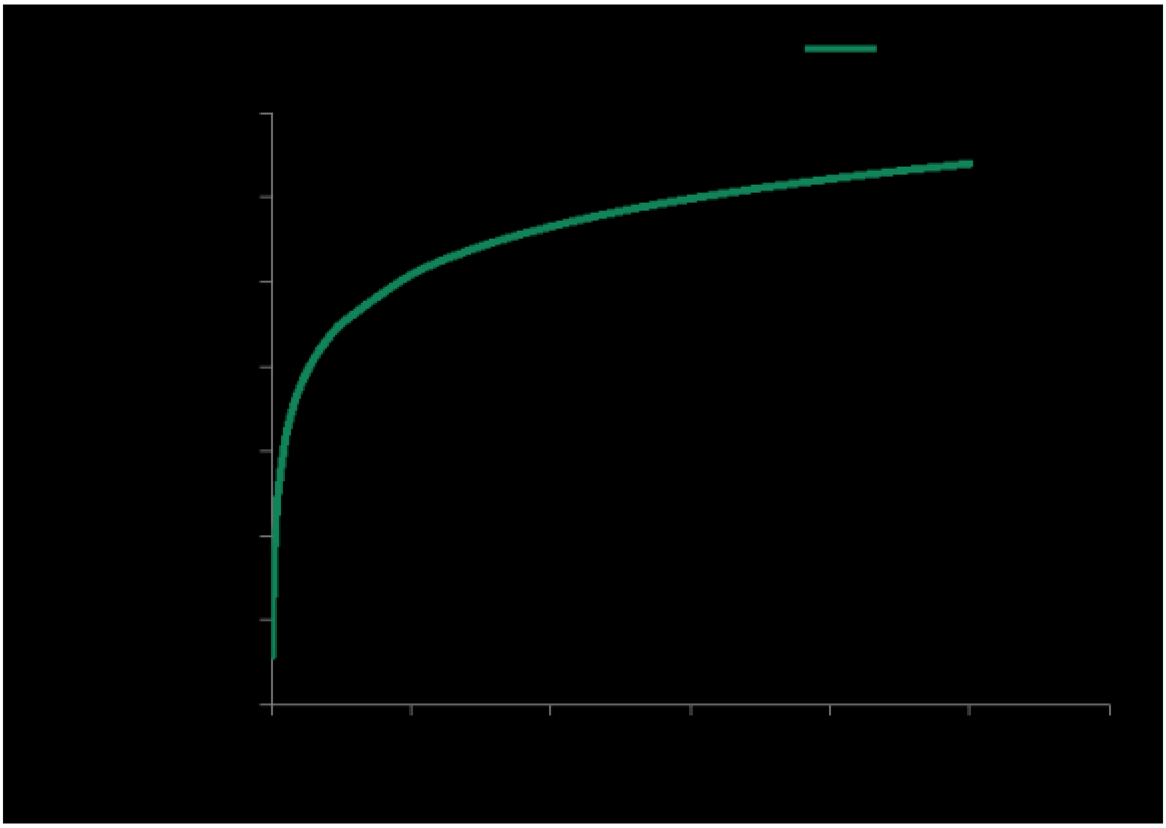


Figure 2:

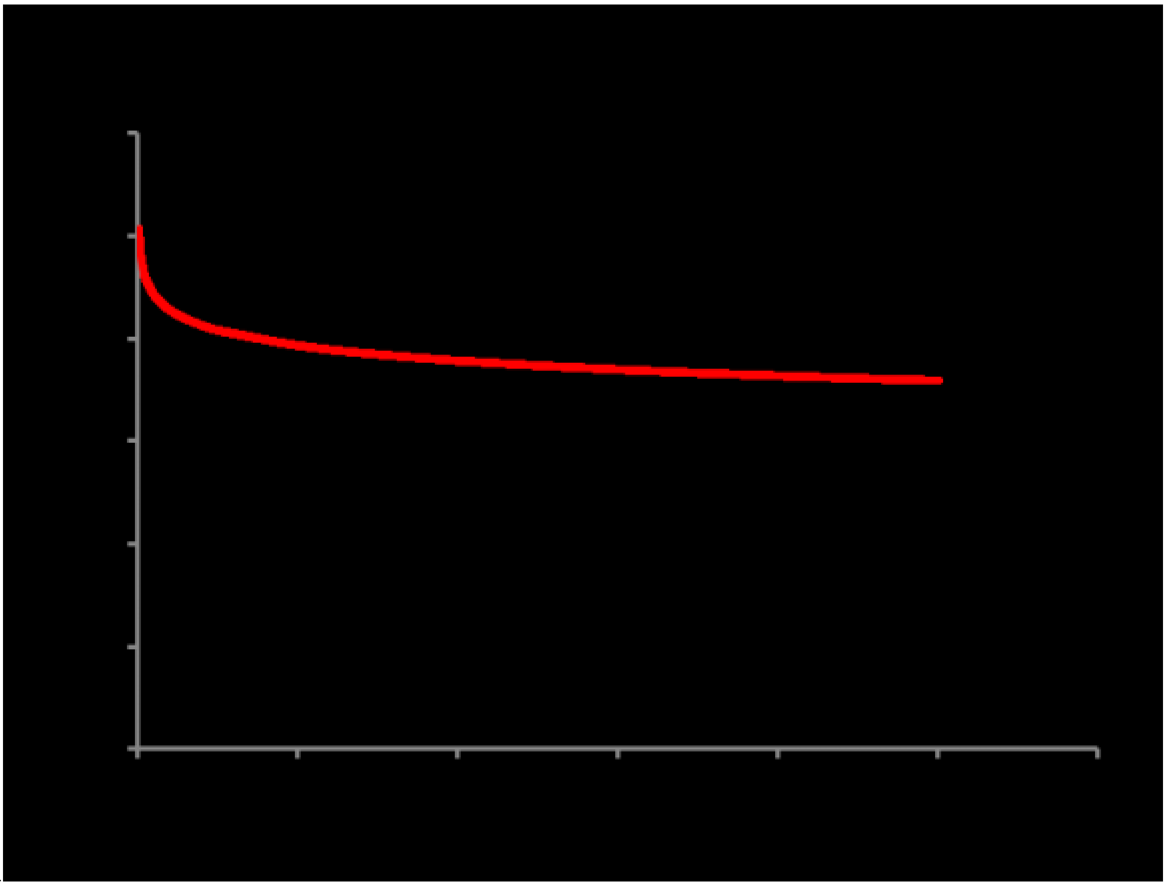
1

Figure 3: Figure 1 :

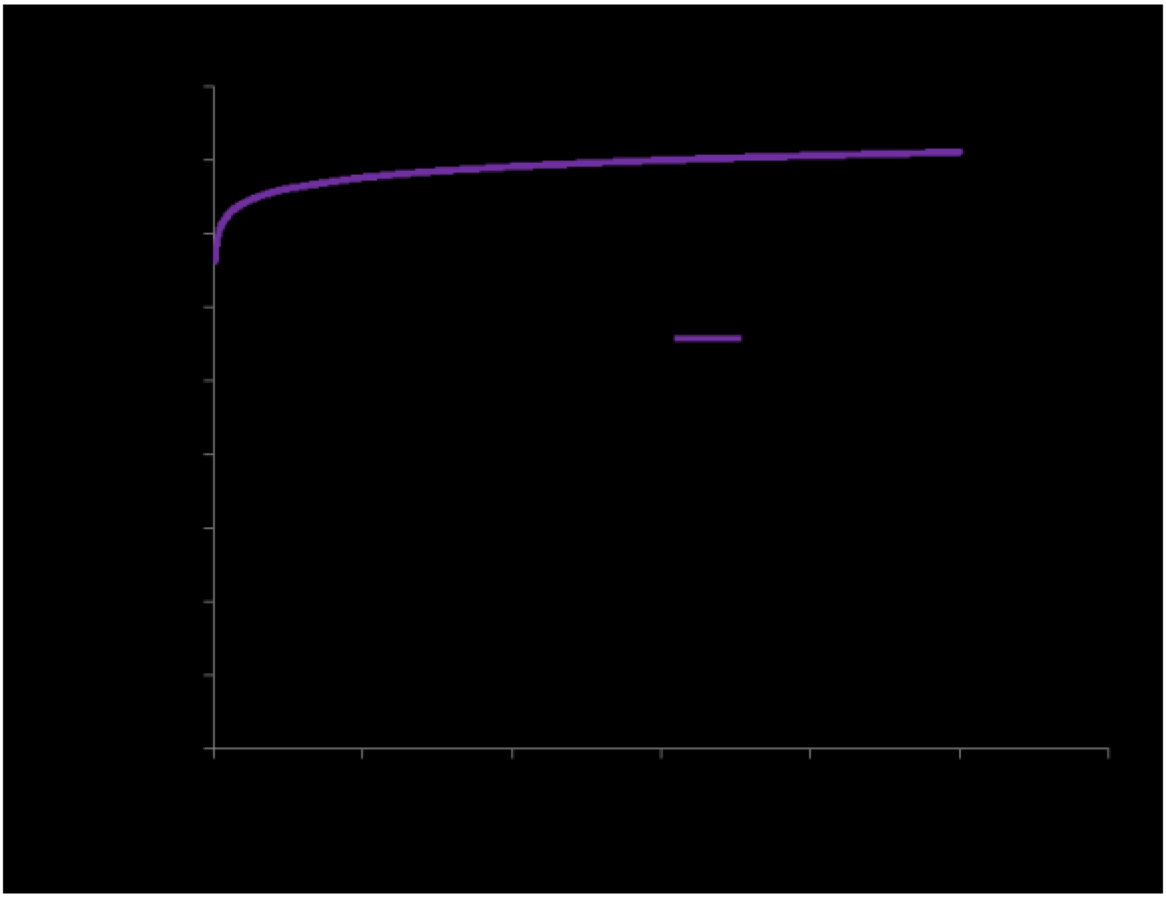


Figure 4: Fatigue

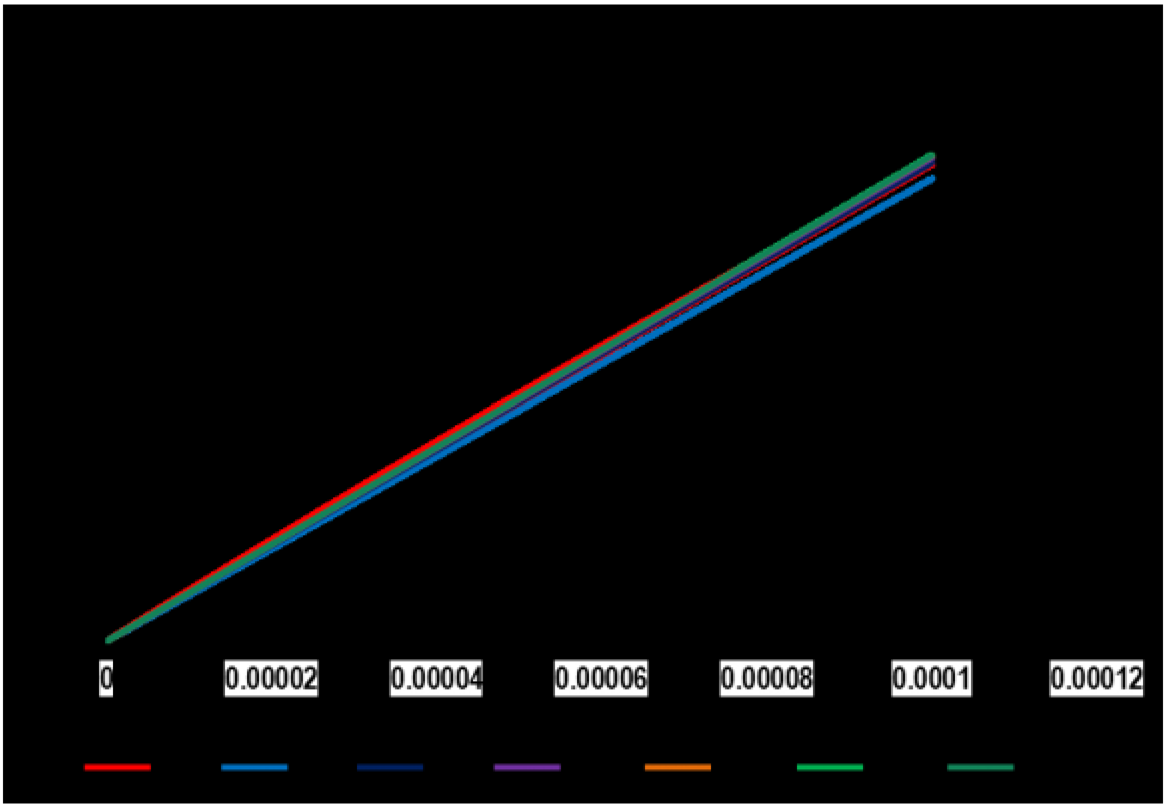


Figure 5: Fatigue

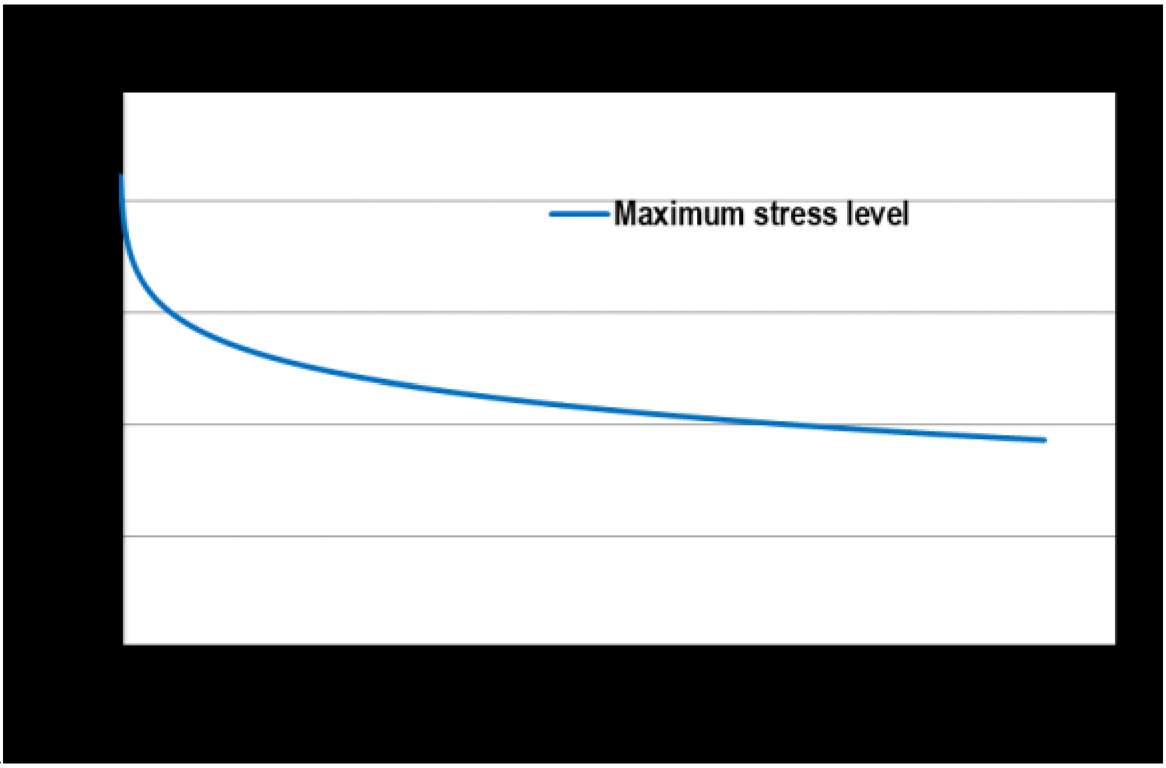
1 

Figure 6: 1)

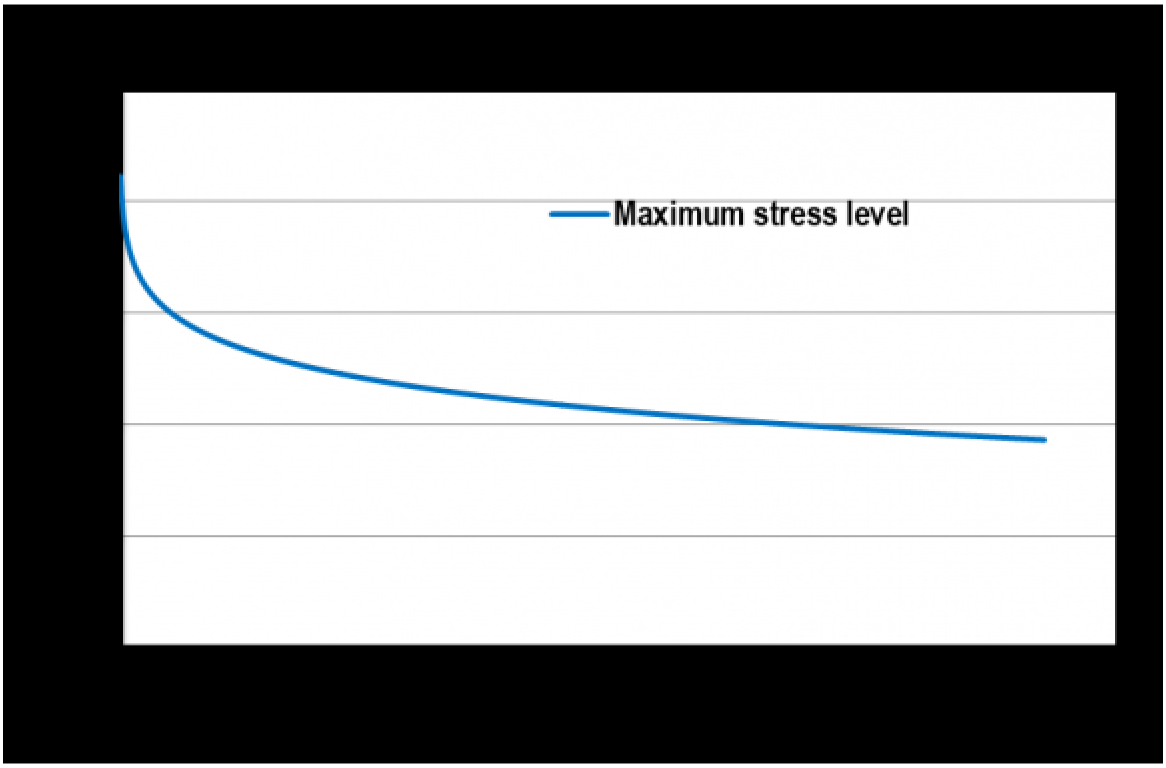


Figure 7:

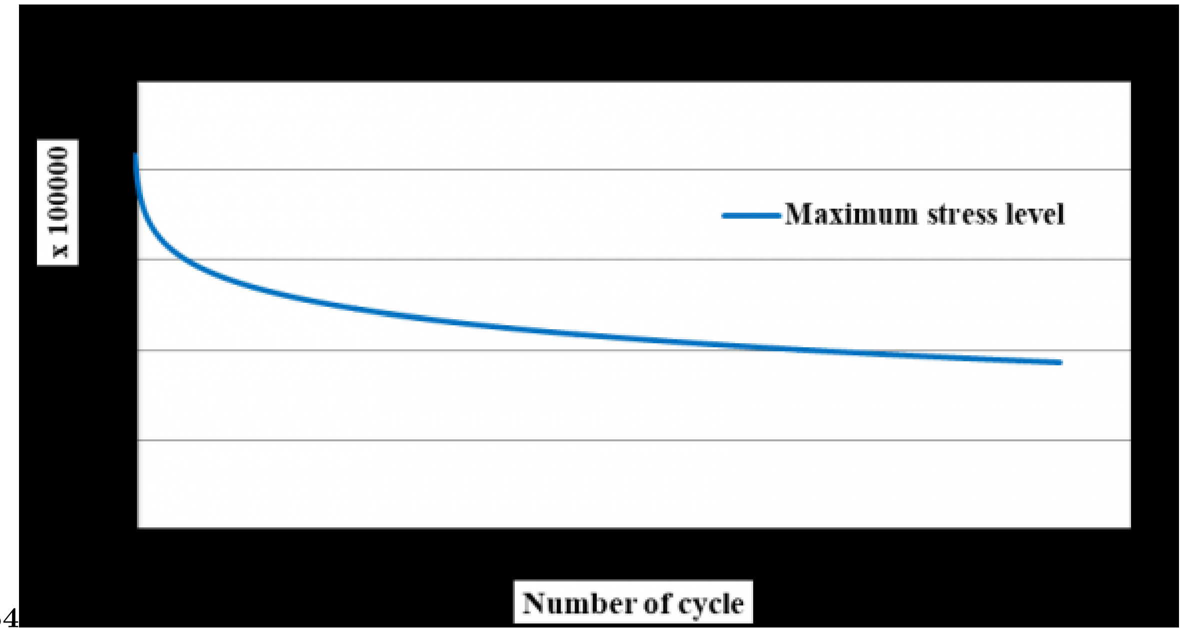
23154 

Figure 8: Figure 2 :Figure 3 . 15 Figure 4 :

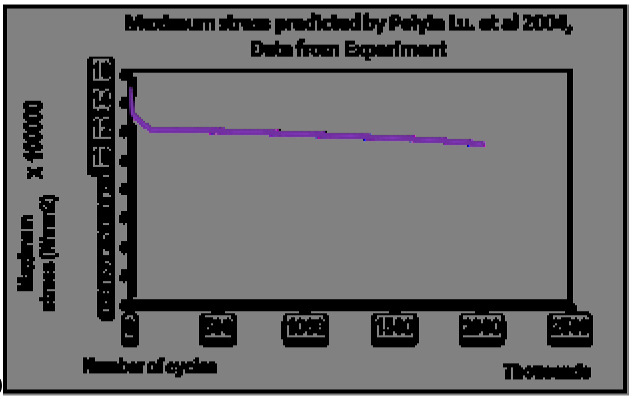
65156789 

Figure 9: Figure (6)Figure 5 : 15 Figure 6 :Figure 7 :Figure 8 :Figure 9 :

10201912201114

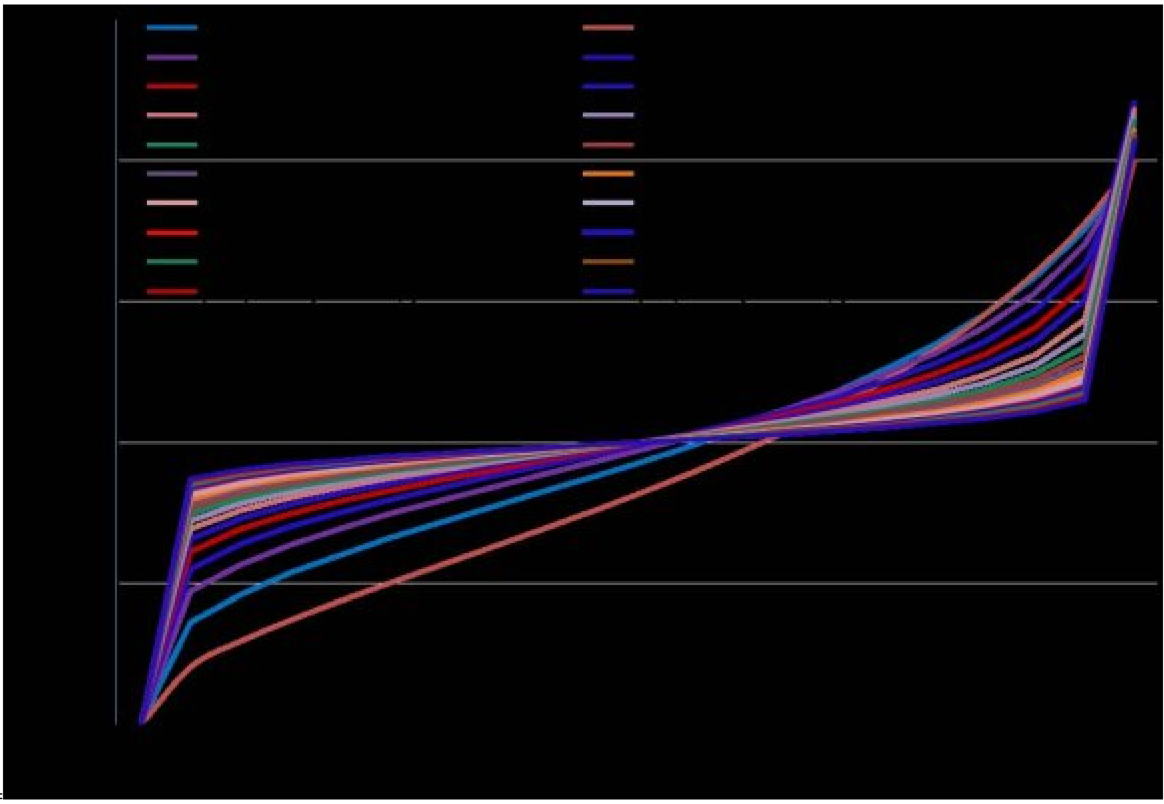


Figure 10: Figure 10 : 2019 EFigure 12 : 20 Figure 11 :Figure 14 :

13

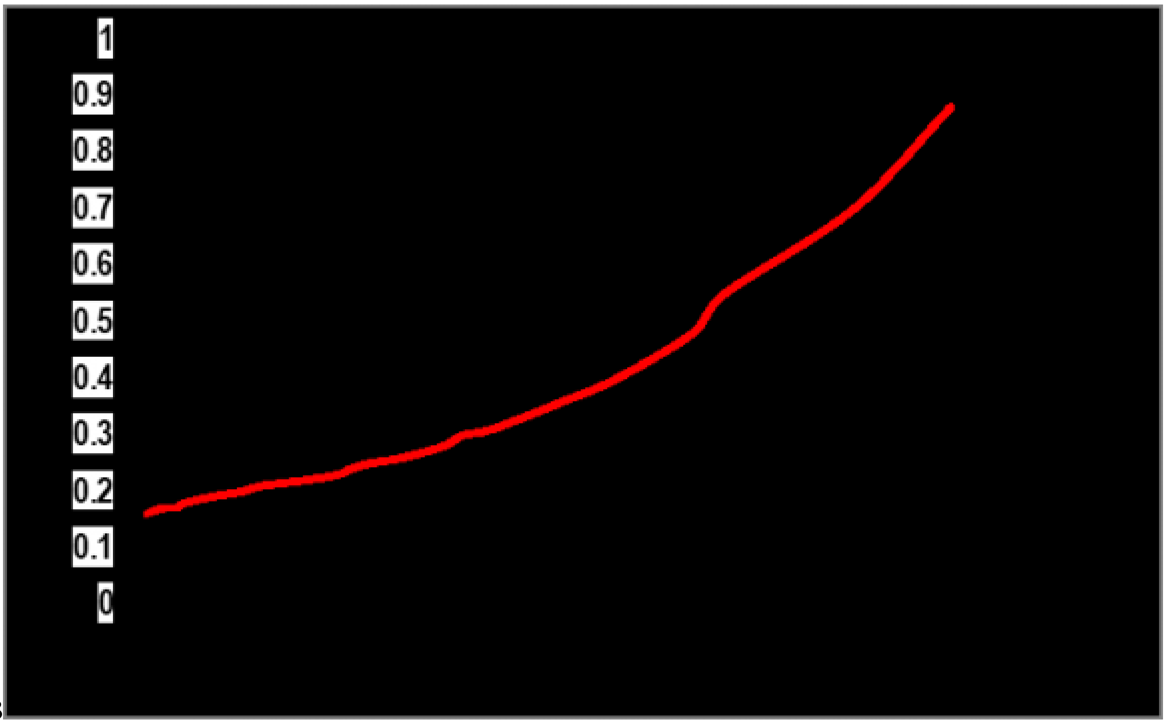


Figure 11: Figure 13 :

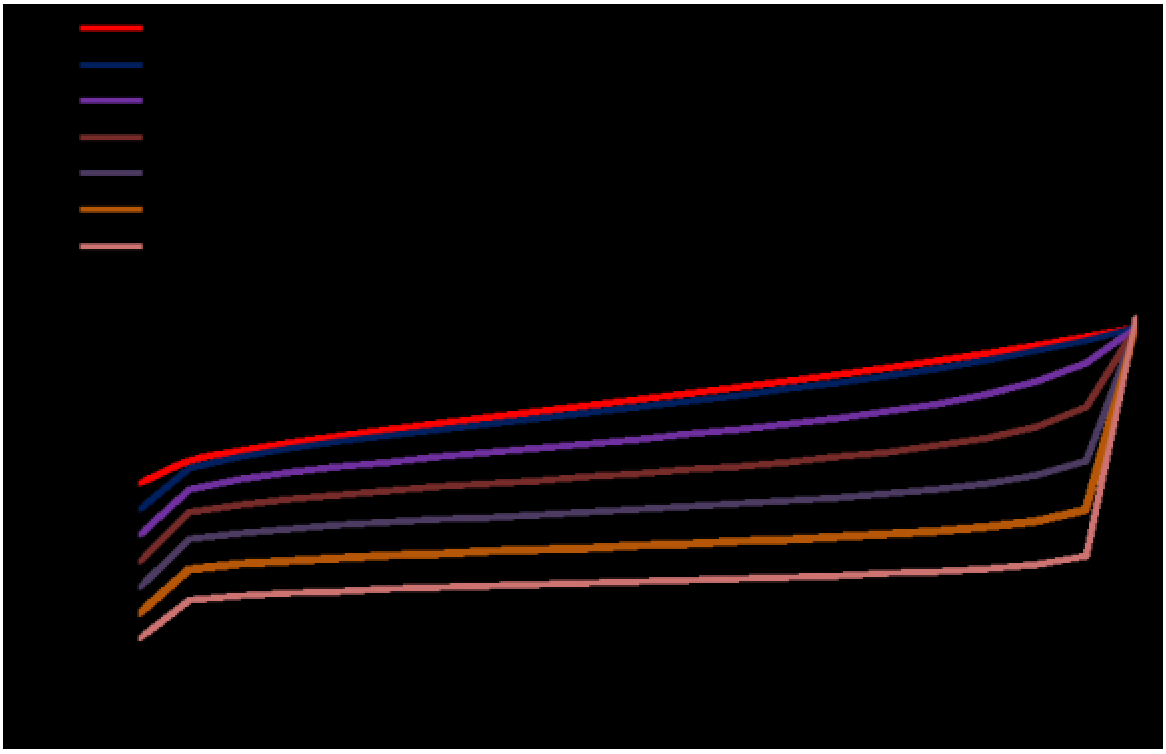


Figure 12:

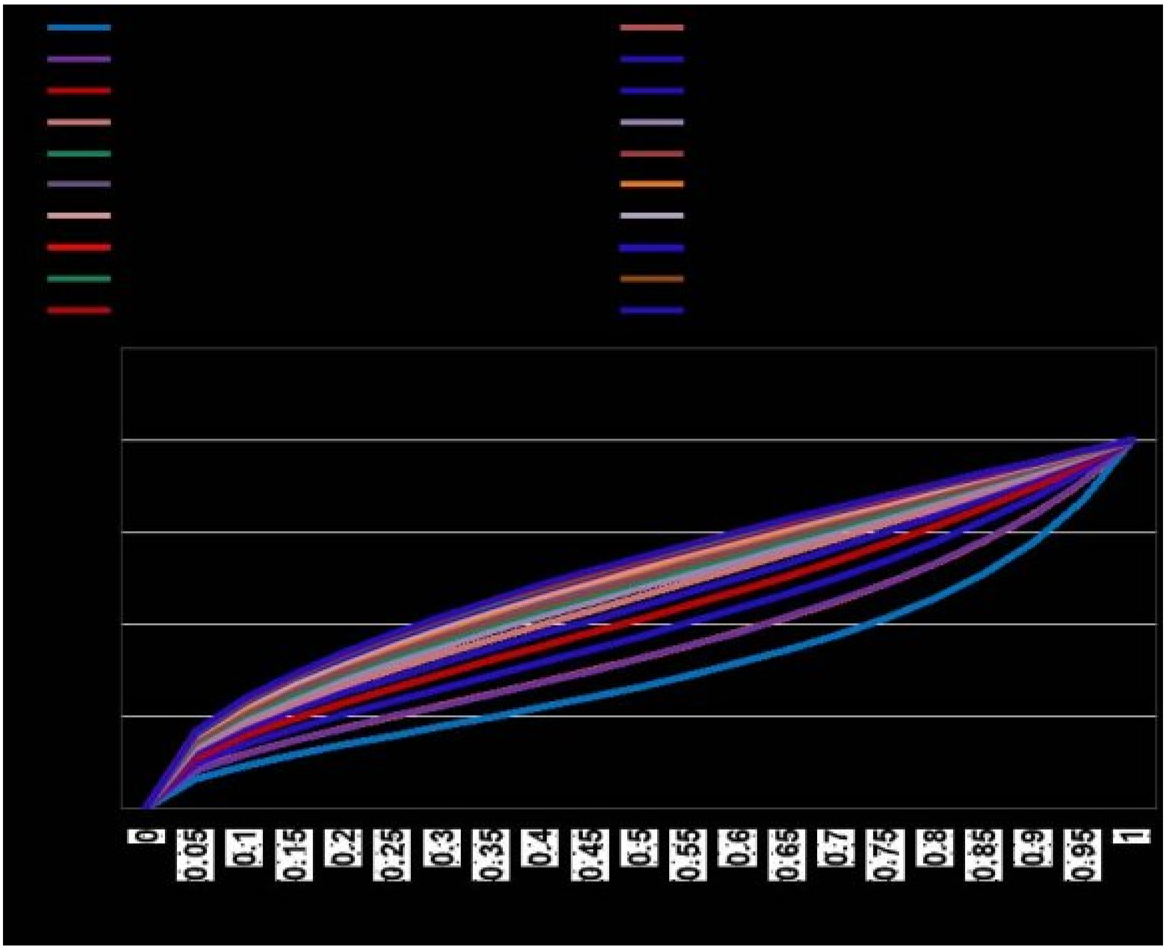


Figure 13:

Figure 14:

1

Smax Assuming , of Concrete No. of Cycle Factor 0.85 1479000 2.2 Max. Stress 158.4893192

		0.84	1461600	2.3 199.5262315
		0.75	1305000	4.1 12589.25412

N (Number of Cycle) Fatigue Damage Parameter (A) Stiffness factor (?) E0 2.34E+10 1E-04 2.718281828 0.367879 8608378923 0.632120559 14791621077 ?u Exp

N (Number of Cycle)	Fatigue Damage Parameter (A)	Stiffness factor (?)	
1 2		0.74 0.69 0.685 0.00	
	0.1	0.00	
	0.1	0.68 0.65 0.63	
3	0.1	0.00	2.34E+10 1E-04 2.876192321 0.347682 8135756372 0.652318104 15264243628
4 5	0.1	0.00	2.34E+10 1E-04 2.920554404 0.342401 8012177404 0.657599256 15387822596 2.34E+10
6 7	0.1	0.00	
8 9	0.1	0.00	
10	0.1	0.00	
20	0.1	0.00	
30	0.1	0.00	
40	0.1	0.00	
50	0.1	0.00	
60	0.1	0.00	
70	0.1	0.00	
80	0.1	0.00	
90	0.1	0.00	
100	0.1	0.00	
200	0.1	0.00	
300	0.1	0.00	
400	0.1	0.00	
500	0.1	0.00	
600	0.1	0.00	
700	0.1	0.00	
800	0.1	0.00	
900	0.1	0.00	
1000	0.1	0.00	
	0.1	0.00	
	0.1	0.00	
	0.1	0.00	

Figure 15: Fatigue Damage Factor related to Surface Energy Microcracks i.e. A= 0.10 and Fatigue Kinematic Damage Factor (Crack Surface closed perfectly after unloading) i.e. ?=0.00

Year 2019 ETable 1 :

3

Figure 16: Table 3 :

4

Fatigue Strain based Approach for Damage Evolution Model of Concrete

n/N f ? 0	max /? f	max	?/? f	ma? p
0	0.6		0.20 1.25 2	
0.05	0.6		0.20 1.25 2 1.041666667	
0.1	0.6 0.6 0.6		0.20 1.25 2 1.086956522 0.20 1.25 2	
0.15				
0.2				
0.25	0.6		0.20 1.25 2	
0.3	0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6 0.6		0.20 1.25 2 1.315789474 0.20 1.25 2	
0.35				
0.4				
0.45				
0.5				
0.55				
0.6				
0.65				
0.7				
0.75				
0.8				
0.85				
0.9				
0.95 1				

Figure 17: Table 4 :

?=1.003906 and ?

n/N	f ? 0 max /? f	max ?/? f	max ?
0	0.6	0.10 1.0625	
0.05	0.6	0.10 1.0625	
0.1	0.6	0.10 1.0625	
0.15	0.6	0.10 1.0625 0.10 1.0625	
0.2	0.6		
0.25	0.6	0.10 1.0625 0.10 1.0625	
0.3	0.6		
0.35	0.6	0.10 1.0625 0.10 1.0625 0.10 1.0625 0.10 1.0625 0.10 1.0625 0.10 1.0625 0.10 1.0625 0	
0.4	0.6		
0.45	0.6		
0.5	0.6		
0.55	0.6		
0.6	0.6		
0.65	0.6		
0.7	0.6		
0.75	0.6		
0.8	0.6		
0.85	0.6	0.10 1.0625 0.10 1.0625 0.10 1.0625 0.10 1.0625	
0.9	0.6		
0.95	0.6		
1	0.6		

[Note: EFatigue Evolution Model]

Figure 18:

6

max =0.10, ?=

Figure 19: Table 6 :

7

max=0.10 to 1.05, ?= 1.05 and ? 0 max /? f max =0.60 and P=2

Figure 20: Table 7 :

8

0	max /?	f	max	=0.70,P=2.00, ?/?	f	max	=0.25, ?=1.694444	=0

Figure 21: Table 8 :

.1 Acknowledgments

The authors gratefully acknowledge the Tribhuvan University, Institute of Engineering, Department of Civil Engineering, Pulchowk Campus, IOE, Dean Office, CARD Section and NTNU Norway for their invaluable contributions and financial support as a scholarship to this research. The authors also acknowledge the assistance received from NTNU, Norway through CARD Section of IOE, Pulchowk Campus, Tribhuvan University.

.2 Competing interests

The authors declare that they have no competing interests.

.3 Availability of data and materials

Not

[J. Chem. Phys] , *J. Chem. Phys* 47 (2) p. .

[Coleman and Gurtin ()] , B D Coleman , M E Gurtin . 1967.

[Yang et al. ()] 'A Bounding Surface Plasticity Model for Concrete, Proc. Paper 19539'. B L Yang , Y F Dafalias , L R Herrmann . ASCE 111/EM3. *J. Engg. Mech* 1985. p. .

[Papa ()] 'A Damage Model for Concrete Subjected to Fatigue Loading'. E Papa . *Eur. J. Mech.-A/solids* 1993. 12 (3) p. .

[Thapa and Yazdani ()] 'A Strain-Based Damage Mechanics Model for Plain Concrete'. K B Thapa , S Yazdani . *International Journal of Civil Engineering Research* 2014. 5 (1) p. .

[Khan et al. (1998)] 'An Elasto-Damage Constitutive Model for High Strength Concrete'. K R Khan , A H Al-Gandhi , M Baluch . *Proceeding of the EURO-C 1998 Conference on the computational model of the concrete structure at Austria*, (eeding of the EURO-C 1998 Conference on the computational model of the concrete structure at Austria) 1998. March. p. .

[Chaboche ()] J L Chaboche . *Damage Induced Anisotropy: On the Difficulties Associated with the*, 1992.

[Thapa and Yazdani ()] 'Combined Damage and Plasticity Approach for Modeling Brittle Materials with Application to Concrete'. K B Thapa , S Yazdani . *International Journal of Civil and Structural Engineering* 2013. 3 (3) p. .

[Edward et al. ()] *Concrete construction*, S H Edward , P G David , S Edward , Ltd Hoffman , Chicago . 2009.

[Gambhir ()] *Concrete Technology*, M L Gambhir . 2005. New Delhi: Tata McGraw-Hill Publishing Company Limited. (Third edition)

[Shetty ()] 'Concrete technology: Theory and practice'. M S Shetty . *S. Chand & Company* 2005.

[Rao and Roesler (2004)] 'Cumulative Fatigue Damage Analysis of Concrete Pavement using Accelerated Pavement Testing Results'. S Rao , J Roesler . *Proceedings of the 2nd International Conference on Accelerated Pavement Testing*, (the 2nd International Conference on Accelerated Pavement TestingMinneapolis) 2004. Sep.

[L???p et al. ()] 'Damage Constitutive of Concrete under Uniaxial Alternate Tension-Compression Fatigue Loading Based on Double Bounding Surfaces'. L???p , Q Li , Y Song . *International Journal of Solids and Structures* 2004. 41 p. .

[Sauris et al. ()] 'Damage Model for Cyclic Loading for Concrete'. W Sauris , C Ouyang , V M Fernando . *J. Engg. Mech., ASCE* 1990. 116 (5) p. .

[Dyduch et al. ()] 'Experimental Investigation of the Fatigue Strength of Plain Concrete under High Compressive Loading'. K Dyduch , M M Szerszen , J-F Destrebecq . *Structures and Materials* 1994. 27 (173) p. .

[Cachim et al. ()] 'Fatigue behavior of fiber-reinforced concrete in compression'. P B Cachim , J A Figueiras , P A A Pereira . *Cement &Concrete Composites* 2002. 24 (2) p. .

[Szerszen ()] 'Fatigue damage model for ordinary concrete'. M M Szerszen . *Open Journal of Functional Material Research (OJFMR)* 2013. 1 (2) p. .

[Chen et al. ()] 'Fatigue defect of layer steel fiber reinforced concrete'. Y B Chen , Z N Lu , D Huang . *Journal of Wuhan University of Technology (Natural Science Edition)* 2003. 18 (1) p. .

[Fatigue of Normal Weight Concrete and Lightweight Concrete, Document European Union -BriteEURamIII ()] 'Fatigue of Normal Weight Concrete and Lightweight Concrete, Document'. BE 96-3942/R34. *European Union -BriteEURamIII* 2000.

[Xie et al. ()] 'Investigation flexural fatigue behavior of steel fiber reinforced concrete for pavement surface stratum under cyclic load'. J B Xie , T C He , H R Cheng . *Journal of Lanzhou University of Technology* 2004. 30 (2) p. .

[Fardis et al. ()] 'Monotonic and Cyclic Constitutive Law for Concrete'. M N Fardis , B Alibi , J L Tassoulas . *J. Engrg, ASCE* 1983. 108 (2) p. .

[Duggal ()] *New Age International*, S K Duggal . 2009. New Delhi, India. (Building materials)

[Neville ()] *Properties of concrete*, A M Neville . 2011. Harlow, England. The UK: Pearson Publications. (Fifth edition)

[Wang et al. ()] 'Research on compression fatigue performance of concrete'. R M Wang , G F Zhao , Y P Song . *China Civil Engineering Journal* 1991. 24 (4) p. .

[Thermodynamics with International State Variables] *Thermodynamics with International State Variables*,

[Smith and Young ()] 'Ultimate Theory in Flexure by Exponential Function'. G M Smith , L E Young . *Proceedings of the American Concrete Institute*, (the American Concrete Institute) 1955. 52 p. .