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Highlights

- Compressive-Strength Dispersion
- Recycled Aggregate Self-Compacting
- Metallurgical Coke Production
- Strategies for the Reconstruction

Discovering Thoughts, Inventing Future

VOLUME 21 ISSUE 2 VERSION 1.0

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Analysis of the Influence of Biomass Addition in Coal Mixture for Metallurgical Coke Production

By Alex M. A. Campos & Paulo S. Assis

Abstract- Metallurgical coke is a common material used for hot metal production in blast furnaces. In addition to the fuel function, it has a physical assignment, supporting the load inside the reactor, and chemical, supplying carbon to hot metal. However, due to growing discourse on environmental issues, the production of hot metal via coke blast furnace has been in evidence. This process is responsible for about 70% of CO_2 emissions in steelmaking. On the other hand, biomasses are materials that are available in different ways in nature and considered neutral in CO_2 emissions since they absorb this gas and release oxygen in the photosynthesis process. Thus, a viable alternative in the short term is the partial replacement of the coal used in coke production with biomass, which would generate environmental gains, and guarantee the sustainable production. Therefore, this work aims to show several published researches using biomass in coke production. The effects that biomass has on the properties of coke will be emphasized, and at the end, an environmental analysis will be shown with the possible use of biomass. It will be possible to see that it is possible to substitute between 2 and 10% of the coal for biomass, producing coke with the characteristics required in the blast furnace.

Keywords: *biomass; coke; cokemaking; ironmaking; steelmaking.*

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Keywords: biomass; coke; cokemaking; ironmaking; steelmaking.

I. Introduction

Steelmaking processes have a high-energy consumption and coal is the main source, and steel production has been responsible for 7–9% of CO_2 emissions in recent years, largely due to the use of fossil fuels. To produce 1.85 t of steelis emitted around 3.3 t of CO_2, which puts the steel sector in the spotlight of the environmental discussion (Holappa, 2020).

In the steel industry, the process that emits more CO_2 is the blast furnace (about 70%) due to the high consumption of fossil fuels, including coke (Orth, 2007). For this reason, efforts to reduce CO_2 emissions must focus on the blast furnace, with solutions to minimize the effects of burning coke and coal. In addition, coke, as well as coal, represents about 40% of the final cost of steel, which makes producers look for sustainable alternatives to compose the coke mixture.

For Noldin (2005), the inevitable dependence on the use of metallurgical coke puts conventional blast furnaces in a difficult situation, due to environmental restrictions and to the global scarcity and exorbitant prices of this raw material. This new scenario of shortages and high coke prices was created by the huge demand for steel in China, which is the largest coke exporter.

One of the alternatives that has been studied, mainly to mitigate environmental impacts, is the replacement of part of coal used in coke making by biomass. Thus, there would be a reduction in CO_2 emissions, since biomass can be considered neutral in emissions as it captures this from the atmosphere during photosynthesis process. In addition, the photosynthesis can generate a drop in the cost of steel production, since the price difference between coal and biomass can be considerable.

Biomass is all vegetable or animal organic matter that is used in the production of energy. Like other renewable sources, biomass can be considered neutral in CO_2 emissions. Compared to fossil fuels, biomass has a higher volatile content, less carbon and a lower calorific value, lower sulfur content, lower ash content, higher hydrogen content, and may be interesting for its use in the steel industry. For Quan (2016), compared to plastic and other waste, biomass is a source of perspective for the replacement of fossil fuels in the future, as it is abundant, renewable, clean, and carbon neutral.

The great gain in substituting part of coal for biomass in metallurgical coke production is in the environmental. What makes biomass neutral in CO_2 emissions is the so-called carbon cycle. Burning biomass causes the release of CO_2 into the atmosphere. However, plants, through photosynthesis, transform CO_2 and water into carbohydrates, which make up their living mass, releasing oxygen. Thus, the use of biomass, not in a predatory way, does not change the average composition of the atmosphere over time (Silva, 2008). In this approach, the GGE balance is negative, which means that the overall sequestration of CO_2 from the atmosphere for the cultivation of biomass is greater than the CO_2 emissions during the production process. In addition, the low sulfur content in biomass results in very low emissions of SOx. This can result in the use of biomass to supply the energy and reducers necessary for the production of hot metal, guaranteeing an ecologically correct operation.

Studies involving the use of biomass in steelmaking processes have been gaining strength due to the factors mentioned. Particularly in the cokemaking, most studies involve charcoal fines or wood residues such as sawdust and bark. All studies in this line show

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that when adding biomass to coal mixture for coke production, there is a drop in coke quality. However, there are results that, in a certain limit, are viable and can bring economic and environmental gains without considerable loss of coke quality.

In view of these facts, this work aims to discuss the use of biomass, replacing fossil fuels, in coal mixtures used in cokemaking for metallurgical coke production. The use of biomass in the coke oven will be shown, presenting some works that have been developed around the world and making a critical analysis, pointing out the pros and cons of this use. Some environmental aspects of the use of biomass will also be discussed. Finally, some suggestions will be given for future work on the use of biomass in steelmaking processes.

II. Development

In the development of this work, some important concepts about coke, its production, about biomass, and its application in the production of metallurgical coke will be shown. At the end, an environmental analysis, an actualization of political discourses, and simulation of possible scenarios that can be reached by steel companies will be made.

a) Coke Production

The coke production process was developed in England in the late 16th century, and at first, the coke produced was not used in hot metal production, that was basically produced in charcoal blast furnaces. After the industrial revolution, coke became an essential fuel for hot metal and steel production, increasing the productivity of blast furnaces (Ricketts, 2000).

Metallurgical coke is produced through coal distillation at temperatures of approximately 1000ºC. This process is called cokeification, and occurs in batteries containing retorts (long, high and strict) in the case of By-product coke ovens or in chambers when the Heat Recovery coke oven is used (Mourão, 2011).

The coke produced must have high resistance properties to avoid degradation insides blast furnace, as well as containing high carbon content, low reactivity, low ash, and sulfur content.

Steelmakers have the coke oven integrated into the steelmaking plant, but there are also independent producers whose main customers are steelmakers. In coke plants, 1000kg of coal produce around (AISE, 1999):

- 750kg of coke (690kg of blast furnace coke, and 60kg of coke breeze);
- 36kg of tar (which includes: 2.5kg of naphthalene, 15kg of light oils, and 18.5kg of tar);
- 7.28kg of total benzol (comprising: 5.35kg of benzene, 1.25kg of toluene, and 0.68kg of xylene);
- 12kg of ammonium sulfate.

World steel production in 2019 was about 1.6 billion tonnes, most of this production is via coke blast furnace, that is, a large production is required to serve steel mills. As can be seen in figure 1, world coke production in 2018 reached 629 million tons.

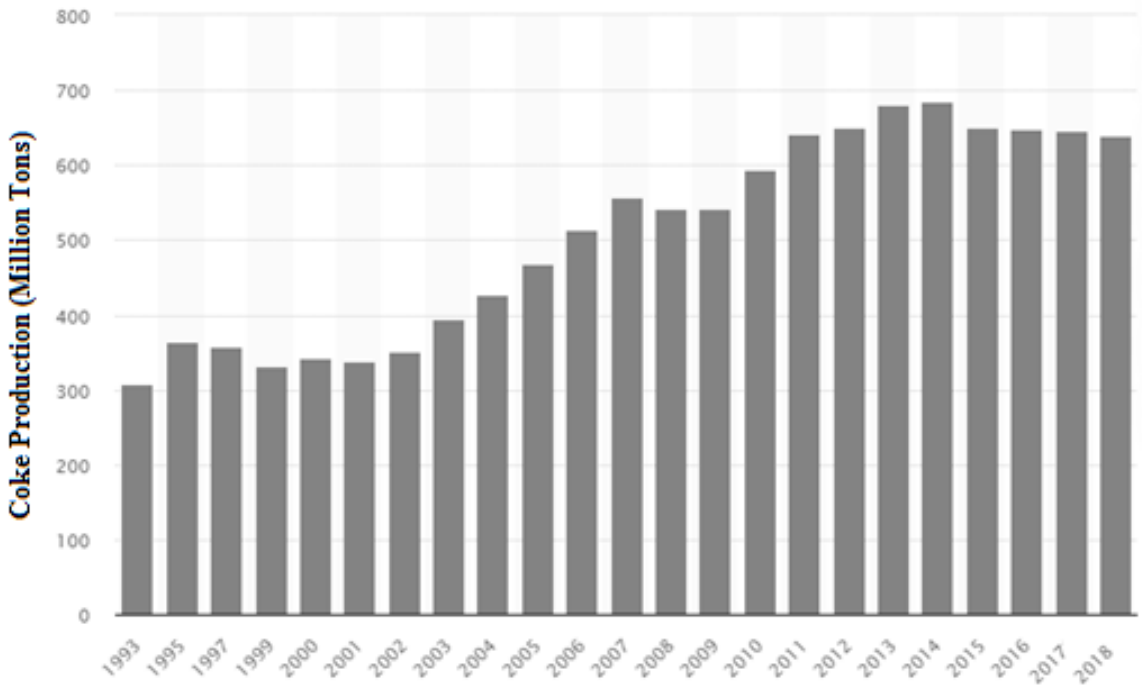

Figure 1: World Coke Production (Garside, 20019)

In the blast furnace, coke has some main functions, including:

- Acts as a generator of reducing gases: its gasification generates reducing gases that are responsible for changing iron oxides to metallic iron.
- Acts as a combustible material: as coke burning reactions are exothermic, they generate heat for reactions to reduce oxides and fuse metallic iron.
- Enriching hot metal carbon content, acting as hot metal fuel.
- And finally, it supports the layers of metallic charge, thus allowing permeable beds to be generated for the passage of upward gases.

To perform the functions listed in the blast furnace, coke must present (Rizzo, 2009):

– Maximum carbon content and minimum ash, sulfur, and moisture content.
– Adequate reactivity values for CO_2 and H_2O.
– Particle size range, when loaded in the blast furnace, suitable and controlled.
– Good resistance to mechanical, thermal, and chemical degradation.

Some quality parameters are necessary to analyze the quality of coke in the blast furnace, including the chemical, physical and metallurgical porperties. Table 1 shows expected values for coke according to each property.

Table 1: Coke properties for blast furnace uses (Rizzo, 2009)

Properties	Coke Quality
Moisture	< 6,0%
Fixed Carbon	65-75%
Ash	< 10,5%
Volatiles	< 1,2%
Sulfur	< 07%
Phosphor	< 0,045%
Alkalis	< 0,35%
Density	180-350 kg/m^3
Drum Index (150/15)	> 85%
CSR	> 65,5%
CRI	21 a 25,5%
Compression Strength	130-160 kgf/cm^3
Particle Size	45-60 mm

These variables presented will affect the operational control of the blast furnace, the permeability of the load, iron ore reduction reactions, and characteristics of hot metal produced. Many tests are done with coke before being used in a blast furnace. The most important ones are CRI (Coke Reactivity index), CSR (Coke Strength after Reaction), DI (Drum Index), average size, compression resistance, among others. In addition, it is important to characterization the materials that will compose the mixtures, so that it is possible to predict the coke quality.

b) Biomasses

Biomass can be defined as the total mass of organic substances that occur in a habitat. The forms of biomass on our planet are many, and varied. According to their origin, biomasses are divided into four basic categories defined by Rocha (2011) as:

- Crops for energy production - grown mainly to generate energy;
- Post-harvest waste - waste generated during harvest such as straw, wood waste and natural waste. They are interesting because they have low cost.
- Organic by-products - are residues from the industrial processing of biomass, livestock manure, vegetable fibers, etc.;
- Organic waste - includes sewage effluents, domestic, commercial, and industrial waste.

To use biomass in the steelmaking process, the most interesting categories are harvest for energy, in the case of charcoal, and the post-harvest residues, which are the types of biomass considered in this work. The amount of waste after harvest can reach 50% of production by weight, and in some cases, such as coffee and soy. Table 2 shows the production of crops in 2019, according to the Food and Agricultural Organization of the United Nations (FAO), and the calculation of possible quantities of post-harvest waste generated according to Carvalho (1992).

Table 2: World biomass production (FAO, 2019)

Biomasses	Production (10^3 t)	Residues* (10^3 t)
Sugar cane	1.949.310,1	633.525,8
Soya	333.671,7	166.835,5
Maize	1.148.487,3	492.701,1
Coffee	10.035,6	5.017,8
Rice	755.473,8	151.094,8

*Calculated according to CARVALHO, 1992.

The use of biomass is the oldest method for providing energy. However, the use of biomass as a renewable energy source must undergo a development of technology. In addition to the positive environmental effects of using biomass as a fuel, it can be said that greenhouse gases are emitted during their burning, but the amount is the same produced by the natural decomposition process. In addition, in the case of plant biomass, during its growth, carbon dioxide is consumed during photosynthesis, which can generate a positive balance when analyzing the emission (Campos, 2018).

In photosynthesis process CO_2 capture from the atmosphere is reduced to organic compounds, and the

more the phytosystem is growing, the more carbon it removes from the atmosphere, calling "carbon sequestration". In growing ecosystems, such as soybean, cotton, and castor plantations, among others, the removal of carbon dioxide from the air via photosynthesis is high, reaching up to 35t CO_2 / hectare (EMBRAPA, 2007).

In addition to chemical properties, biomasses differ in their physical properties like lower density, and greater porosity. To analyze economic aspects, is necessary evaluate two restrictions. First, it is necessary to know whether the biomass to be exploited energetically has no other uses (industrial or food). Second, if all the costs of the biomass harvested are compatible with the energy benefits and comparable with other fuels. Finally, technological restrictions are due to the existence or not of reliable processes and operations to convert biomass into fuels.

c) *Influence of Biomass Addition in Coal mixtures for Cokemaking*

The use of biomass in the industrial sector has been gaining ground for presenting unique properties such as renewability, carbon neutrality, low sulfur content, low ash content, high reactivity, among others, which, when properly treated, are able to replace fossil fuel in the production of coke, for example (Mousa, 2016). For the steel industry, it is not advantageous to use biomass in its raw state, and therefore, it is necessary to convert them through processes such as torrefaction, pyrolysis, combustion, etc.

Biomass, according to Babich (2019), can be used in steel mills in three different ways, such as injection into blast furnaces or electric arc furnaces, incorporation into cargo materials or into the mixture of coal for coke or generation of reducing gas.

Silva (2008) performed an analysis of biomass in coal mixture using a pilot furnace with concentrations of 2%, 4%, and 6% with different types of biomass such as rice husk, soy, coconut, macadamia husk, coffee husk, and charcoal. The biomasses with concentrations of 6%, presented a good behavior due to their presence does not alter the swelling index and to reduce the sulfur content and its fluidity.

The calcined rice husk with a 6% concentration was used in an industrial test. Its addition to the coal mixture increased the average size of the coke, without changing its mechanical resistance. In figure 2, it is possible to observe a comparison of the data obtained on the industrial scale compared to the standard coke produced. It is possible to notice that there were no changes in the DI, its reactivity was maintained and the ash content had an increase due to the presence of silicon oxides in the rice husk.

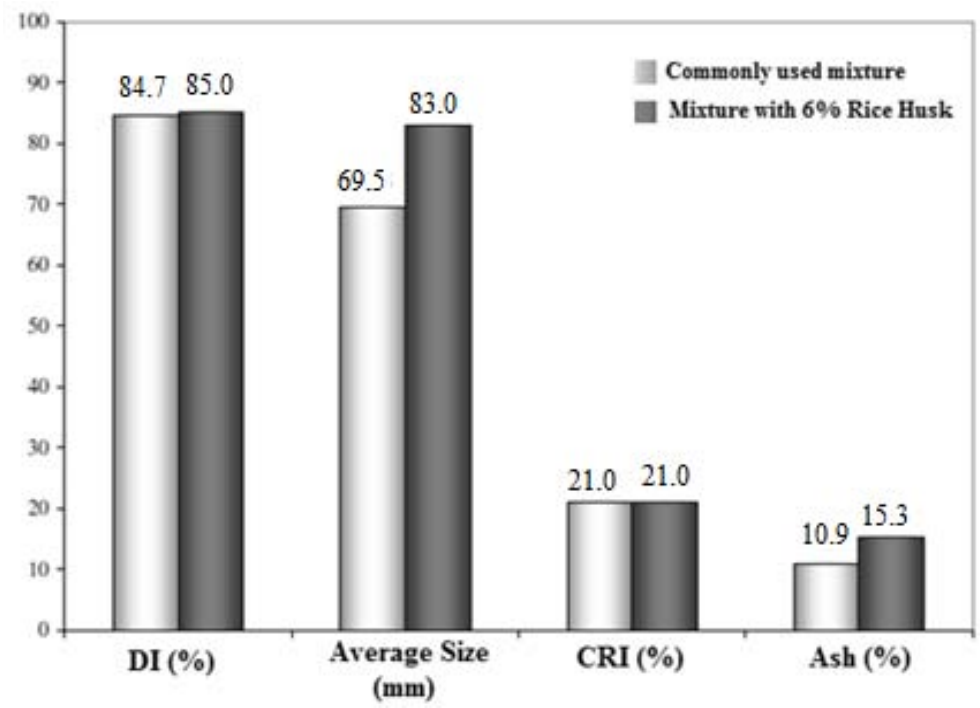

Figure 2: Industrial test of the use of 6% rice husk in the coke mixture (Silva, 2008)

A drop in the mechanical resistance of the coke was observed when adding biomass. The Main effects, and interaction analyzes between the addition of biomass and granulometry factors allows to conclude that the coarse grinder aggravates the drop in DI in relation to biomass with smaller particle size for the same level of addition. In figure 3 is possible to see a research using charcoal with different particle sizes.

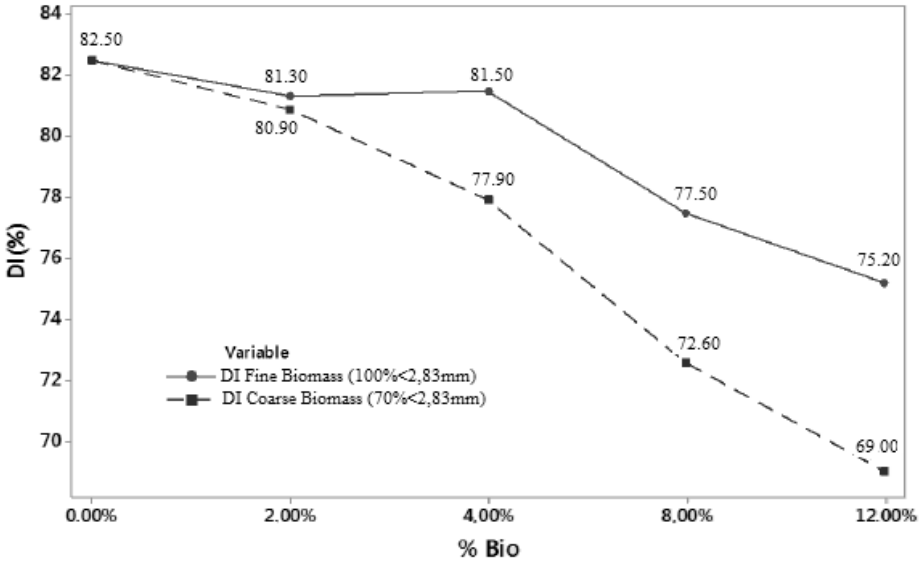

Figure 3: Evolution of DI with the addition of biomass (Silva, 2016a)

The drop in DI can be attributed to the increase in the inert content of the mixture, decreasing its coking power. According to Kubota (2008), the greater participation of aggregates above 1.5mm increases the concentration and propagation of cracks, depreciating the mechanical resistance of the coke.

Carvalho (2021) found an inverse and direct relationship between biomass participation in CSR and CRI, respectively. In figure 4, it is possible to notice that the addition of 2% of sawdust generated a drop of 3.9 % in the CSR and an increase of 0.63 % in CRI. In the addition of 5%, there was a significant drop of 12.29 % in CSR and an increase of 2.54 % in CRI.

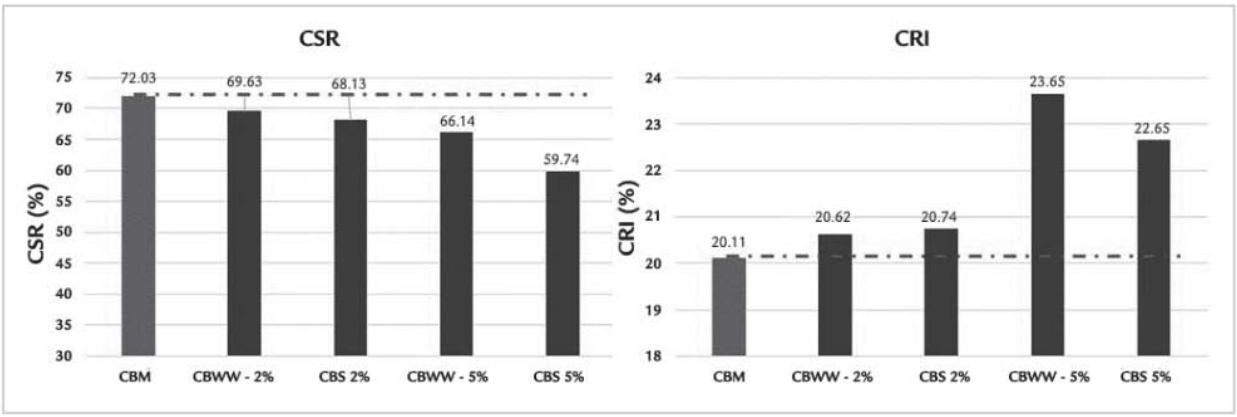

Figure 4: CSR e CRI of coke produced with wood and sawdust (Carvalho, 2021)

When compared to sawdust 2%, wood 2% showed a lower drop in CSR values (1.5%) and a smaller increase in CRI values (0.12 %). Wood 5% showed a higher CSR value (66.14 %) compared to the sawdust level 5% (59.74 %), with an increase in CRI to 23.65 % against 22.65% of sawdust.

Another important point is the sulfur content, which is not desired in hot metal production. Liziero (2017) concludes in his work that whenever biomass is added to the coal mixture, there will be a decrease in the sulfur content of the mixture, as shown in figure 5.

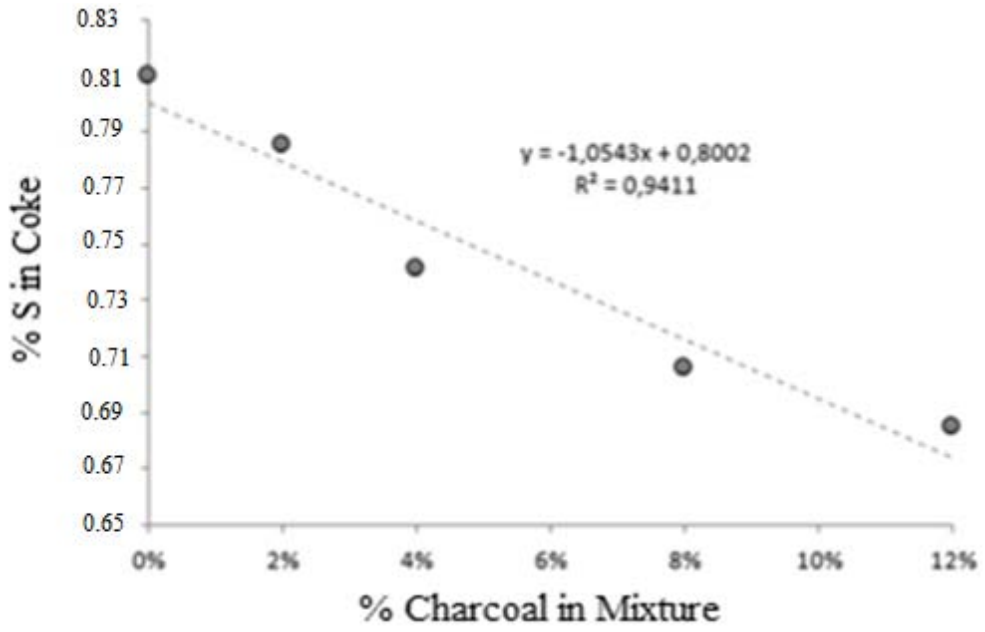

Figure 5: Effect of sulfur content in coke with biomass addition (Liziero,2017)

Regarding the ash content of coke with the addition of biomass, a linear decrease with the increase in biomass can be seen in the dispersion diagram shown in figure 6.

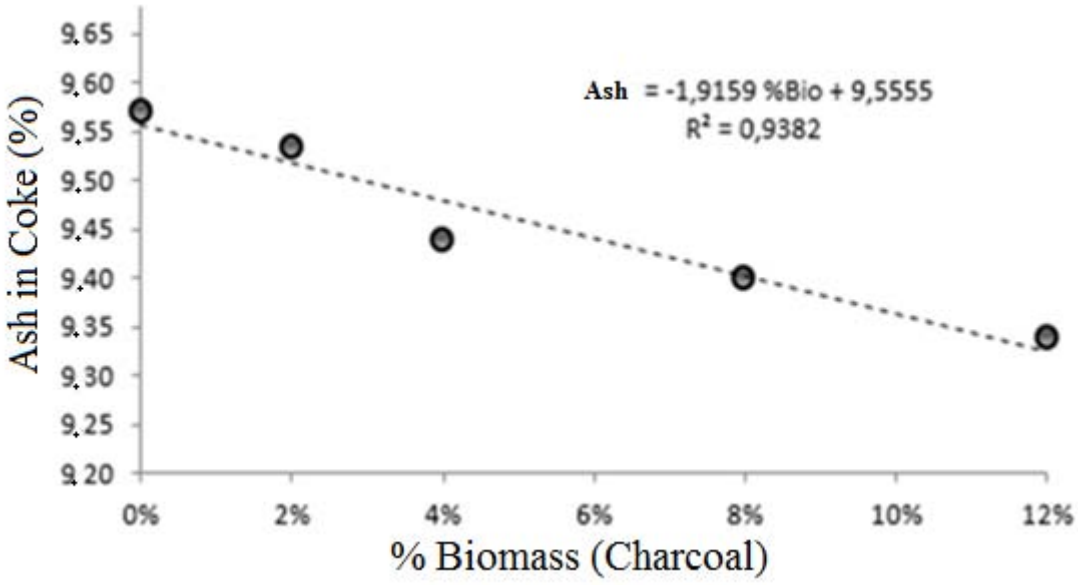

Figure 6: Ash behavior with biomass addition (Silva, 2016).

This behavior is expected since the ash contents of biomasses tend to be much lower than coals used in coke mixtures. In this way, the insertion of biomass improves the coke ash balance, with a direct reflection on the drop in fuel consumption in the blast furnace. For each 1% reduction in ash in coke, 7kg /t hot metal is saved in coke rate practiced in the blast furnace (Silva, 2016). In addition, the low ash content of biomass is interesting for the coking process, since there is a decrease in tar formation.

Some additives can improve the coking capacity of a coal mixture and, therefore, can partially reduce the negative effects of biomass additions. This can be seen in figure 7.

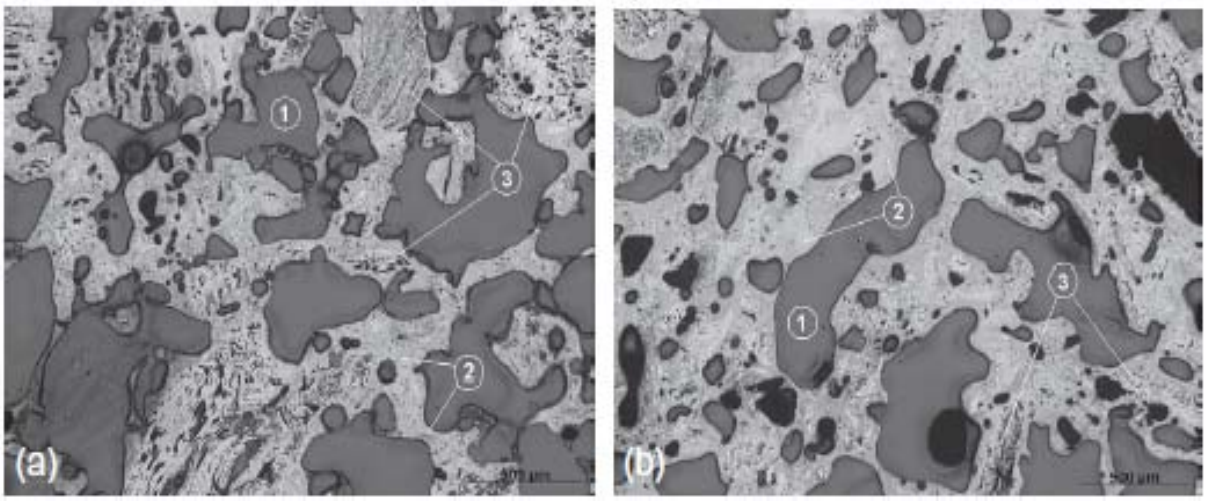

Figure 7: Biocoque optical micrographs: (a) coke with 10% charcoal; (b) coke with 10% charcoal and an additive. 1-Voids; 2-coke matrix; 3-particles of charcoal (Mathieson, 2015)

The left side micrograph (a) refers to biocoque obtained without the addition of an additive, showing that surfaces of residual biomass particles are poorly assimilated in the coke matrix, evidenced by the well-defined limits of inclusions. The encapsulation of charcoal particles in the coke matrix was considerably improved when 2% of an organic additive was added to the mixture (b). CRI and CSR also tend to improve since the addition of an additive reduce the reactivity of coke (Mathieson, 2015).

These presented studies show that biocoque, coke produced with the addition of biomass, can be an adequate substitute for conventional fossil fuels with the potential to reduce CO_2 emissions and reduce costs in the steel industry.

d) Environmental Evaluation

Environmental changes has become one of the most important issues in global politics. The Kyoto Protocol, introduced in 1997, was the first international agreement to reduce greenhouse gases. The Paris agreement, signed in 2015 and valid since November 2016, determined an increase in the planet's temperature by 2°C by 2100. This agreement was ratified by 179 countries that were in different stages of implementation and development of their environmental policies. Countries that have ratified the agreement recognize that the need to take action against climate change will imply accelerated policies and regulations that inevitably affect the industrial competitiveness of all nations and their respective economies. In parallel, several countries have set their own targets for reducing emissions. Table 3 shows some goals presented by countries in COP 21 for reducing greenhouse gas emissions.

Table 3: Goals are set by some countries to reduce greenhouse gas emissions (IRENA, 2020)

Countries	Goals
Australia	5-25% lower than 2000, until 2020
Brazil	37% lower than 2005 until 2025 and 43% until 2030
Canada	17% lower than 2005, until 2020
China	20-25% reduction in emissions per unit of GDP from 2005, until 2020
European Union	Reduce 20% until 2020, 40% until 2030 and 80-95% until 2050 (compared with 1990)
India	20-25% reduction in emissions per unit of GDP from 2005, until 2020
Russia	15-20% lower than 1990, until 2020
USA	17% lower than 2005, until 2020

Even with all these goals set by the countries, it will still be difficult to reach the global goal. The effort will have to be greater, and each contribution can be useful. Therefore, replacing fossil fuels with biomass in the steel industry will be interesting to help in this process. Thus, it will be presented how much it is possible to contribute with the partial replacement of coal in the cokemaking.

According to Sathler (2017), a Brazilian steel company in 2016 had an average coke rate and injection rate of, respectively, 295kg/t of hot metal and 188 kg/t of hot metal. For Silva (2016), it is necessary around 1.2tons of coal to produce 1 ton of coke, therefore, for this situation, the consumption of l coal to produce 1 ton of hot metal is 188kg in PCI and 354kg of

coal in coke. Consider equation 1 presented by Carvalho (2003):

$$1C + 0.5\,O_2 + 1.88N_2 = 0.9CO_2 + 0.1CO + 1.88N_2 \quad (1)$$

Doing a simple stoichiometric calculation, it is possible to say that burning 1 ton of carbon produces 3.3 tons of CO_2. It is possible to find in the literature several characterizations of coal with an average carbon content of 85%. Concluding, 542kg of coal have 460kg of carbon, and its burning emits 1520kg of CO_2, that is, the emission in a blast furnace process reaches 1520kg/t of hot metal. Considering only the share of emissions from coke, this value would be 1168.2kg/t of hot metal.

The main question is how much CO_2 can be avoided with the use of biomass in coal mixtures for cokemaking.

Researches developed by Silva (2008), Campos (2018), Suopajärvi (2017), among others, analyzing the use of biomass in coke production, point out that it is possible to use an average of 6% of the biomass in coal mixture, producing coke with qualities and requirements to be used in a blast furnace. Therefore, if we consider the data presented above (354kg of coking coal per ton of hot metal), replacing 6% of coal used in coke production by biomass, there would be a decrease of 22kg of coal per ton of hot metal produced. Finally, the contribution of coke burning to CO_2 emissions in a blast furnace would be 1095.6kg of CO_2 /t of hot metal, a decrease of 72.6kg of CO_2/t of hot metal.

When considering world production, this value can be significant. According to the World Steel Association (2021), hot metal production in 2019 reached 1.2 billion tons, that is, considering that all hot metal was produced via a coke blast furnace and that 6% of the coking coal was replaced by biomass, around 87 million tonnes of CO_2 emissions would be avoided in one year.

Obviously, these numbers are just to provoke reflection and point some numbers of the use of biomass in the coke production. Other factors must be analyzed for use, but it is a fact that environmental restrictions are increasingly demanding, and the steel industry must adapt to meet the environmental schedule and show that it is a strong sector, which aims a sustainable production.

III. Conclusions

The addition of biomass in coal mixture can be used in a certain limit. Researches shows that an average quantity is around 6%, without an expressive change in coke quality. The quantity used can vary according to the granulometry and type of biomass, which case presented show the differences.

The Di decrease with the increase of biomass in the mixture. This was associated with the quantity of inert content, which influences in the mechanical resistance. In addition, the coarse granulometry decreases more than the fines one.

The addition of biomass to the coal mixture is still considerably low, despite significantly influencing the cost and CO_2 emission, since it acts with a lower CRS and a higher CRI in relation to the coke conventionally used by steel companies.

In terms of the environment, the use of 6% of biomass in the blast furnace is capable of reducing CO_2 emissions by up to 6.21% per ton of hot metal, according to the calculations carried out, and despite being a low value; it causes an immense effect when considering the annual 87 million tonnes of reduced CO_2 emissions.

Is necessary to optimize the processes for obtaining, transporting and stocking biomass so that they can compete with fossil fuels as a raw material for the cokemaking. Cooperation between industrial sectors and agribusiness is essential. The development of alternatives is extremely important in order to guarantee an increase in the useful life of the coke plant.

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Compressive-Strength Dispersion of Recycled Aggregate Self-Compacting Concrete

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Abstract- Self-Compacting Concrete is a type of concrete characterized by its high flow ability in the fresh state, which makes it very sensitive to changes in its composition. The use of Recycled Concrete Aggregate (RCA) for its manufacture affects its compressive strength, although this effect is highly conditioned by the characteristics of RCA itself as well as by the composition of the mix. This bibliographical review aims to analyze in detail the most common aspects that cause the effect of RCA on the compressive strength of SCC not to be always the same. Thus, the bibliographical analysis reveals that, although the compressive strength decreases linearly with the RCA content if the flow ability of the SCC remains constant, this reduction is smaller when only coarse RCA is used. In addition, the use of RCA obtained from concrete of higher strength reduces this decrease, as well as the non-compensation of the water additionally absorbed by the RCA. The internal curing and the interaction of the RCA with different aggregate powders and mineral additions are factors that also favor this dispersion. The difficulty in defining the effect of adding RCA to SCC results in the need to experimentally study the particular effect of RCA on SCC in each case to ensure that it meets the requirements established.

Keywords: self-compacting concrete, recycled concrete aggregate; compressive strength; dispersion; mix design.

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Compressive-Strength Dispersion of Recycled Aggregate Self-Compacting Concrete

Víctor Revilla-Cuesta [α], Vanesa Ortega-López [σ], Marta Skaf [ρ], Francisco Fiol [ω] & Juan M. Manso [¥]

Abstract- **Self-Compacting Concrete is a type of concrete characterized by its high flow ability in the fresh state, which makes it very sensitive to changes in its composition. The use of Recycled Concrete Aggregate (RCA) for its manufacture affects its compressive strength, although this effect is highly conditioned by the characteristics of RCA itself as well as by the composition of the mix. This bibliographical review aims to analyze in detail the most common aspects that cause the effect of RCA on the compressive strength of SCC not to be always the same. Thus, the bibliographical analysis reveals that, although the compressive strength decreases linearly with the RCA content if the flow ability of the SCC remains constant, this reduction is smaller when only coarse RCA is used. In addition, the use of RCA obtained from concrete of higher strength reduces this decrease, as well as the non-compensation of the water additionally absorbed by the RCA. The internal curing and the interaction of the RCA with different aggregate powders and mineral additions are factors that also favor this dispersion. The difficulty in defining the effect of adding RCA to SCC results in the need to experimentally study the particular effect of RCA on SCC in each case to ensure that it meets the requirements established.**

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I. Introduction

Increasing sustainability is one of the major challenges that the construction sector is currently facing [1]. Both the construction methods and the materials used have great environmental impacts. The impacts related to construction methods range from riverbed pollution to deforestation and greenhouse gas emissions. This issue has made the elaboration of an Environmental Impact Assessment (EIA) in each single construction project mandatory. In that document, all environmental impacts produced during the building phase must be identified, so that the mitigation actions to reduce their relevance in the environment are precisely defined. In addition, it is necessary to establish a monitoring system to ensure that the measures adopted successfully fulfill their purpose [2]. Regarding construction materials, such as asphalt mixtures or concrete, environmental damage is caused by the processes of manufacturing their raw materials. Thus, the bitumen used in asphalt mixtures is obtained during the refining of oil, with the consequent emissions of greenhouse gases [3]. Cement, a fundamental material for the production of concrete, is one of the main sources of CO_2 emissions, since approximately each ton of cement emits one ton of CO_2 to the atmosphere [4]. Finally, Natural Aggregate (NA), which is obtained from quarries, is used in both materials, with the consequent damage in the extraction area.

In the field of construction materials, and the measures adopted to increase their sustainability, one of the main research lines is the use of wastes and industrial by-products for their manufacture [5]. There are a large number of possibilities, but two wastes/by-products stand out as substitutes of NA: Electric Arc Furnace Slag (EAFS) and Recycled Concrete Aggregate (RCA).

- EAFS is obtained during the process of manufacturing steel from scrapin electric furnaces. Its sudden cooling results in a granular material that can be used as substitute of NA[6]. It is mainly characterized by its high density, around 3.5 Mg/m^3, much higher than that of NA (around 2.6 Mg/m^3), and its high micro-porosity. However, it has a high surface hardness and mechanical strength that allows creating high quality Interfacial Transition Zones (ITZ) between it and the cementitious matrix or the bitumen, in concrete and asphalt mixtures respectively [7].
- RCA is obtained from demolition works or by crushing precast concrete elements whose use is not possible due to aesthetic or geometric defects [8]. Therefore, this residue can be defined as natural aggregate with cementitious matrix (mortar) adhered, which leads it to have a lower density than NA and a notably higher water absorption. The smaller the particle size, the lower the density and the higher the water absorption [9].

Increasing the sustainability of the construction materials has also been sought through their design. For example, concrete generally needs an energetic vibration when it is placed on site, so that it adapts perfectly to the formwork and the air inside it is expelled. However, at the beginning of the 21st century, Self-Compacting Concrete (SCC) emerged, which is characterized by its high flowability, filling ability, and passing ability [10]. Therefore, this type of concrete is able to adapt to the shape of the formwork and pass

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through the reinforcements without vibration. This is linked to lower energy consumption during its placement, which indirectly saves emissions of greenhouse gases from the production of the energy consumed. For the design of this type of concrete, a cement paste that can uniformly drag the coarser aggregate particles without producing segregation must be obtained [11]. To get this, three key aspects have to be considered, among which an adequate balance must be found:

- Firstly, a suitable ratio between coarse and fine aggregates must be defined. It is common that the content of coarse aggregate is lower than the amount of fine aggregate added, unlike the usual practice in conventional vibrated concrete[12].
- Secondly, it is essential to add an aggregate powder that provides particles smaller than 0.25-0.50 mm. These particles allow obtaining a cement paste with a high dragging capacity[10].
- Finally, it is necessary to use super plasticizers and define a high water-to-cement (w/c) ratio to provide high flowability to the cement paste and to get an optimal slump flow or spreading[13].However, the SCC must also have an adequate viscosity (V-funnel test) and passing ability (L-box test)[14].

The use of RCA in the production of vibrated concrete decreases workability mainly due to its higher water absorption compared to NA, which can be compensated by increasing the water content [15]. Furthermore, the compressive strength is also negatively affected due to the appearance of weaker ITZ with less adherence between the coarser particles and the cementitious matrix. Furthermore, the use of fine RCA usually increases the porosity of the cementitious matrix, which results in lower strength [16]. However, this behavior is not so clear in SCC due to its high sensitivity to changes in its composition [13]. Thus, for example, the workability of SCC may not be significantly affected by the use of RCA if the content of particles smaller than 0.25-0.50mm of this material is high [17]. On the other hand, the use of RCA can increase compressive strength despite of the adjustment of the water content of the SCC mix. This can be explained by the high relevance of the internal curing caused by RCA due to its deferred water release [8].

Therefore, it is clear that there are multiple factors that can affect the compressive strength of SCC manufactured with RCA. Moreover, the interactions between them cause that the effect of adding RCA can be different although the same amount of RCA is added This article aims to analyze in detail all these aspects. For this purpose, a bibliographic review of the different studies in which RCA is used for the elaboration of SCC has been conducted and the different factors that can affect this behavior have been identified and explained. Furthermore, the reasons why the effect of some of them is not always the same are also analyzed. The final objective is to explain how each change in the composition of SCC modifies its compressive strength.

II. Practical Procedure

The procedure followed to carry out the bibliographic review was divided in three steps. The objective was to conduct this process in a systematic and orderly way.

- Firstly, all studies in which the behavior of SCC manufactured with coarse and/or fine RCA was addressed were searched in different databases, mainly Google Scholar.
- Subsequently, each article found was studied in detail, thus identifying the factors that affected the compressive strength of SCC.
- Finally, from the results provided by the different studies, trends were established about how each factor affects the compressive strength of SCC.

In addition to analyzing the effect of each factor individually, the simultaneous effect of the different factors on the compressive strength of SCC was also evaluated. So, an overview of the effect of RCA on the compressive strength of the SCC is also provided.

III. Results and Discussion

Through the analysis of the different articles, five aspects that notably condition the compressive strength of recycled aggregate SCC were identified: RCA content[13]; quality of the parent concrete from which RCA is obtained by crushing[18]; w/c ratio and, therefore, flowability of SCC[8]; interaction between the aggregate powder and the mineral additions used[19]; and finally, the internal curing caused by RCA[20].

a) RCA content

Recycled Concrete Aggregate (RCA) is a by-product obtained from rejected concrete elements that are subsequently crushed and sieved [21]. It can have two different origins. Firstly, it can be obtained from the demolition of existing buildings or structures, so in this case it is mixed with other wastes such as brick, plastic, or glass [9]. Secondly, it can be produced from concrete elements rejected due to aesthetic or geometric defects, as well as surplus concrete, from the precast industry. RCA is characterized by lower density than Natural Aggregate (NA), around 2.4 Mg/m^3, while its water absorption, around 5-7 %wt., is notably higher [22]. In addition, each fraction of this by-product (coarse and fine), regardless of their origin, has particular properties:

- On the one hand, the coarse fraction (larger than 4 mm) has some mortar adhered to the NA itself as a result of the crushing process. This explains the higher density, the lower water absorption, and the higher porosity of this fraction compared to fine

RCA[23]. Besides, this adhered mortar also causes the appearance of Interfacial Transition Zones (ITZ), union zones between the aggregate and the cementitious matrix, less dense and weaker than those produced by NA[24]. The lower density of the adhered mortar and its higher porosity cause this problem.

- On the other hand, the fine fraction (size less than 4 mm) shows a mixed behavior. While the larger particles have similar characteristics to the coarse fraction, the smaller particles are mixed with particles of both other components (gypsum, clay ...) and altered cement[17]. The presence of particles from other components is especially common in RCA from demolition works, which generally reduce the purity of this by-product[8]. The presence of those components is harmful for the strength of any type of concrete, including that manufactured with RCA.

Therefore, it can be observed that RCA has different disadvantages compared to NA, which decrease the compressive strength of SCC [25]. There are multiple factors that impact negatively. On the one hand, the use of coarse RCA leads to an increased porosity of the cementitious matrix due the porosity of the adhered mortar itself [9]. Nevertheless, the most notable effect is that produced by the addition of fine RCA, which modifies the rheology of the cementitious matrix and increases its porosity more notably [26]. On the other hand, the weaker ITZ caused by using RCA favor the sliding between the aggregate and the cementitious matrix, generally where the adhered mortar is found[24]. In addition, both phenomena are usually combined, as it is usual that the increase of porosity caused by fine RCA occurs mainly in the area of the ITZ, due to the existing discontinuity between materials [24]. All this commonly leads to adherence problems between these two components, instead of the breakage of the aggregate, which is the optimal situation that would allow reaching the maximum compressive strength [17]. In case the aggregate breaks when adding RCA, it usually occurs through the adhered mortar, weaker than the aggregate that forms the RCA, and, therefore, the load to get this breakage is lower than that obtained when NA is used[16].

All of the above aspects cause a situation that can be considered logical. The increase of the RCA content, regardless of the fraction used, decreases the compressive strength of the SCC [13]. Although both RCA fractions are detrimental to the compressive strength, generally the effect of the fine fraction is more pronounced due to its greater effect on both the ITZ and the porosity of the cementitious matrix [27]. When adding RCA, if the workability of the SCC remains constant, the existing literature shows that the decrease in strength usually occurs linearly [28]. However, the slope of this line can vary very notably due to numerous aspects, such as the properties of RCA (purity of fine RCA, mechanical properties of the parent concrete…)[29], as well as the dosage of the SCC itself. Therefore, it is clear that a precise study of the characteristics of RCA and the control of the compressive strength of the SCC manufactured with it is necessary for the correct and safe use of this waste.

Figure 1 shows the evolution of the compressive strength of SCC manufactured with different RCA contents according to different studies. In each of them, different RCA fractions were used: only coarse RCA [30], only fine RCA [31], or fine RCA with 100% coarse RCA [17]. It can be seen that the mentioned slope of the line is different in each case, although the linear adjustment is adequate for all of them, reaching R2 correlation coefficients higher than 95 %. Furthermore, this slope is higher when using fine RCA due to the fact that its properties are worse for its use in SCC. It can therefore be concluded that, regardless of the particular characteristics of the RCA used, the decrease in strength is proportional to the amount of RCA added.

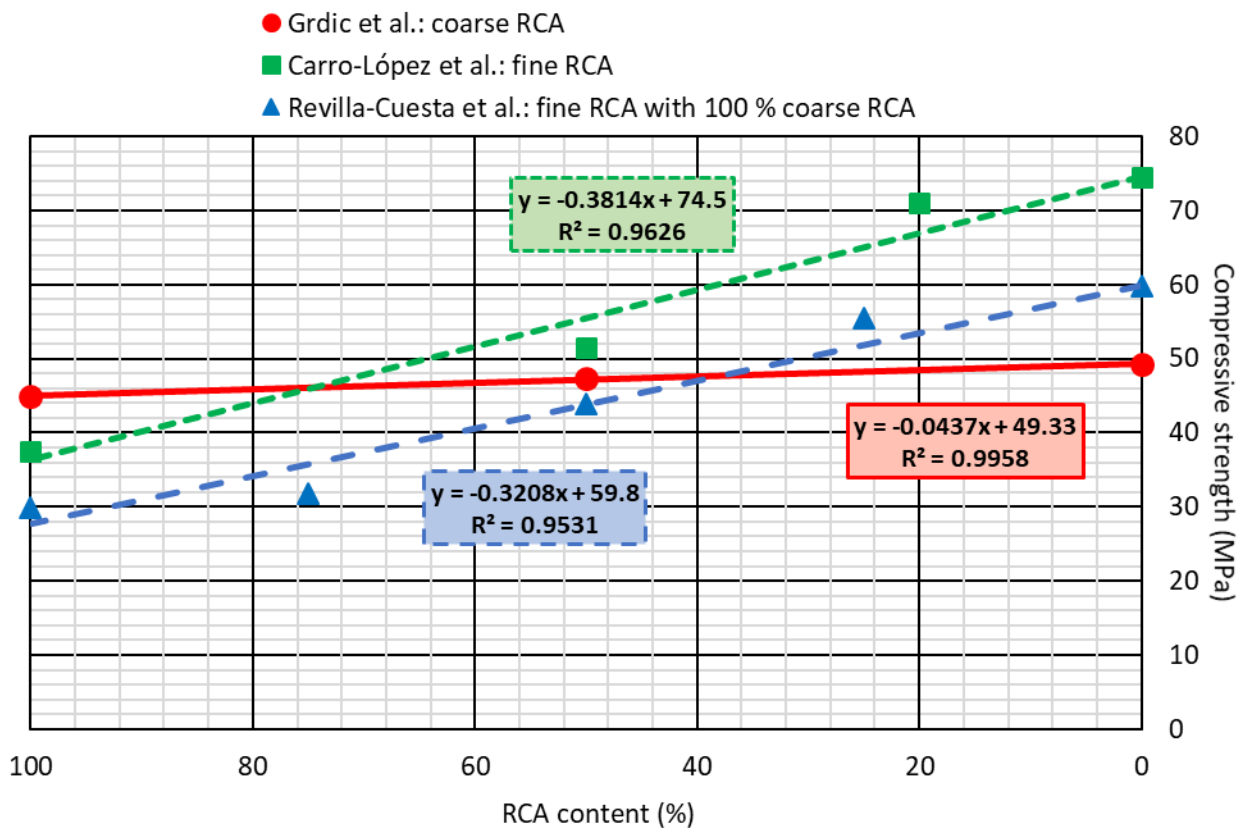

Figure 1: Examples of linear decrease of compressive strength of SCC with the RCA content[17, 30, 31]

b) Properties of the parent concrete

In the field of concrete manufactured with RCA, the term *"parent concrete"* refers to the concrete from which RCA is obtained by crushing [32]. It is obvious that this parent concrete may have notably different compositions, which would lead to completely different properties [33]. Thus, the parent concrete may presentvery different compressive strength, which can range from the minimum required value by international standards for structural concrete[34], 25 MPa, to strengths in the order of 130-140 MPa (ultra-high-performance concrete) [35]. Those different compositions also result in different work abilities, which in turn influence the strength that the concrete develops. The raw materials are also remarkably influent, because in each geographical area, the aggregates and cement produced are completely different. Thus, trying to establish a global overview about how the parent concrete conditions the compressive strength of the SCC is extremely complicated[36].

This variability of the quality of RCA causes a dispersion of the compressive strength of the SCC, which in turn hinders both its precise definition and its possible prediction [13]. Nevertheless, a clear rule can be established: the use of a parent concrete of higher quality, that is, higher strength, results in a higher quality RCA [37], which leads recycled aggregate SCC to have a higher strength [12]. This behavior is closely related to two aspects commented in the previous section:

- Firstly, the use of RCA from a parent concrete of higher strength results in the appearance of more robust ITZ. Since the weakest part of the ITZ is the contact area between the adhered mortar and the cementitious matrix, this is where the adhesion problems between the RCA and the cementitious matrix usually occur[38]. A higher-strength adhered mortar, thanks to the use of a higher-strength concrete, makes this zone less sensitive to the application of a force and does not produce the failure in that area so easily[39].
- Secondly, the most beneficial situation is the presence of an adhered mortar of the highest possible strength [40]. In this way, the breakage is more likely to occur both through the adhered mortar and through the NA that composes the RCA. This situation is possible thanks to the higher strength of the adhered mortar, which causes a more similar behavior to NA[41]. This in turn results in an increase of the compressive strength of the SCC manufactured with this by-product.

Within this situation, the source from which RCA is obtained (demolition works or precast elements) is also important[8]. The concrete used in the precast industry usually has a higher strength due to the singular characteristics of the elements that are manufactured with it. In addition, the presence of the previously mentioned contaminants is usually notably lower[23].

Therefore, the RCA from the precast industry has better properties for its use (higher strength, less quantity of harmful components...) which leads to the development of SCC with higher strength and, in general, with a better behavior in the hardened state[42].

c) Water-to-cement ratio, flowability

The water content of concrete is generally expressed by the quotient between the amount of water and cement added to the mix (water-to-cement ratio, w/c)[34]. Ifmineral additions with pozzolanic properties, such as fly ash or ground granulated blast furnace slag, are also included, this quotient is usually labelled water-to-binder (w/b) ratio, and both the cement and the different mineral additions used to partially replace or supplement it are considered binders [43]. In concrete, the amount of water added is essential for two different properties:

- On the one hand, the content of water added defines the workability of the mixture [44]. Thus, in general, the greater the water content of the concrete, the greater its workability. Therefore, regarding SCC, the higher the w/c (or w/b) ratio, the higher the flowability [45]. However, to obtain an adequate flowability in the SCC it is necessary, in addition, to consider other design criteria indicated in the introduction (adequate powder content, correct relationship between the amount of coarse and fine aggregate added to the mix, and addition of an adequate amount and type of superplasticizer)[14].
- On the other hand, the w/c ratio also plays a fundamental role regarding concrete strength. A higher water content leads to a greater dilution of the cement particles and, in turn, to a decrease of the strength[46]. The commonly high w/c ratio of SCC leads the strength of this type of concrete to be even more sensitive to the modification of this parameter [47].

These two aspects show that the water content in all types of concrete, but especially in SCC, has to be precisely defined to achieve adequate workability without a great loss of strength [48]. In this way, both properties must be adjusted to the requirements established for the specific application in which the concrete will be used [7].

RCA has different characteristics from NA, among which, regarding concrete's workability, its higher water absorption stands out [32]. This causes that the water not absorbed by the aggregate is reduced when this by-product is used [47]. This leads to a lower amount of water that reacts with cement, which results in a decrease of workability [19]. When RCA is added, workability is also diminished by the irregular shape of the particles of this material, which increases the friction between the mix components [49]. The increase of the water content also partially compensates for this phenomenon[50].

As mentioned in section 3.1, the effect of using RCA can be precisely defined maintaining the workability (flowability) of the SCC constant [35]. However, the design of a concrete does not have to meet this criterion, which favors an increase in the dispersion of its compressive strength [34]. Thus, the use of 100 % RCA but without a total compensation of its water absorption can allow obtaining a SCC with higher strength than the concrete manufactured with 100 % NA [16]. This solution is generally suitable for coarse RCA, since the presence of components of different nature is generally reduced, even if it proceeds from demolition works, and it does not alter the expected behavior of RCA [13]. However, the situation is completely different in relation to the use of fine RCA, due to its greater influence on the microstructure and porosity of the SCC. In addition, its content of other components is higher, which can alter the expected performance [32]. Thus, it can be observed that the effect of the water content cannot be defined either, especially when the fine fraction of this by-product is used. Therefore, the water content of the SCC is other parameter that can alter the strength behavior of SCC[42].

It is also important to note that the flowability of SCC significantly influences the effect of RCA. In general, the use of a SCC of lower flowability while maintaining the other variables constant reduces the loss of strength caused by RCA [13]. On the other hand, the flowability of SCC depends largely on the amount of water added to the mixture. Unlike conventional vibrated concrete, a minimal decrease of the water content can result in a significant change of workability, i.e., of the slump-flow class [14]. It is clear that the decrease of the water content can compensate for the decrease of strength initially caused by the use of RCA, but inevitably, this will cause a decrease in the workability (flowability) of the SCC [15]. Flowability is the differential aspect of SCC, and its modification at high levels can render the use of this type of concrete meaningless[10]. Therefore, it is fundamental to obtain a balance between the increase of strength and the reduction of flowability that the adjustment of the water content when adding RCA causes.

As an example, Figure 2 shows the results of a study carried out by Fiol et al.[8]. In this research work, the non-compensation of the water content led to an increase of the strength when different contents of RCA from precast elements were added. However, the use of this strategy also resulted in a significant decrease of the slump flow of the SCC produced. This clearly shows the need of finding the balance between these two aspects, flowability and strength, when the water content is adjusted to compensate for the negative effect of RCA.

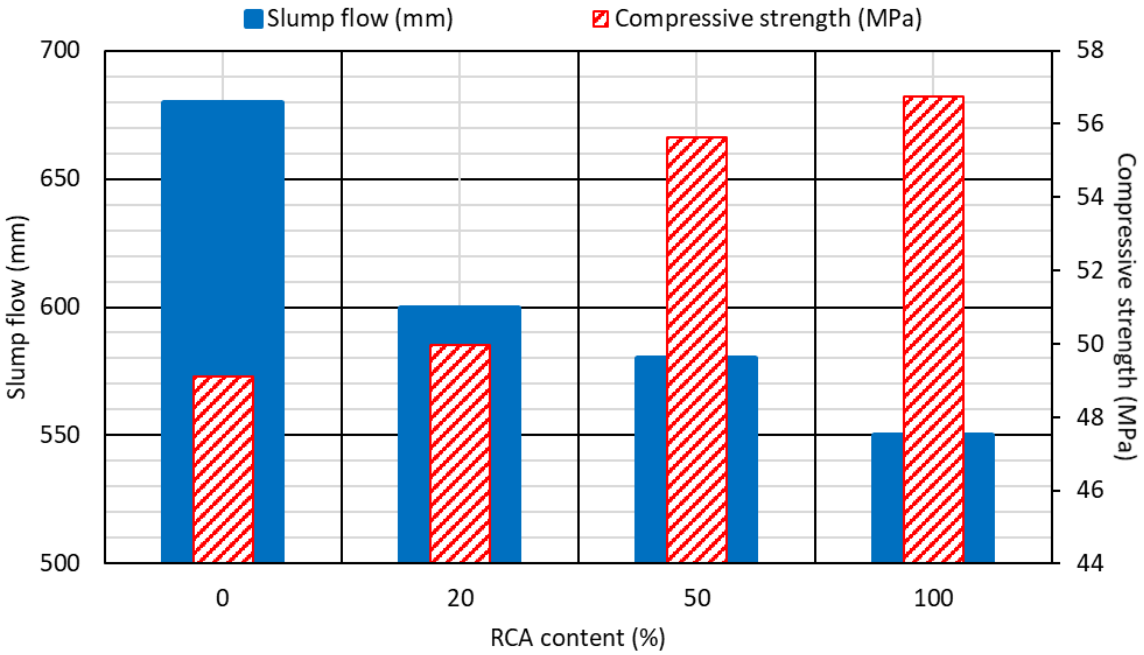

Figure 2: Beneficial effect on compressive strength of a constant w/c ratio when adding RCA (w/c ratio equal to 0.45)[8]

Finally, it is also important to highlight the usefulness of the staged mixing processes to maximize the flowability of SCC. These processes consist of adding the different components of the mixture in a progressive way, not all simultaneously, and applying an intermediate mixing process [51]. A typical mixing process consists, for example, of the following two stages:

- Adding RCA with a certain amount of water (usually 70 % of the mixing water) and mixing for 3-5 minutes.
- Addition of the cement, the remaining water, and the super plasticizer. Mixing for another 3-5 minutes.

This procedure allows maximizing the flowability of SCC by adding RCA without excessively increasing the water content[31]. The first stage maximizes the water absorption of the RCA, so that its increase compared to that of NA does not affect the flowability of the SCC. In the second stage, effective hydration of cement is achieved, maximizing flowability and strength, by adding water specifically intended for hydration. In this way, the amount of additional water to remain the flowability constant when using RCA is reduced[47]. This enables to reduce the decrease of compressive strength experienced by the SCC when this residue is added[51]. Thus, the mixing process also favors the dispersion of the compressive strength.

d) Aggregate powder and binder

In order to obtain self-compactability, concrete must have a high content of particles smaller than 0.25-0.50 mm[14]. Cement provides an important proportion of these particles, but, generally, it is necessary to complete it with the addition of an aggregate powder. The aggregate powder is a very fine aggregate fraction that provides the particles of that size[27]. The most commonly used aggregate powder is limestone filler, with a particle size under 0.063 mm[17]. However, the use of limestonefines 0/1.2 mm has also shown to be a good option, because it allows creating a very compact cement paste in the fresh state that efficiently drags the coarsest aggregate particles, even when heavy aggregates, such as the Electric Arc Furnace Slag (EAFS), are used [48].

The content of aggregate powder added to SCC is not a trivial issue, as this material also provides strength to SCC by supplementing the cement due to its small particle size. Moreover, its addition in a correct quantity allows obtaining a greater flowability by adding less water, since it allows creating a cement paste with high dragging capacity[52]. This in turn results in a lower dilution of the cement and in a higher compressive strength[12].

The type of aggregate powder added is also relevant, especially when using fine RCA. As previously mentioned, RCA has significant influence on the rheology of the cement paste, so its use generally leads to an increase of the micro-porosity of the mixtures[26]. If there is not an optimal affinity between the aggregate powder and the fine RCA, which contains particles of the same size as the aggregate powder, this micro-porosity can be increased, resulting in a reduction of the compressive strength[51].

The use of mineral additions with pozzolanic properties has the same effect as the nature of the aggregate powder[13]. In the case of SCC with RCA, the mineral addition whose effect has been studied in more detail is fly ash, which increases the percentage decrease of strength when RCA is added (without modifying the type and quantity of binder used when varying the RCA content)[53]. The increase in the micro-porosity of the mixture due to the interaction between fine RCA and fly ash explains this behavior[29].

e) Internal curing

As indicated above, the water absorption of RCA is higher than that of NA, which causes this by-product to absorb a greater amount of water during the mixing process[9]. The water absorbed does not remain indefinitely inside the aggregate, but is released in a delayed and slow way by the RCA. Part of that water is released once the concrete has hardened. Therefore, RCA provides water in a deferred way to the cementitious matrix, thus allowing a deferred hydration of the cement non-effectively hydrated during the mixing process[54]. This causes the long-term increase of strength of the SCC made with RCA to be more noticeable compared to conventional concrete (100% NA)[17].

In view of the above, it is clear that the effectiveness of this internal curing depends on the level of water absorption of the RCA[33]. Thus, the use of fine RCA, with higher water absorption than the coarse fraction of this waste[9], performs an internal curing that increases the compressive strength of the SCC more effectively[55]. The better this internal curing, the better the hydration of the cement, which allows reducing the decrease of strength caused by RCA[55]. The last compressive-strength-dispersion factor analyzed is, therefore, the water absorption of the RCA.

f) Global overview

Many factors influence the compressive strength of SCC. In addition, the great sensitivity of this type of concrete to all the aspects mentioned makes the effect of all the factors even more remarkable[21]. Figure 3 shows the quotient between the compressive strength of the SCC made with RCA and the compressive strength of a SCC with the same composition but with 100 % NA (reference concrete) for the mixes developed in different research works[8, 29, 49, 53, 56-60]. Thus, the values less than 1.00 correspond to cases in which the compressive strength of SCC increased when RCA was added, while the values higher than 1.00 refer to SCC with RCA that presented a lower strength than the reference concrete. This figure provides a clear representation of the ideas addressed in this article:

- Firstly, the effect of RCA on the compressive strength of SCC depends on many factors, such as the RCA content, the quality of this by-product, the amount of water added to the mixture, and even the water absorption of the RCA itself. Thus, it cannot be stated categorically whether the use of RCA will increase or reduce the compressive strength of SCC, as this will depend largely on the mix design.
- Any RCA content can lead to an SCC of higher strength than that obtained with 100% NA. Once again, this will depend on the composition of the mix.

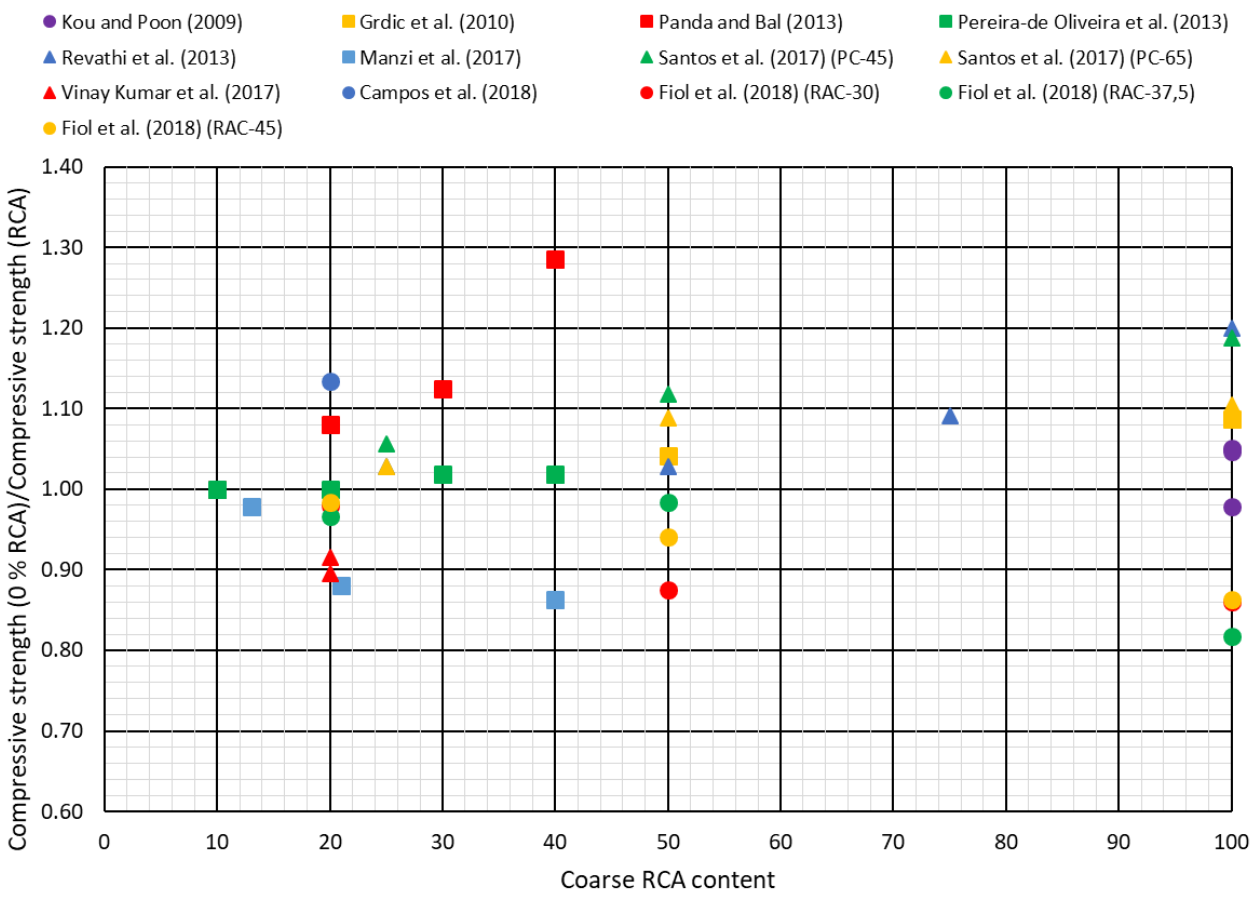

Figure 3: Compressive-strength dispersion of SCC with RCA[8, 29, 49, 53, 56-60]

IV. Conclusions

Throughout this article, the effect of the addition of Recycled Concrete Aggregate (RCA) on the compressive strength of Self-Compacting Concrete (SCC) has been studied. This type of concrete is very sensitive to changes in its composition, so the effect of RCA on the compressive strength can be very noticeable. However, this sensitivity also causes that any small change to affect the compressive strength differently, so the effect of RCA may be different than expected. From all the above, the following conclusions can be drawn:

- If the flowability of SCC remains constant, the compressive strength of SCC decreases linearly with RCA content, regardless of the fraction used. This decrease is usually more noticeable when fine RCA is used due to the presence of altered cement particles or from other materials, such as brick or gypsum, in it.
- The higher the quality (strength) of the concrete from which the RCA is obtained by crushing, the higher the strength of the SCC manufactured with it. The use of a concrete of higher strength results in the behavior of this residue being more similar to that of natural aggregate.
- The non-modification of the water content when RCA is added can compensate for the decrease of strength experienced by SCC when RCA is added, especially when the coarse fraction of this waste is used. However, this will lead to a decrease of the flowability of SCC, so a balance must be found between the desired fresh and hardened state behavior.
- The interaction between the aggregate powder used to achieve self-compactability and the fine RCA also significantly conditions the compressive strength of SCC. A bad interaction can cause an increase of the micro-porosity, with the consequent additional decrease of the compressive strength of SCC.
- Increased water absorption by RCA can reduce the decrease of compressive strength in the long term. This is because a higher water absorption leads to a remarkable internal curing and thus, a more efficient hydration of the cement.

Overall, the effect of adding RCA to SCC cannot be predicted, as it is conditioned by numerous factors that depend on the composition of the mixture. Therefore, it is advisable to experimentally study the behavior of the SCC when RCA is added and to check whether it meets the requirements of the application in which SCC is being used.

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Methodological Strategies for the Reconstruction and Sustainable Improvement of the Habitat of Localities in the State of Chiapas, Mexico

By Lorenzo Franco Escamirosa Montalvo, María de Lourdes Ocampo García, Carlos Uriel del Carpio Penagos & Sergio Naraín Zebadúa Velasco

University of Chiapas

Abstract- The dispersal of the population of the state of Chiapas with about 20 thousand small towns with less than 2,500 inhabitants and the orography of the territory, characterized by mountains, highlands, depressions, plains and coasts, are factors that limit the access of these localities to the basic services of water and sanitation, health, education, culture, recreation, communication, etc. Families living in small communities are essentially peasants and indigenous people with low economic incomes and, for this reason, have precarious, unsafe and unhealthy housing, without basic water and drainage services, among others. In the search for solutions to address this problem, the work team of the Academic Body Urban Development of the Autonomous University of Chiapas, has carried out research oriented towards the reconstruction and improvement of housing and its environment (habitat), in Nuevo San Juan Chamula, Zinacantán, Ocuilapa de Juárez, Chiapa de Corzo, El Encanto, among other communities, through the application of a methodological process that has allowed the analysis of problems and the elaboration of proposals safe, affordable, healthy and sustainable housing, considering the typology, culture of peoples and environmental conditions, based on the use of ecotechnologies and materials of the place, with low environmental impact.

Keywords: housing, security, sanitation, materials, typology, environment.

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Abstract- The dispersal of the population of the state of Chiapas with about 20 thousand small towns with less than 2,500 inhabitants and the orography of the territory, characterized by mountains, highlands, depressions, plains and coasts, are factors that limit the access of these localities to the basic services of water and sanitation, health, education, culture, recreation, communication, etc. Families living in small communities are essentially peasants and indigenous people with low economic incomes and, for this reason, have precarious, unsafe and unhealthy housing, without basic water and drainage services, among others. In the search for solutions to address this problem, the work team of the Academic Body Urban Development of the Autonomous University of Chiapas, has carried out research oriented towards the reconstruction and improvement of housing and its environment (habitat), in Nuevo San Juan Chamula, Zinacantán, Ocuilapa de Juárez, Chiapa de Corzo, El Encanto, among other communities, through the application of a methodological process that has allowed the analysis of problems and the elaboration of proposals safe, affordable, healthy and sustainable housing, considering the typology, culture of peoples and environmental conditions, based on the use of ecotechnologies and materials of the place, with low environmental impact. This work presents methodological strategies implemented in various communities in mexico's Chiapas state to address the problem of housing and the environment, and contribute to habitat improvement and increase the quality of life and well-being of low-income families.

Keywords: housing, security, sanitation, materials, typology, environment.

I. Introduction

In Mexico, rural towns are characterized by small population groups, which are essentially peasants and indigenous people, who are associated with their natural environment. Communities are generally located in isolated territories and away from population centres with the greatest social and economic development. In rural areas, mostly, families are low-income and because of this condition they have long lived with deficiencies of all kinds. The houses they own are of poor quality, unsafe, built by them with materials obtained from nature such as wood, stone, earth, palm, carrizo, bamboo, etc.; some build their homes with low-cost industrialized materials, such as metal or cardboard sheets; others use waste materials: cardboard, plastic or metal sheets. In these places, unhealthiness prevails, in part, because water and drainage services are inadequate and, in some cases, do not exist, which limits personal hygiene; also, as a result of the mis management of solid and liquid waste generated inside the house and in the immediate environment, processes of decomposition of organic matter and pollution are generated, which attracts harmful fauna and proliferates the reproduction of vectors carrying different diseases, which is undoubtedly one of the main risk factors in the health of the inhabitants.

The state of Chiapas registered in 2015 (INEGI), a total of 5,217,908 inhabitants and it was recognized that 49% of the population is urban and 51% rural, with a total of 1,238,565 homes, of which 23.1% do not have a kitchen, 10.7% in floor of soil, 3.3% do not have sanitary furniture, 42.8% use firewood for food processing, 38.6% have poor garbage management and 2.3% are without electricity (INEGI, 2015). On the other hand, the National Council for the Evaluation of Social Development Policy (CONEVAL, 2015 and 2018), indicates that in housing, 0.8% of ceilings and 4.6% of the walls are built with precarious materials, and in 13.5% cases live in overcrowding, 57.1% lack access to basic services and 23.6% have poor quality housing spaces; of the total population, 22.3% lack access to food, 83.6% to social security, 17.6% to health services, 29.2% have educational lag and 78.9% have incomes below the poverty line by income and 50.7% income below the extreme poverty line by income. The above images place Chiapas nationally in the last places in social lag.

With regard to the degree of marginalization, which relates the deprivation of the inhabitants to

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education, conditions of their housing and lack of property, according to the estimates made by the National Population Council, in 2010, the Entity occupied the first national place, with degrees of marginalization, Very high and high, at 67% of the total population (CONAPO, 2012); also, the recent estimates of the Human Development Index, which assesses the health conditions, education and incomes of the population, place the state of Chiapas in the last place throughout the country, below the states of Oaxaca and Guerrero (UNDP/UN, 2015).

On the other hand, it is well known that in the territory of Chiapas there is a vast variety of landscapes and diversity of species and ecosystems, the result of the different soils, climate and orography it possesses, the latter characterized by mountains, highlands, depressions, plains and coasts; Also, Chiapas is recognized as one of the most culturally rich entities in the country, the birthplace of indigenous ethnic groups such as *tsotsiles, tseltales, zoques, lacandones, mames, tojolabales*, among others, which have resulted in an extraordinary variety and number of peoples, which according to INEGI there are more than 20 thousand localities, of which, 99% have fewer than 2,500 inhabitants, 85% less than 250 and of these, 74% have fewer than 100 inhabitants (INEGI, 2010); in this sense, the dispersion of the population of the Entity and the existing orography, are factors that limit access to localities to basic water and sanitation services, health, education, culture, recreation, communication, etc.

In this context, the search for solutions that contribute to increase the quality of life and well-being of low-income families has been one of the main purposes of the Academic Body Urban Development (CADU), constituted by professors-researchers of the Faculty of Architecture of the Autonomous University of Chiapas (UNACH). The research carried out by the team, with the collaboration of students from the UNACH Faculty of Architecture and researchers from faculties and centers of other institutions, has been oriented towards the reconstruction and improvement of the habitat of rural and urban communities, mainly in the social sectors with low incomes.

At first, a site analysis is carried out, which allows the identification and interpretation of the problem of the house and its environment, as well as the characteristics of the place of study; a situational diagnosis is then developed which, at a second moment, is the basis for the elaboration and development of alternative housing proposals, safe, economic and healthy, sustainable with the environmental, socioeconomic and cultural conditions of the inhabitants, built with the use of materials of the region, environmentally friendly, and respecting the typology of the place, culture and customs of the inhabitants. In this work, the methodological strategies applied in the processes of the research carried out by the team in the state of Chiapas, in the localities are presented: Nuevo San Juan Chamula, Zinacantán, Ocuilapa de Juárez, Chiapa de Corzo and El Encanto.

II. Methodological Process

The research activities carried out by the team (CADU-UNACH), they are often linked to teaching, according to the subjects taught in architecture, such as: "Natural Habitat Environment", "Research Methods and Techniques", "Material Laboratory Workshop", "Zero Impact Building Materials Workshop", "Urban Planning", "Urban Design Workshop", "Sustainable Architecture", "Topography". The purpose is to strengthen the teaching-learning processes, with the use of information obtained in a real context, for the realization of analyses, exercises or practices established in the analytical programs of the subjects; that is, reality is analyzed in the classroom and, with this, students are directly involved in the development of research activities, specifically in the survey and analysis of information, and subsequently in the elaboration of solution proposals.

The analysis of the reality of case studies begins with the identification and interpretation of the problem of housing and its environment (site diagnosis) and, based on the information obtained on site, the proposals for habitat reconstruction and improvement are developed. The process of obtaining and analyzing the information is carried out with the Model for the Assessment of rural housing conditions and the environment (MECVE) (Escamirosa, 2015), which allows to evaluate in a comprehensive way, the possible causes and risk factors to the health of the inhabitants of the rural environment, related to the conditions of the house they inhabit and their immediate environment. The analyses will consider the housing, the use and consumption of water and the management of organic and inorganic waste generated, in addition to the interactions that exist between these elements and the environmental conditions: biotics and abiotics of the housing environment.

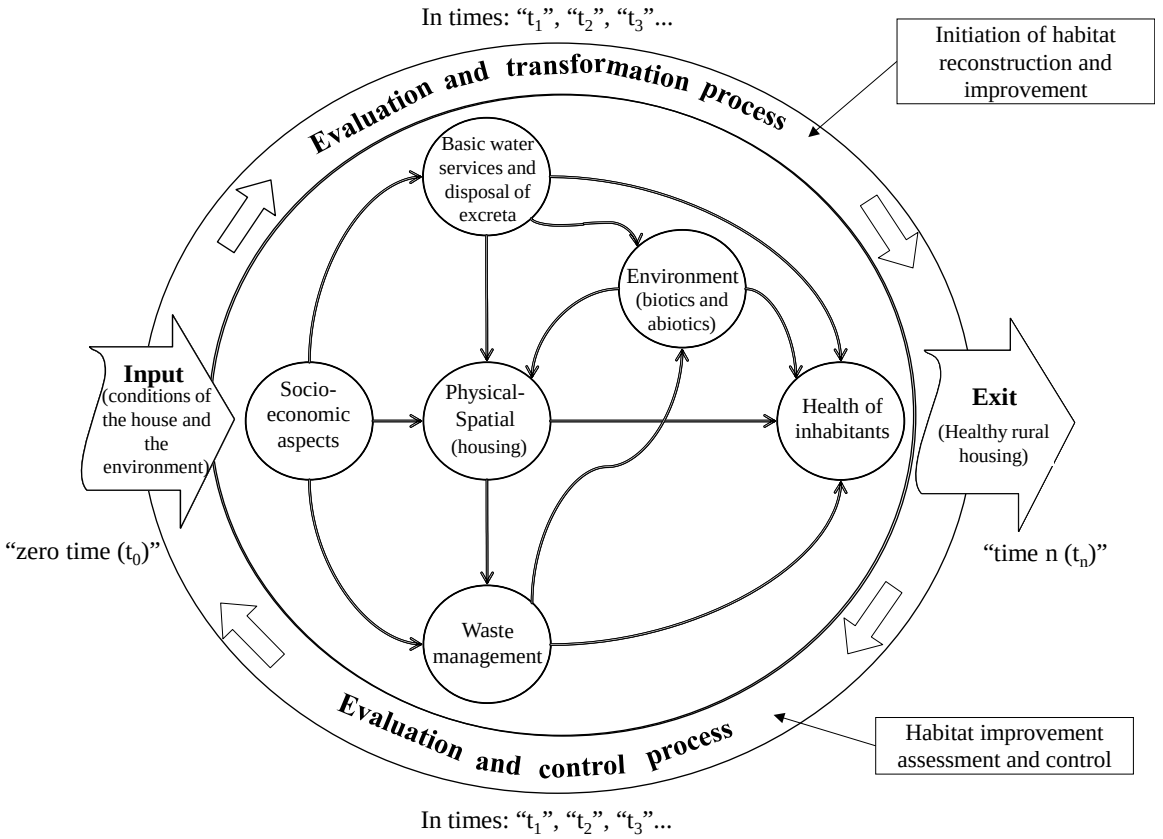
The MECVE analyses 5 dimensions: a) Socioeconomic aspects, b) Physical-spatial (housing), c) Basic water services and disposition of excreta, d) Management of liquid, solid and gaseous waste, and, e) Environmental components (biotics and abiotics); These dimensions are also interrelated with: (f) Family Member Health and (g) Environmental Environment. The specific time at which the information is surveyed is identified as "zero time (t_0)". With the analysis of the situation in the case of study, the diagnosis of the house and its environment is integrated (see image 1).

The assessment of habitat problems and risk factors is based on the variables determined in the model, which allows to measure the negative effects on human health, based on the indicators and quality

ranges established according to the basic principles of sanitation and sustainability for habitat improvement; also, the model establishes the analysis tools (surveys, registration cards, etc.), necessary to carry out the information survey on site.

Image 1 shows that the model raises 3 phases operation and analysis: input, processes and output. In the "entry phase", the diagnosis of the site is obtained at "zero time (t_0)", and based on it, the conditions of the house and the environment are evaluated and the transformations to be made are recognized. In the second phase, processes, corresponds to the "habitat reconstruction phase", where the control and monitoring of the transformations that have been executed is considered, from a re-evaluation of the 5 dimensions in atime other than "t_0", so this moment is defined as "time one (t_1)". These evaluations are carried out according to the indicators and quality ranges, and are carried out as many times as necessary in different times: "t_1", "t_2", "t_3"..."t_n", until achieving the established quality of a "healthy rural housing", which corresponds to the last phase of the model, called "exit phase". At this final stage, families are guaranteed to live in a healthy, safe and sustainable environment over time; however, further assessments confirming that this condition is maintained will be required.

MECVE is a tool that guides the realization of healthy rural housing (RSV), which aims to keep its inhabitants in a healthy environment over time, without pathogenic germs and thereby avoid possible communicable diseases; in addition, it helps to reduce risk factors to the detriment of human health, so RSV will help family social development, addressing the biological, social and psychological needs of people by minimizing tensions with the internal environment of housing and the immediate environment to it.



Source: Escamirosa, 2015

Image 1: Condition assessment model rural housing and the environment (MECVE)

a) Site diagnosis

The site is studied in 2 stages: Stage 1. Initial work. It refers to work to be carried out, which consists of obtaining and analyzing the largest amount of information from the study area, available from official sources, government units, research work of the site, etc., related to the 5 dimensions posed with the MECVE; also, we proceed to design those instruments of analysis, which does not consider the model and are necessary to identify and interpret the additional information required for the elaboration of the intervention proposals, such as: the characterization of the elements of the urban image, typology and materials used of the place, as well as guided interviews aimed at

notable people or key informants, representatives of the inhabitants of the place, among others. All instruments shall collect information exhaustively from the primary source on site, since the accuracy and variety of the records obtained avoids more than one field work exercise, which corresponds to stage 2 of the site study, thereby streamlining the available resources for that purpose.

Stage 2. Fieldwork: It consists of approaching reality, where observation becomes a fundamental exercise; on the one hand, to interpret the problem focuses on housing and its environment, and, on the other hand, on the process of identifying the natural resources of the site, including the materials of the place, technically safe for construction, and the experience of traditional techniques of the inhabitants of the locality, which are important and opportunity elements in the definition and solution of the intervention proposals. At this stage of site analysis, students involved in research need to be trained to properly interpret the analysis tools and perform the required data and information records, with sufficient clarity and precision; they should also be trained to behave with respect and formality towards people during the interview process.

After the two stages, the results obtained are systematized and the study case diagnosed.

b) Variables, indicators and quality ranges of the dimensions planted in the MECVE

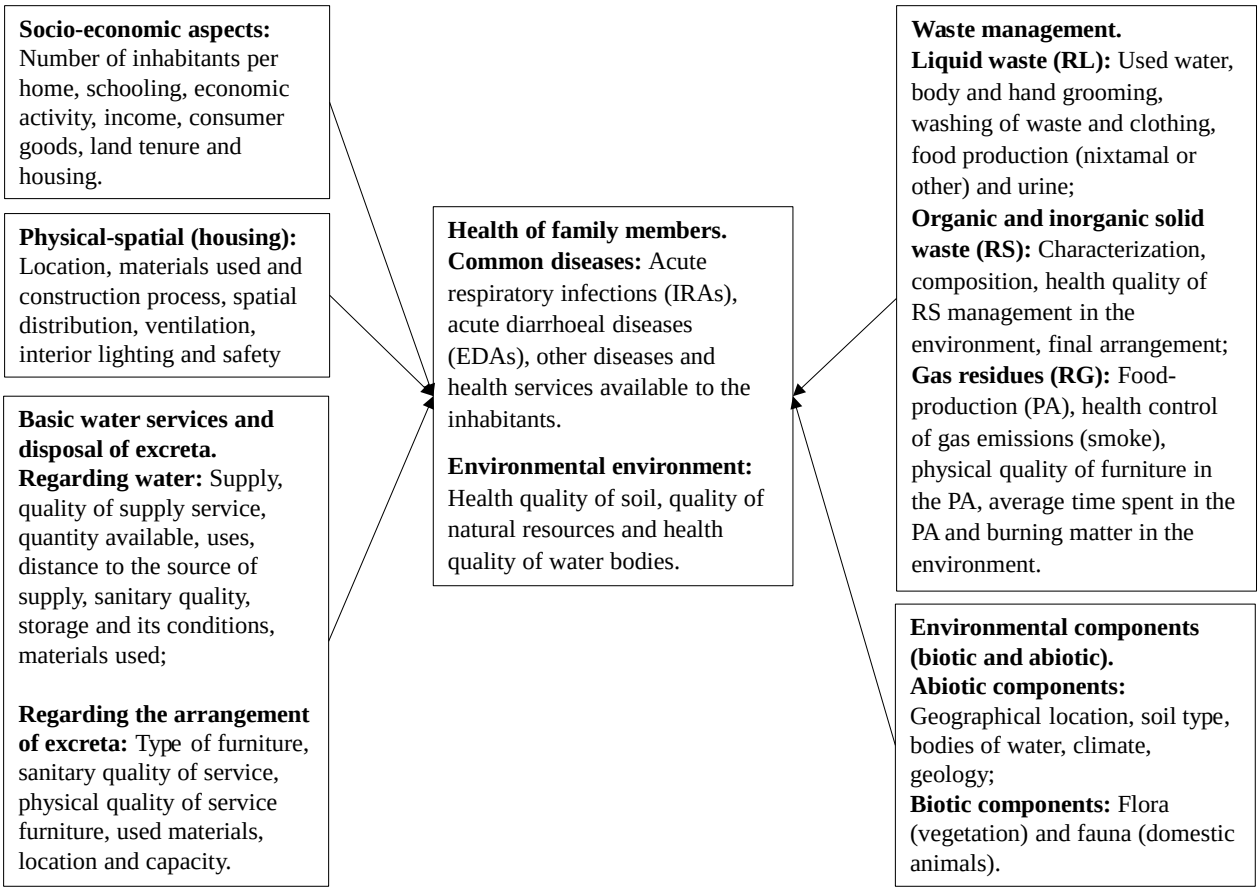
The analysis focuses on "the house", it is part that it constitutes the space that comprises the architectural object and its relations with its immediate environment "the context", where it is located. This relationship –housing and immediate environment– defines the nature of the object and integrates it as a unit of assembly, and both, form the essential cell of the inhabited territory that provides identity with respect to the social group to which it belongs, which for our case refers to the rural environment.

The variables considered in each dimension of the MECVE model (image2) are as follows:

1. Socio-economic aspects: Number of inhabitants per home, schooling, economic activity, income, consumer goods, land tenure and housing.
2. Physical-spatial (housing): Location, materials used and construction process, spatial distribution, ventilation, interior lighting and safety.
3. Basic water services and disposal of excreta. Regarding water: Supply, quality of supply service, quantity available, uses, distance to the source of supply, sanitary quality, storage and its conditions, materials used; Regarding the arrangement of excreta: Type of furniture, sanitary quality of service, physical quality of service furniture, used materials, location and capacity.
4. Waste management. Liquid waste (RL): Used water, body and hand grooming, washing of waste and clothing, food production (nixtamal or other) and urine; Organic and inorganic solid waste (RS): Characterization, composition, health quality of RS management in the environment, final arrangement; Gas residues (RG): Food-production (PA), health control of gas emissions (smoke), physical quality of furniture in the PA, average time spent in the PA and burning matter in the environment.
5. Environmental components (biotic and abiotic). Abiotic components: Geographical location, soil type, bodies of water, climate, geology; Biotic components: Flora (vegetation) and fauna (domestic animals).

Respect for the interrelationship of the previous 5 dimensions, with the health of the inhabitants and the environmental environment, are as follows:

6. Health of family members. Common diseases: Acute respiratory infections (IRAs), acute diarrhoeal diseases (EDAs), other diseases and health services available to the inhabitants.
7. Environmental environment: Health quality of soil, quality of natural resources and health quality of water bodies.



Source: Escamirosa, 2015

Image 2: Model Dimensions and Variables (MECVE)

The model is proposed as an open system that, in terms of the sciences of biology and social sciences, dimensions and variables are subject to external conditions to maintain a certain level of functioning. In the process of analyzing housing and the immediate environment, for the determination of possible causes or risk factors to human health, it is directly related to habitat conditions in general. According to Quesada (1978), the system refers to a set of interrelated elements and the whole as such has a number of properties that are not individualized in any of the elements of the model, the consideration of the system is justified as unity and not as a simple sum of elements that make up it; therefore, the approach proposed of the MECVE model is integral, holistic that corresponds to the conduct of a case analysis with the joint study of all the elements.

The parameters and quality ranges of the variables are established with a health and sustainability approach, which facilitates the identification and evaluation of current conditions (zero time "t_0"),of rural housing and its immediate environment; they also allow to measure, on a scale, the quality levels according to the condition in which it is located: R1: excellent (green color), R2: sufficient (yellow), R3: partially (orange), R4: not met (red) and R5: critical (intense red); and it is determined that the desirable quality ranges for healthy rural housing (RSV), are R1 and R2 (see image 3).

Dimention: b) Physical-spatial (housing)					
Variables	Sub variables	Indicator	Existing parameters and standards	Quality ranges	Instrument
Materials used in housing	Floor	Type of floor	The analysis of the physical characteristics of the house allows to evaluate the quality of the house and the living conditions of the inhabitants. Homes that have the best materials in floor, walls and ceiling are considered to have a good quality. In addition, the health effects are related to the materials used in the construction, where the floor of land stands out, which limits people's chances of having a healthy life and raises the risk of disease. Also, the materials used on the walls and ceilings, are related to affectations on the health of the inhabitants (OMS, 1999), (NTC, 2004)((Sedesol, 2004), (UNAM, 2000), (Gómez, *et al*., 2000).	R1 = Wood on firm or separated from natural soil; R2 = Mosaic, fine coating or polished cement; R3 = Concrete (firm), stone or block with mortar joint; R4 = Stone or block unwithout gasket; R5 = Soil	Observation *In situ* (survey)
	Walls	Type of wall		R1 = Whit fine coating: septum, hollow or solid block, stone or cement; R2 = Non coated: septum, hollow or solid block, stone or cement; R3 = Wood or adobe; R4 = Sheet-zinc or metalic; R5 = Cardboard sheet, otate, lower, waste material.	Observation *In situ* (survey)
	Roof	Type of roof		R1 = Cement whit fine coating; R2 = Cement non fine coating; mud shingle, sheet made of alternative material with thermal and/or acoustic insulation system; R3 = Sheet-zinc or metalic; R4 = Palm or wood; R5 = Cardboard sheet or waste material.	Observation *In situ* (survey)

Quality ranges

- R1: is excellently met (Very Good)
- R2: is sufficiently met (Well)
- R3: partially complied with (Regular)
- R4: not true (Bad)
- R5: critical condition (Bad)

Expected quality ranges for RSV (Healthy Rural Housing)

- R1: is excellently met (Very Good)
- R2: is sufficiently met (Well)

Source: Escamirosa, 2015

Image 3: Model Dimensions and Variables (MECVE)

c) Intervention proposals

Possible solutions to the identified problems are analyzed by the team, based on the diagnosis of the site obtained. The proposals for habitat reconstruction and improvement; on the one hand, they focus on the development of structurally safe, economical and healthy homes, with water and drainage services, functional spaces and suitable to environmental conditions, which preserve the typology, with ecotechnologies and use of local building materials, alternative and environmentally friendly, with the purpose of preserving the biodiversity of species and ecosystems; and, on the other hand, proposals are carried out for habitat improvement in general such as community equipment: recreational, cultural public spaces, education, etc., consistent with the characteristics of the locality, in accordance with the environmental environment and the socio-economic conditions of the inhabitants.

Intervention proposals are submitted to users of the information; that is, to the inhabitants, notable people and representatives of the locality, with the aim of knowing their opinions or comments, which will be analyzed and taken care of, since they are important to

achieve the relevance and appropriation of the proposals put forward by the inhabitants.

III. Results

The team, integrated into the Academic Body Urban Development (CADU), with the participation of architecture students, have developed research work in various locations in the state of Chiapas, especially in the communities of low-income families, with the purpose of analyzing housing problems and their environment, and, from this, developing proposals for a solution. Below are some of the studies conducted.

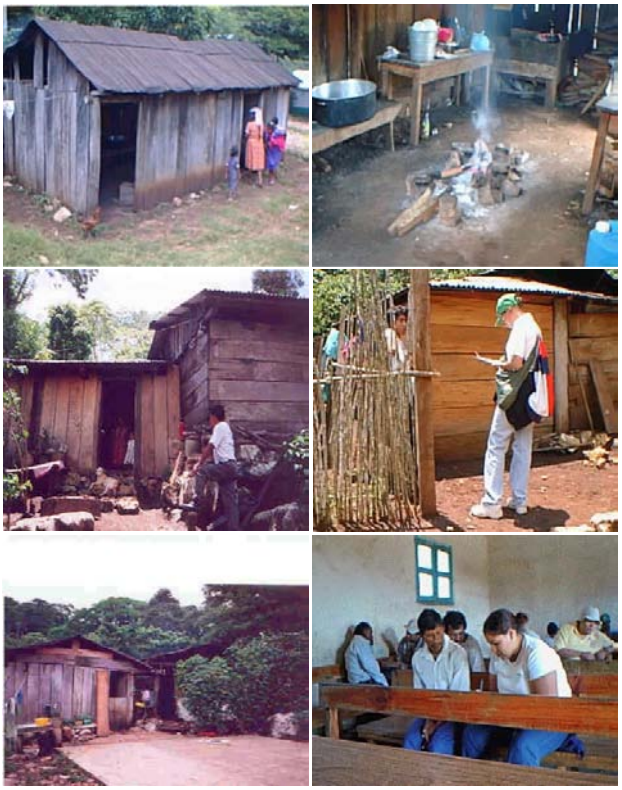


Image 4: Indigenous housing in precarious condition

- Nuevo San Juan Chamula, municipality of Ocozocoautla de Espinosa. It is an ejidal community located in the forest protection area and Fáunica Selva "El Ocote". It is located in the coordinates: Longitude 16 x 53 55.8", Latitude -93o 30'55.1", with an altitude of 1,042 meters above sea level. It was founded in 1969 by 70 indigenous people from San Juan Chamula and San Andrés Larrainzar, who were placed by the government in this new territory, in usufruct for people, due to various conflicts that the inhabitants had with other groups of indigenous people due to the tenure of the land. Some indigenous people found conditions similar to their places of origin; however, 30 of them were returned. From 1969 to 2000, the population increased to 500 inhabitants, today there are more than 850.

Image 5: Proposed alternative housing with local materials

Agriculture is the main economic activity, they grow coffee, corn and beans. In study, 3 main problems were identified: Access road (2.2 km of road in poor condition), health service (clinic, with only a medical assistant and midwife) and agricultural production-marketing (lack of transport). Of the houses: 34.6% in floor of soil, 64.4% do not have sanitary furniture, more than 30% do not have sanitary furniture or body grooming area, etc. (see image 4). The source of water supply is a spring, the water is not drinkable and is supplied by surface hoses, they have no sanitary drainage network or public cleaning service, among others (see image 4).

The proposed house (see image 5), was developed based on existing materials and environmental conditions: 1) The wooden walls of the original house, if the quality of the material allows, thus recycling the existing wood; Also, the walls are supported on a low wall built of stone: 40 cm wide, 50 cm high and 40 cm deep (foundation), to prevent deterioration by moisture, 2) The structure of the walls and roof, will be made of wood and the roof of sheet-zinc placed on a thermal layer, to conserve or isolate the heat , 3) A bathroom with tank to store water, for the purpose of dignifying the body grooming of women, 4) A dry latrine of 2 chambers.

Image 6: Presentation of housing prototypes to indigenous communities

- On 3 December 2008, CADU members, students and community representatives met: *Ichilho, Jolnajojtic*, Monte Bonito and *YutU'Kum* of Chamula municipality and *Ajtectic Bajo, Pij, Gechvó* and *Chajtoj* de Zinacantán, with the purpose of presenting and delivering 8 alternative housing proposals prepared by architecture students, advised by teachers-researchers; this activity was carried out to interact with the inhabitants and representatives of the communities, and, with it, listen to their comments, in relation to the prototypes of housing, which includes dry latrines, water storage tank, among others (see image 6).

Image 7: Precarious homes in Ocuilapa

The research carried out in the ejido Ocuilapa de Juárez, municipality Ocozocoautla, was funded by Fomix-CONACYT (2006-2008) and UNACH. The objectives set were: to carry out the diagnosis of housing and to develop prototypes appropriate to the characteristics and social conditions of the community. Analyses identified that 13% of homes are in precarious condition (see image 7), 80% with masonry walls built with concrete block parts with 2 holes, confined vertically with steel only at the intersections of walls and in the perimeter a dala; However, 77% of the condition of the structure of the houses is poor (R4), there are cracks in the spaces of doors and windows. Problems are attributed to the use of sand with 22% clay, technical deficiency in construction, etc.

Dimention	Variable	Subvariable	Quality ranges	R 5	R 4	R 3	R 2	R 1
b) Physical-spatial (housing)	Materials used in housing	Floor 34%	1					
			2				42%	
			3			24%		
			4		7%			
			5	27%				
		Walls 13%	1					
			2				80%	
			3			7%		
			4		9%			
			5	4%				
		Roof 12%	1					
			2				21%	
			3			67%		
			4		2%			
			5	10%				
		Structural condition in masonry walls 77%	1					
			2					
			3					
			4		77%			
			5					
		Roof (Structural condition) 40%	1					
			2				58%	
			3					
			4		40%			
			5					

Image 8: Records of the condition of floors, walls and roof of homes

In Image 8, the table shows the records obtained in the Ocuilapa community, specifically in the dimension: "Physical-spatial", in the "zero time" (site diagnostics) that identifies the materials used and the structural condition in which the walls and roofs are located. It is observed in homes that, 27% with floor, and, based on the quality ranges, corresponds to "R5" (Very bad); also, of the total homes with concrete block masonry, 77% record a structural condition on the "R4" (Mala) walls, which warns of insecurity. Regarding the ceiling, 10% have cover of cardboard sheet or waste material, 2% palm and 67% sheet-zinc; of these, 40% of the structure has various "R4" problems; In addition, the sheet covers have no insulators, which generates unfavorable thermal variation inside: cold and heat.

Image 9: Alternative housing for Ocuilapa

Image 9 shows the meeting with farmers from Ocuiapa, where architecture students presented prototype models, to listen to family feedback and make decisions in the configuration of homes. The construction plans of the homes that were built by 5 families were then developed, with the technical assistance of the team. The proposed walls with concrete blocks with 3 holes were reinforced with steel inside; vertical and horizontal senses, based on technical standards. The sand of the place that has 22% clay was used, due to the usual use of this material, as well as its availability and low cost. The technical information was integrated into a self-construction manual that was delivered to the ejidal representative (Escamirosa, *et al*, 2017).

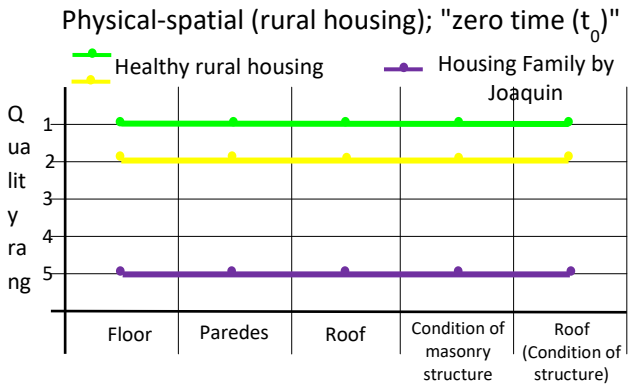


Image 10: Graph of record in "zero time" condition of the house

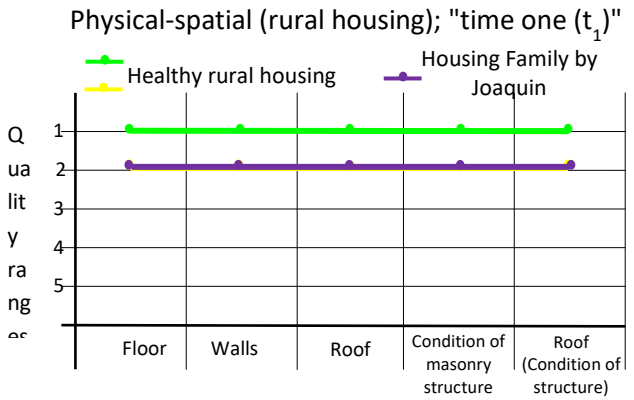


Image 11: Record chart in "time one" condition of the house

With the MACVE model, it is also possible to obtain the individual analysis of the house and its surroundings. The image shows some records in the "zero time (t_0)", of Joaquin's family home (see image 12). The walls, ceiling and structural, were in critical condition, "R5" (Very bad).

Identified the elements to be transformed (image10), Joaquin's family built their home in 10 months, which included training, advising and supervising the work, which ended in "time one (t_1)". The research project financed the materials used: cement, reinforcing steel, etc. The labor, for the extraction of stone and sand from the place and the construction, was in charge of the family.

Image 12: Housing before and after the intervention

The home of Joaquín Hernández, his wife Norbel Jiménez and their two children, during construction received no financial support, as it was a commitment raised from the beginning. Image 12 shows the housing conditions before and after the intervention: "zero time (t_0)" and "time one (t_1)", respectively. The house has 2 bedrooms, living room, dining room, on 36 m^2 of surface, plus an ecological stove, dry latrine with 2 chambers and bathroom with water storage tank. Also, the seismic-resistant capacity of housing built with concrete block walls with 3 holes was assessed and resulted from "low vulnerability", indicating that the walls have good resistance in cases of seismic action (Escamirosa, *et al*, 2017 and 2018).

In the town of Chiapa de Corzo, the research project was carried out: "Proposal for structural strengthening for the consolidation of traditional housing...", funded by PROMEP-SEP (2013-2015) and the objective was to contribute to the conservation of traditional adobe homes and increase structural security. The proposal was to reinforce the walls with a concrete membrane of 2 cm and steel mesh (electrowelded mesh 6x6/10x10). In Image 13, you can see the houses and their initial conditions (zero time), the construction process and the completion (time one). The work carried out did not require specialized labor, only one masonry officer and one pawn per dwelling (Ecamirosa, *et al*, 2014 and 2019) were employed.

Image 13: Structural intervention in 2 adobe homes in Chiapa de Corzo

The sism-resistant capacity of the houses of Ocuilapa de Juárez and Chiapa de Corzo, was examined with measurements of accelerographer, analysis and structural modeling with finite elements, and it was determined that the structure was adequate. This fact was corroborated by physically inspecting the dwellings, after the earthquake that occurred off the coast of Chiapas, on September 7, 2017, which had a magnitude of 8.2 on the Richter scale and caused damage and collapsed homes in different locations in Chiapas state. In the structural analyses carried out, the team of researchers of the Academic Corps Natural Risks and Geotechnology (CARNG)of the Autonomous University of Guerrero (UAG) collaborated.

The sism-resistant capacity of the houses of Ocuilapa de Juárez and Chiapa de Corzo, was examined with measurements of accelerographer, analysis and structural modeling with finite elements, and it was determined that the structure was adequate. This was corroborated by noting that the houses physically did not record damage, after the earthquake that occurred off the coast of Chiapas, on September 7, 2017, which had a magnitude of 8.2 on the Richter scale and caused damage and landslides in different locations in Chiapas state. In the structural analyses carried out, the team of researchers from the Academic Corps of Natural Risks and Geotechnology (CARNG) of the Autonomous University of Guerrero (UAG) collaborated.

Image 14: Proposal for housing and community public spaces

- In the town of El Encanto, municipality of Tapachula, on the coast of Chiapas, CADU-UNACH and CARNG-UAGro academics, developed the project: "Proposal for the improvement of the habitat of El Encanto, Puerto Madero, Tapachula, Chiapas", funded by the Institute of Science, Technology and Innovation of Chiapas (2019-2020) and by the Faculty of Architecture of UNACH (Escamirosa, et al, 2020). The objectives were: to make a diagnosis of the problem of housing and its environment (habitat) and, from this, develop adequate, safe, economic and healthy housing proposals, with services, the use of ecotechnologies, etc.

Intervention proposals were also developed for habitat improvement in general, according to the site. The team proposed 5 housing prototypes, as well as public spaces necessary for the community, among which are: Health Unit, Sports Court and Children's Games, Center of Art and Culture, among others. Image 14 shows the process of obtaining information from the site, with the participation of students; also, the presentation of alternative housing to low-income families, to know their comments and opinions of the proposals.

The alternative housing was developed for low-income families, without losing the essence of the local typology, habits of the inhabitants and materials used in the construction. The proposals are economical, with water and sanitation services, natural ventilation and thermal cover with sheet on insulating layer built with bamboo or cane of the place, which supports a mixture of soil and fiber of the coconut shell, to reduce the heat inside the houses. An important aspect of the proposal was the safety of the structure, as El Encanto is located

2.5 km from the Pacific Ocean and in the region of greatest teluric activity that exists in the country, so, the houses will have to withstand the strong winds and hurricanes that occur, as well as the seismic action.

IV. Conclusions

In the search for solutions for the reconstruction and improvement of housing and its environment (habitat) of low-income families living in rural communities in the state of Chiapas, the team has implemented a methodological strategy, based on the implementation of the rural housing condition assessment model, as a tool to assess initial conditions, monitor and control habitat transformations. The model has the possibility of being implemented in a community, which will guide the development of strategies and actions for collective housing improvement, but also, the instrument is used in the particular analysis of housing, at the beginning of "zero-time" reality assessments and the conduct of follow-up and intervention control assessments at various times ("time 1, 2, 3,... n"), and thus assesses the continuity of healthy and sustainable rural housing status over time.

The work presented, carried out in localities in the state of Chiapas, shows the importance of identifying and interpreting habitat problems in a holistic way and developing proposals for a solution in the same direction, which, according to the availability of economic resources, interventions can be progressive but aimed at meeting and ensuring the safety, health, well-being and quality of life of the inhabitants, especially for the benefit of low-income families living with high levels of social lag, poverty and vulnerability. And finally, with these works we try to consummate one of the aspirations of the Autonomous University of Chiapas, link their work with social reality, through teaching and research.

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Deflection Response of Structural Circular Sandwich Plates Subject to Uniform, Concentrated and Linearly Varying Load

By Obanishola. M. Sadiq & Ayotomiwa O. Salau
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Keywords: *sandwich plate, circular plate, deflection, variational iteration method, finite element method, analytical method, numerical method.*

GJRE-E Classification: *FOR Code: 090599*

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Keywords: sandwich plate, circular plate, deflection, variational iteration method, finite element method, analytical method, numerical method.

I. Introduction

Sandwich construction has been used in many earlier circumstances, one of the earliest notable application of sandwich panels was in Second World War, incorporated into the construction of the "Mosquito" aircraft, also, its use, particularly the clamped sandwich plates is seen in the design of commercial and military vehicle for both land and sea, for example, the outermost structure on a ship comprises of plates welded to an array of stiffener, sandwich plates are more preferred to monolithic solid plate in shipbuilding because of its high quasi strength, over time its use has been seen in other industries ranging from the space industry, civil engineering, radio electronics, and other sectors of the nation economy (Allen, 1969). Further recent applications can also be seen ranging from Blast resistant door, External cladding, Machine covering, Walls of temporary structures, Signage, Building partitions.

Structurally, it basically consists of two face-sheets made of high-strength material which may be isotropic or anisotropic and a core made of relatively flexible, less dense material. The core ensures the operation and stability of the plate. The face-sheet can be made of metal or composite materials and the core can be made of reinforced and unreinforced foamed plastics, rubber, balsa, metal in the form of corrugated sheet, cellular elements, etc.

(Zadeh & Masoud, 2017) investigated the bending analysis of a circular sandwich plate under distributed loads with both simply supported and clamped boundary conditions, the governing equations of the circular sandwich plate are obtained and solved using the Bessel functions, validated using the finite element method. The results indicated that under distributed load, maximum deflection happens at 0.3 of outside radius, away from the centre, and minimum deflection occurs at the outer edge of the circular sandwich plate. The results from analytical and numerical methods are compared and it shows that the analytical method provides acceptable accuracy. (Fleck & Deshpande, 2004) proposed an analytical model for the dynamic response of clamped sandwich beams to shock loadings including the effects of fluid-structure interaction, this loading represents shock loading in air. The analytical formulas are used to determine the optimal designs of sandwich plates that maximize shock resistance in the air for a given mass and the performance gain of these optimal sandwich plates.

This paper focuses on the deflection behaviour exhibited by circular sandwich plates under three basic loading conditions (Uniform, Concentrated and Linearly Varying load) whose boundary conditions are simply supported and clamped. This was done using an analytical solution, Variational Iteration method, to solve the governing nonlinear differential equation of a circular sandwich plate derived by Ren-huai, (1980) while using the Finite element method to validate the solution.

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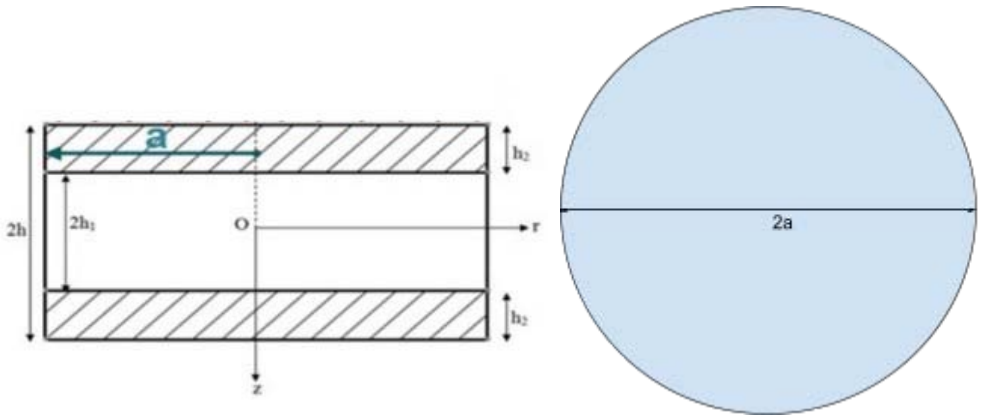
II. Analysis

a) b)

Figure 1: A Sandwich Circular plate with metal face-sheet and soft foam core



a) b)

Figure 2: Schematics of Sandwich Circular plate a) Side view b) Top view
$h_1 = 5\text{mm}$, $h_2 = 1\text{mm}$, $q_0 = 100\text{KN/m}$, $a = 100\text{mm}$

Table 1: Mechanical properties of the face-sheet and Core

Plate section	poisson ratio (v)	Young's modulus E (Mpa)	Material
Face-sheet	0.3	5500	(Polyester resin/glass fibres) M450 Shell
Core	0.41	896	(Polypropylene) Core

a) Loading Parameters

Uniformly Distributed $= q_0$

Point Load $= -\ q_0 .\ 2\pi r$

Linearly Varying load $= \frac{q_0}{2} - \frac{q_0 . r}{2a}$

b) Analytical solution (Variational Iteration Method)

The deflection function for both the simply supported and clamped sandwich circular plates were derived from the nonlinear governing differential equation modelled by Ren-huai (1980) for a circular sandwich plate, stated in expression (1). It was done using the analytical solution. Variational Iteration Method, which is an iterative method for solving the nonlinear equations of an engineering system by rewriting the given nonlinear equation as a system of coupled equations, it is capable of reducing the size of many calculations and it also gives rapid convergent successive approximations of the exact solution (He, 2005). It was executed using MAPLE (a computational software).

$$\frac{d^3w}{dr^3} . r + \frac{d^2w}{dr^2} - \frac{dw}{r.\,dr} - \frac{2t}{D} . \frac{d\varphi}{dr} \frac{dw}{dr} + \frac{2t}{Gh_0 r} . \left(\frac{d^3\varphi}{dr^3} . \frac{dw}{dr} r + \frac{d\varphi}{dr} \frac{d^3w}{dr^3} r + 2r\left(\frac{d^3w}{dr^2} - \frac{dw}{dr}\right) \frac{d^2\varphi}{dr^2} - \frac{d\varphi}{dr} . \frac{d^3w}{dr^3}\right)$$

$$- \frac{1}{2.D} qr^2 = 0 \qquad \ldots (1a)$$

$$\frac{d^3\varphi}{dr^3} + \frac{1}{r} \cdot \frac{d^2\varphi}{dr^2} - \frac{1}{r^2} \cdot \frac{d\varphi}{dr} + \frac{1}{2r} E\left(\frac{dw}{dr}\right)^2 = 0 \quad \ldots (1b)$$

Having the boundary conditions as follows

At $r = 0$, and at $r = a$

$$\delta w = 0 : \delta u = 0 \ \ \delta\phi = 0 \quad \ldots (2)$$

We introduced two different initial trial functions for both expressions (1a & 1b)

$$w_0 = w(0) + \frac{r^2}{2!} w'(0) \quad \ldots (3)$$

$$\varphi_0 = \varphi(0) + \frac{r^2}{2!} \varphi'(0) \quad \ldots (4)$$

$$A = w(0),\ \varphi(0),\ B = w'(0),\ \varphi'(0). \quad \ldots (5)$$

The Lagrangian multiplier for optimization,

$$\lambda := -\frac{1}{2}(s - r)^2 \quad \ldots (6)$$

Consider a general nonlinear system such as,

$$L[u(x)] + N[u(x)] = \psi(x) \quad \ldots (7)$$

Its correction function takes the form

$$u_{k+1}(x) = u_k(x) + \int_0^x \lambda(s)\,[L[u_k(s)] + N[u_k(s)] - \psi(s)]ds \quad \ldots (8)$$

Applying the above function to the nonlinear expression in (1) to obtain its correctional function,

$$w_{n+1} = W_n(r) + \int_0^r \lambda \left(\left(\frac{d^3}{ds^2} w(s) \right) s + \left(\frac{d^2}{ds^2} w(s) \right) - \frac{1}{s} \left(\frac{d}{ds} w(s) \right) \right)$$

$$- \frac{2t}{D} \left(\frac{d}{ds} \varphi(s) \right) \left(\frac{d}{ds} w(s) \right) + \frac{2t}{Gh_0 s} \cdot \left(\left(\frac{d^3}{ds^3} \varphi(s) \right) \right) \left(\frac{d}{ds} w(s) \right) s$$

$$+ \left(\frac{d}{ds} \varphi(s) \right) \left(\frac{d^3}{ds^3} \varphi(s) \right) s + \left(2s \left(\frac{d^3}{ds^2} w(s) \right) - \left(\frac{d}{dr} w(s) \right) \right) \left(\frac{d^3}{ds^2} \varphi(s) \right)$$

$$- \left(\frac{d}{ds} \varphi(s) \right) \left(\frac{d^2}{ds^2} w(s) \right) - \frac{1}{2.D} q s^2) ds \quad \ldots (9)$$

$$\varphi_{n+1} = \varphi_n(r) + \int_0^r \lambda \left(\left(\frac{d^3}{ds^2} \varphi(s) \right) + \frac{1}{s} \left(\frac{d^2}{ds^2} \varphi(s) \right) - \frac{1}{s^2} \left(\frac{d}{ds} \varphi(s) \right) \right) \quad \ldots (10)$$

Substituting the value of w0 and φ0 into the correctional function (9) & (10) and iterating each time to improve the accuracy with due consideration of the Lagrangian optimization function, the value of φ is looped into w to get the first iteration indicated as W1 below

$$W_1 := A + \frac{1}{2} r^2 B + \frac{1}{5} \left(\frac{tB^2}{D_f} + \frac{1}{4} \frac{q}{D_f} \right) r^5 + \frac{1}{4} \left(r \left(- \frac{2tB^2}{D_f} - \frac{1}{2} \frac{q}{D_f} \right) + \frac{1}{2} \frac{B}{r} \right) r^4$$

$$+ \frac{1}{3} \left(- \frac{1}{2} r^2 \left(- \frac{2tB^2}{D_f} - \frac{1}{2} \frac{q}{D_f} \right) - B \right) r^3 + \frac{1}{4} r^3 B$$

$$W_2 := A + \frac{1}{2} r^2 B + \frac{1}{5} \left(\frac{tB^2}{D_f} + \frac{1}{4} \frac{q}{D_f} \right) r^5 + \frac{1}{4} \left(r \left(- \frac{2tB^2}{D_f} - \frac{1}{2} \frac{q}{D_f} \right) + \frac{1}{2} \frac{B}{r} \right) r^4$$

$$+\frac{1}{3}\left(-\frac{1}{2}r^2\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)-B\right)r^3+\frac{1}{4}r^3B+\frac{1}{120}\frac{qr^5}{D_f}$$

$$W_3:=A+\frac{1}{2}r^2B+\frac{1}{5}\left(\frac{tB^2}{D_f}+\frac{1}{4}\frac{q}{D_f}\right)r^5+\frac{1}{4}\left(r\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)+\frac{1}{2}\frac{B}{r}\right)r^4$$

$$+\frac{1}{3}\left(-\frac{1}{2}r^2\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)-B\right)r^3+\frac{1}{4}r^3B+\frac{1}{60}\frac{qr^5}{D_f}$$

$$W_4:=A+\frac{1}{2}r^2B+\frac{1}{5}\left(\frac{tB^2}{D_f}+\frac{1}{4}\frac{q}{D_f}\right)r^5+\frac{1}{4}\left(r\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)+\frac{1}{2}\frac{B}{r}\right)r^4$$

$$+\frac{1}{3}\left(-\frac{1}{2}r^2\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)-B\right)r^3+\frac{1}{4}r^3B+\frac{1}{40}\frac{qr^5}{D_f}$$

$$W_5:=A+\frac{1}{2}r^2B+\frac{1}{5}\left(\frac{tB^2}{D_f}+\frac{1}{4}\frac{q}{D_f}\right)r^5+\frac{1}{4}\left(r\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)+\frac{1}{2}\frac{B}{r}\right)r^4$$

$$+\frac{1}{3}\left(-\frac{1}{2}r^2\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)-B\right)r^3+\frac{1}{4}r^3B+\frac{1}{30}\frac{qr^5}{D_f} \quad \ldots (11)$$

The iteration is repeated five times to get an accurate value of the w, a cumulative sum is applied to the iterations steps

$$w:=\sum_{j=0}^{n+1}W[j] \quad \ldots (12)$$

the expression for w is gotten as,

$$w:=3r^2B+6A+\frac{5}{4}\left(r\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)+\frac{1}{2}\frac{B}{r}\right)r^4+\frac{5}{3}\left(-\frac{1}{2}r^2\left(-\frac{2tB^2}{D_f}-\frac{1}{2}\frac{q}{D_f}\right)-B\right)$$

$$r^3+\frac{5}{4}r^3B+\left(\frac{tB^2}{D_f}+\frac{1}{4}\frac{q}{D_f}\right)r^5+\frac{1}{12}\left(\frac{tB^2}{D_f}+\frac{1}{4}\frac{q}{D_f}\right)r^5+\frac{1}{12}\frac{qr^5}{D_f} \quad \ldots (13)$$

Where the value of Df is substituted in eq. (13)

$$D_f:=\frac{E.t.h^2}{2.(1-\nu^2)} \quad \ldots (14)$$

Substituting the values of q for the uniform loading conditions as stated in loading parameters,

$$w:=3r^2B+6A+\left(2.96494555\times10^{-9}B^2+0.00007412363638\right)r^5+$$

$$\frac{5}{4}\left(r\left(-5.929890910\times10^{-9}B^2-0.0001482472728\right)+\frac{1}{2}\frac{B}{r}\right)r^4+$$

$$\frac{5}{3}\left(-\frac{1}{2}r^2\left(-5.929890910\times10^{-9}B^2-0.000148247278\right)-B\right)r^3+$$

$$\frac{5}{4}r^3B+0.00002470787879\,r^5 \quad \ldots (15)$$

- Applying simply supported boundary conditions with uniform distributed loading, where

$$w=0,\quad \frac{d^2w}{dr^2}=0 \text{ at } r=1$$

This resolves the value of constants A and B

$$\{A = 0.00004849276213,\ B = -0.0001022394985\},$$
$$\{A = 3.479371193 \times 10^{8},\ B = -7.335716713 \times 10^{8}\} \quad \ldots (16)$$

Substituting value of A & B in w, we get the deflection function for a simply supported, ws

$$w_s := -0.0003067184955r^2 + 0.0002909565728 + \frac{5}{4}\left(-0.0001482472728r - \frac{0.00005111974925}{r}\right)r^4 +$$
$$\frac{5}{3}(0.00007412363640r^2 + 0.0001022394985)r^3 - 0.0001277993731r^3 + 0.00009883151517r^5 \quad \ldots (17)$$

- From (15), Applying clamped support boundary conditions with uniform distributed loading, where

$$w = 0,\ \frac{dw}{dr} = 0$$
$$\{A = 0.000008779843721,\ B = -0.00002797118353\},$$
$$\{A = 8.416399911 \times 10^{8},\ B = -2.681330934 \times 10^{8}\} \quad \ldots (18)$$

Substituting the value of A & B in w, we get the deflection function for a clamped support, wc

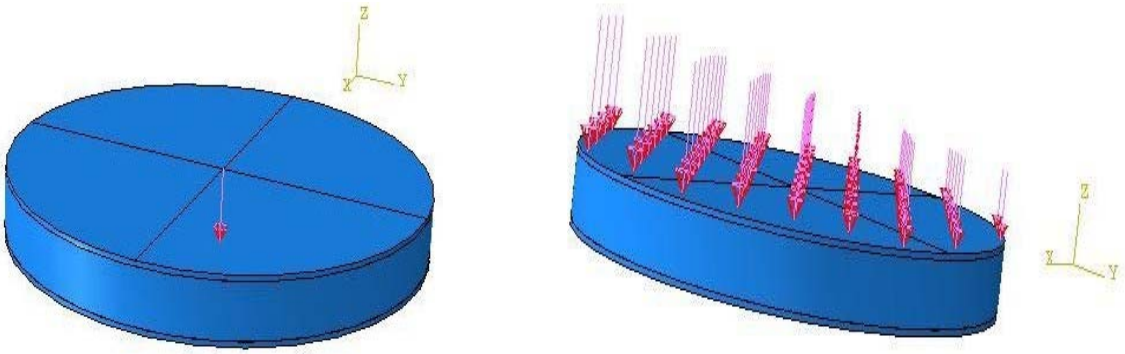
$$w_c := -0.00008391355059r^2 + 0.00005267906233 + \frac{5}{4}\left(-0.0001482472728r - \frac{0.00001398559176}{r}\right)r^4 +$$
$$\frac{5}{3}(0.00007412363640r^2 + 0.00002797118353)r^3 - 0.00003496397941r^3 + 0.00009883151517r^5$$
$$\ldots (19)$$

Expression (17) and (19) represents the deflection functions for the circular sandwich plate on simply supported and clamped support conditions respectively under a uniform loading.

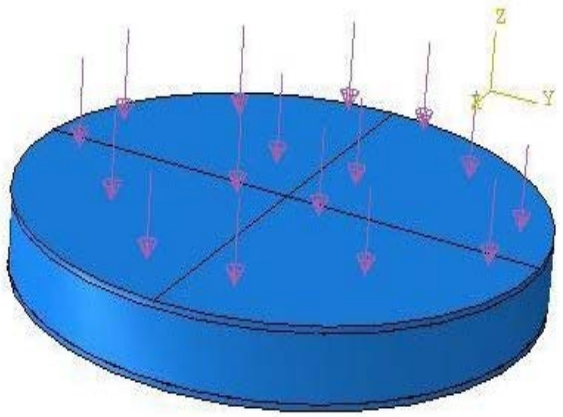
The deflection functions for point load and linearly varying loading conditions with each boundary conditions (simply supported and clamped) were also derived and the functions are plotted accordingly to get a visual representation of the deflection response across the symmetric half-length of the sandwich circular plate. The plots are shown in Figure 4 -10.

c) Finite Element Method

Here the finite element solution has been implemented using ABAQUS to verify the accuracy of the analytical method. The sandwich plate was modelled in parts based on the three different layers using 3D deformable solid extrusion, for both the core and the face-sheets, C3D8R, an 8 node linear brick element with reduced integration and hourglass control was applied, and parts were assembled under a tie constraint where the corresponding nodes of connecting layers are joined while considering the surface to surface interaction between the individual parts.



a) b)



c)

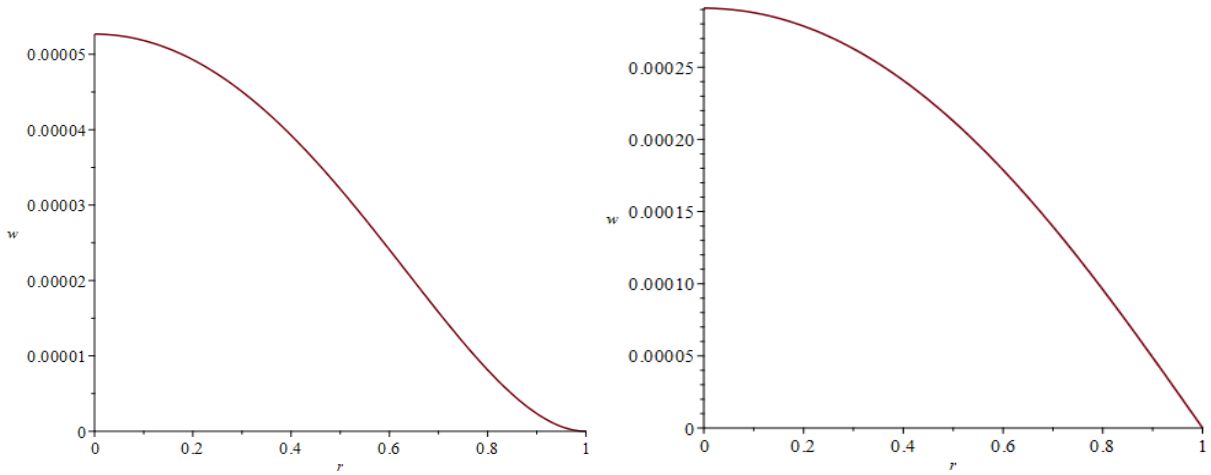
Figure 3: Loading configuration on the Sandwich Circular Plate. a) Concentrated load b) Linearly varying load c) Uniform load

A full model of the plate was used in the analysis, with an element size of about 0.0010 and different loading conditions of Uniform load, Point load and Linearly-varying load acting under boundary conditions of both clamped and simply supported for each loading configuration. The deflection responses under each loading conditions with the corresponding support conditions was measured and the result compared with the analytical model.

III. Result Discussion

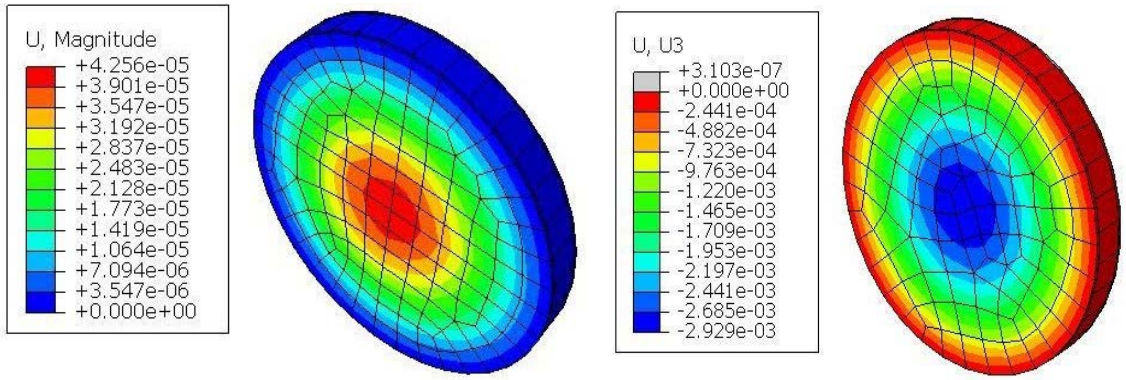
The resulting plots below showed the deflection behavior across the symmetric half-length of the plate, it showed the deflection curve of half the sandwich plate starting from the edge of the plate to the center at origin, under which a Clamped and simply supported boundary is considered for the plate as seen in the figures below. The curve for the Clamped boundary showed a slight tangent relationship with the x-axis indicating a dip before rising to its peak at the center of the plate, this was due to the moment generated due to its Clamped boundary conditions whereas simply supported showed a straight rise from the x-axis to its peak at the center of the plate, unlike the Clamped, there was no dip in the curve indicating the absence of moment at the boundary conditions, the curve for the simple support was quite steeper than of the Clamped support.

The shapes of the plot were quite similar to each other, point load is a form of uniform load only that it's concentrated at the center making a more visible impact on the plate, visual representation of this was seen in the finite element model. The clamped support generally showed a lower maximum deflection compared to the simple support, this was due to the moment resistance encountered by the load at the support as a result of its Clamped nature ensuring rigidity.



a) b)

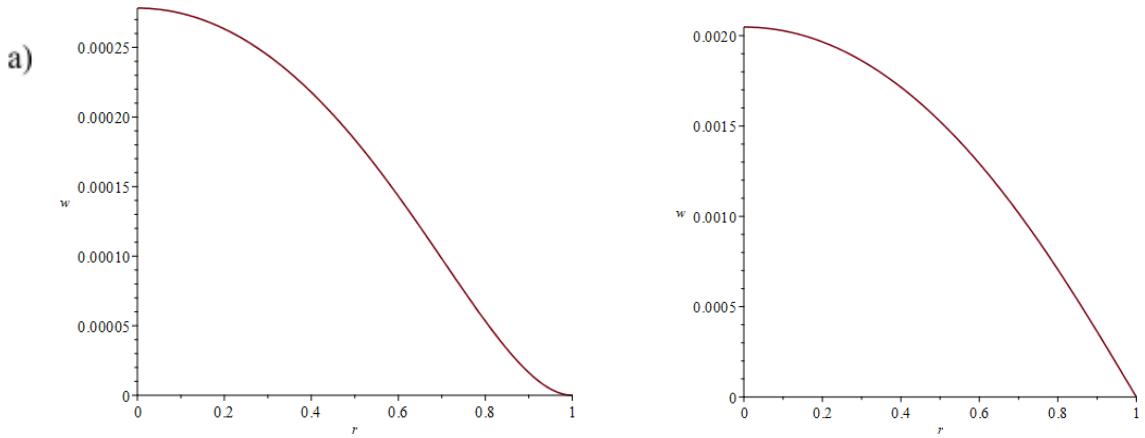
Figure 4: Analytical solution (VIM) deflection plot for Uniform load under a) Clamped support b) Simply supported



a) b)

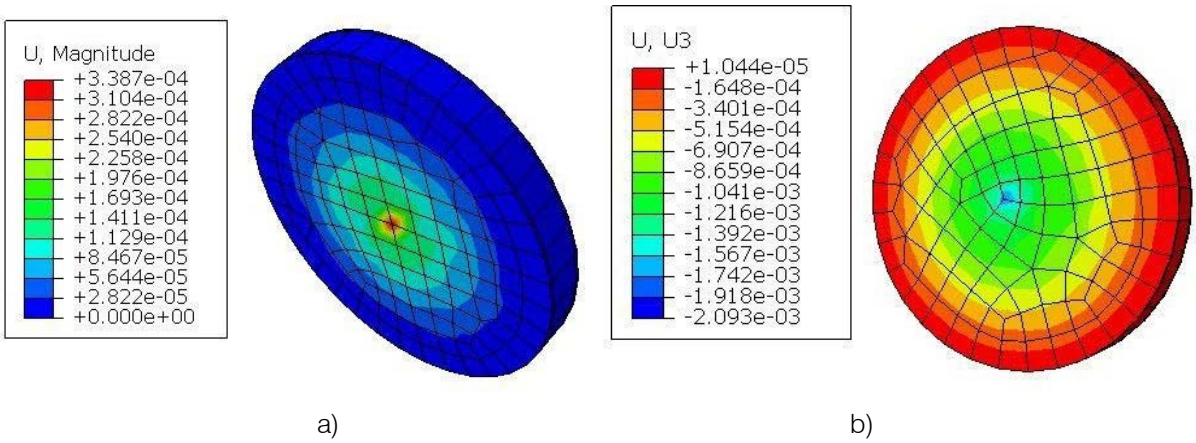
Figure 5: 3D Finite Element deflection plot for Uniform load under a) Clamped support b) Simply supported

The Uniformly distributed load generates a maximum deflection for the Clamped support at a max value of 0.05mm while a higher max deflection value for the simple support at 0.25mm.



a) b)

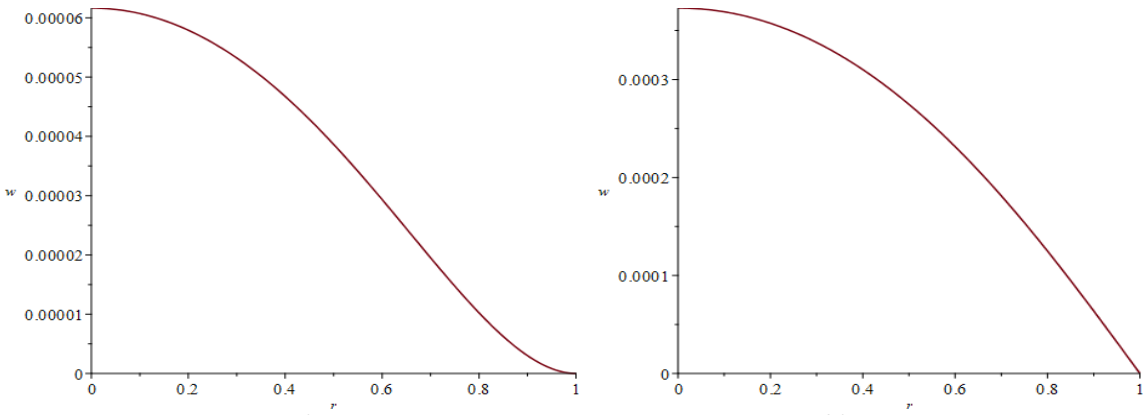
Figure 6: Analytical (VIM) deflection plot for concentrated load under a) Clamped support b) Simply supported



a) b)

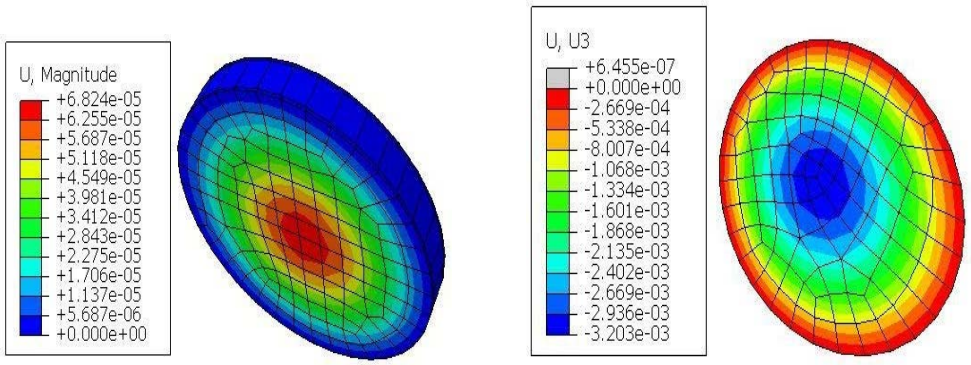
Figure 7: 3D Finite Element deflection plot for concentrated load under a) Clamped support b) Simply supported

The equivalent Point load shows a higher value of the maximum deflection of 0.28mm and 2.1mm across the length of the plate for both Clamped and simply supported conditions respectively but it gives a higher value for the simply supported compared to the Clamped of which reason is due to the focus of the load at the center of the plate whilst all other factors remain constant, figure 9 shows the finite element illustration of the deflection behavior in colour variation across the elemental planar face of the plate indicating the deflection, there was a correlation in values from both method indicating accuracy of results.



a) b)

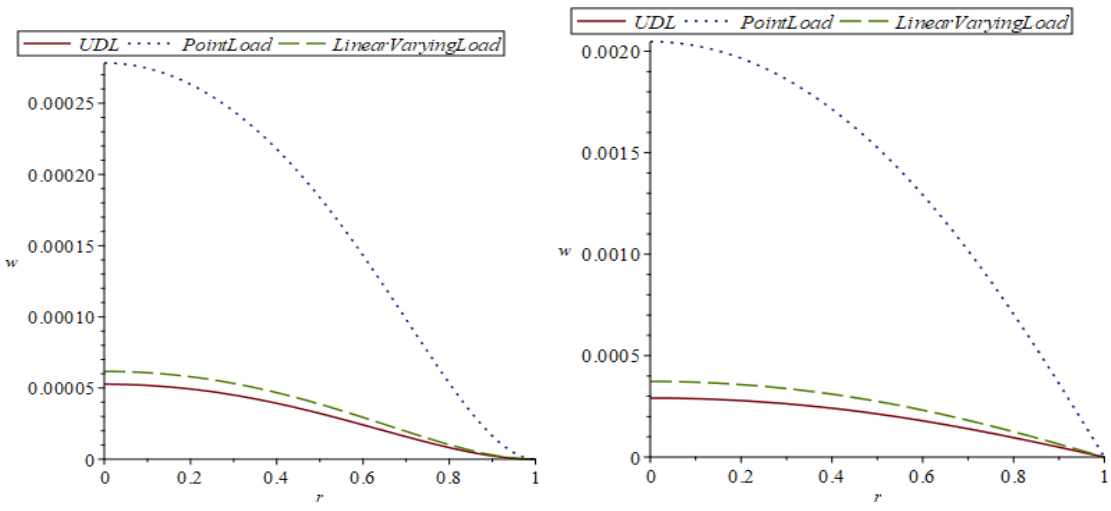
Figure 8: Analytical (VIM) deflection plot for linearly varying load under a) Clamped support b) Simply supported



a) b)

Figure 9: 3D Finite Element deflection plot for linearly varying load under a) Clamped support b) Simply supported

The Linearly varying load-deflection curve shows a rising deflection plot but a slight shift from the center of the plate, the analytical method could not visually represent this phenomena but the 3D plot show a shift in maximum deflection away from the center of the plate, this is a common behaviour of a member loaded with linearly varying load, the loading values. It showed a higher deflection for the simply supported compared to the Clamped, at 0.3mm to 0.06mm for both supports respectively.



a) b)

Figure 10: Combined Analytical (VIM) deflection plot for the different loading conditions with a) Clamped support b) Simply supported

Upon combining the deflection plot of the three required loading conditions, it was observed that overall the point load had the highest value of deflection at a max of 0.28mm for Clamped support and 2.1mm for simply supported, the curve for the point load shows a steeper gradient compared to the remaining load types, but both possess similar curve structure as regards its boundary conditions.

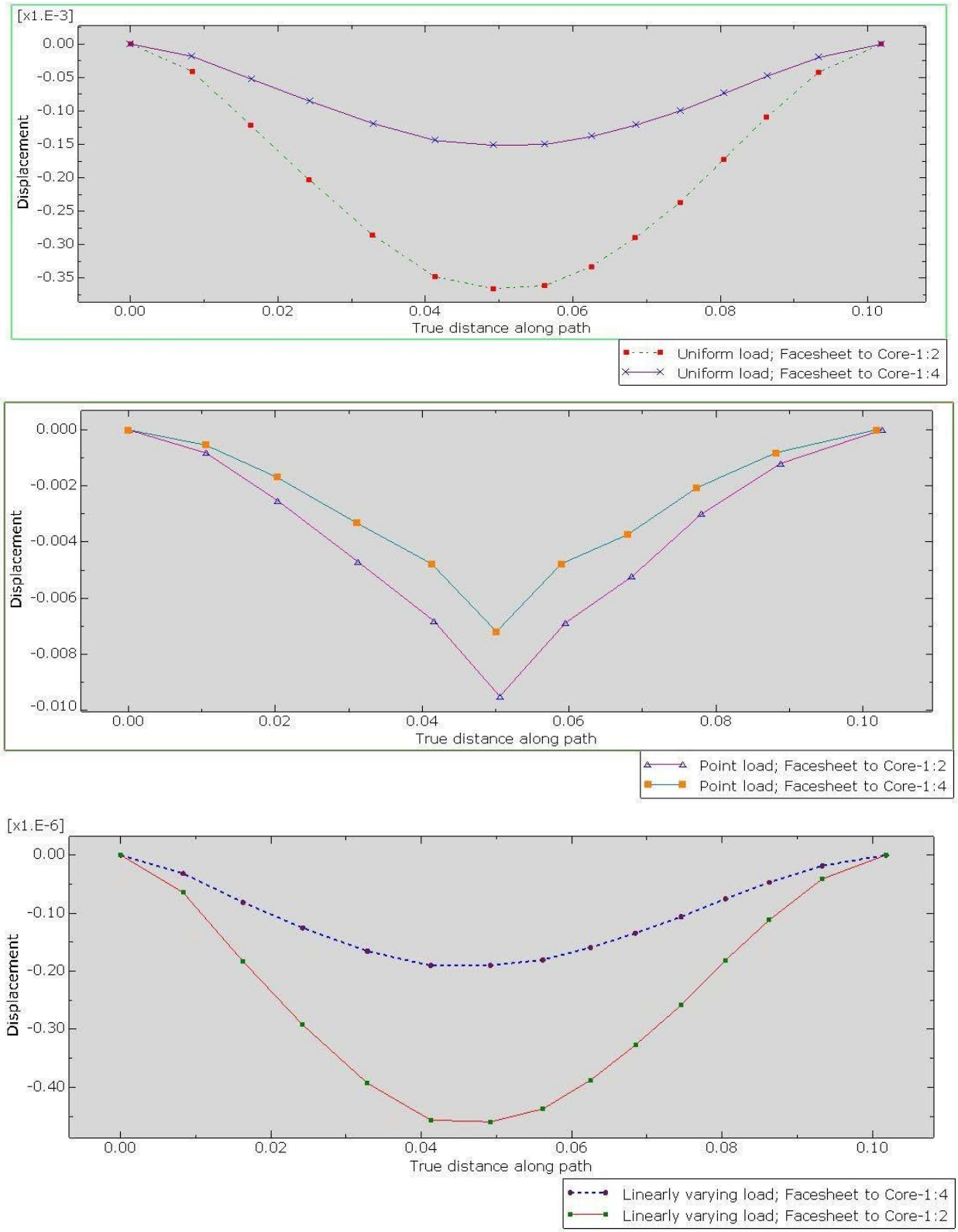


Figure 11: Variation of the thickness of the facesheet to core in the ratio 1:2 & 1:4 under clamped condition

Figure 11 represents the deflection behaviour of the circular sandwich plate when the thickness of the facesheet to the core is assembled in the ratio 1:2 and 1:4 i.e. the thickness of the core is 2x and 4x the thickness of the a facesheet for each respective loading conditions, The respective loading conditions being applied to the surface of the plate include uniform, point and linearly varying load. This was done assuming the boundary conditions are Clamped.

The uniform load deflection curve for both thickness ratios show a difference in the magnitude of each respective deflections, the plate with the thickness ratio of 1:2 for facesheet to core shows a higher deflection compared to that of ratio 1:4. In subsequent variations of the loading, with point load in focus, similar symmetrical behaviour is seen in the deflection disparity of both thickness ratios, a steeper curve is seen here as corroborated by analytical method figure 8 with the plate of ratio 1:4 for facesheet to core having a lower deflection compared to that of ratio 1:2. One common trend seen in the plot for the point load and uniform load is that they both have their max deflection at the center of the plate, but the case is slightly different for the linearly varying load.

The linearly varying load experiences maximum deflection slightly away from the center of the plate as can be seen in 3D plot in finite element plots, the deflection curve shows a steeper gradient on the side of the plate with the larger load magnitude while a less steeper gradient on that of the lower load magnitude, this is seen in both variations of the thickness ratios, with thickness ratio of 1:4 having a lower deflection compared to that of 1:2.

Overall, an inverse relationship is seen between the thickness ratio and deflection of the sandwich circular plate, when the core was twice the size of the facesheet, a larger deflection was obtained while when the core was four times the size of the facesheet, a lesser deflection was obtained. This means a substantial increase in the thickness of the core in relation to the facesheet leads to a lower deflection.

IV. Conclusion

From the study, it can be concluded that simply supported sandwich circular plate generally experienced a higher deflection compared to the Clamped supported when placed under the various loading types considered in this research, this is due to the rigid end of a Clamped support which generates a moment to resist the bending as a result of the load. On the other hand, a Point load on a sandwich plate generates a larger deflection compared to that of uniform load and a linearly varying load, this is as a result of the load magnitude concentrated at the centre of the plate causing a focused effect as seen in both the analytical method and the Finite Element Method. A sandwich plate is quite susceptible to a point load, making it not entirely suited from that kind of loading configuration, a linearly varying load causes a slight deviation of the deflection of the sandwich plate from its centre, this would likely result in a strain on one support end compared to the other. Applications of Sandwich plates can be seen in shipbuilding, staircase landing constructions, walls, and platforms as well, offering space savings and high accuracy resulting in reduced straightening work and rapidly constructed housing using steel sandwich modules.

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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.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. 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.

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

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

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

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

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. 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 for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

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

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

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

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon 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 for 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 of 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 criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to 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 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 avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

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

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite 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 approaches 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. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a 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 limit the initial two items to no more than one line each.

Reason for writing the article—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 for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity 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 of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets 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 for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory 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 soundly written procedures segment allows a capable scientist to replicate 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 to give the least amount of information that would permit another capable scientist to replicate 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 section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show 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:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the 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—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and 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 as 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. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give 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 manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit 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 section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an 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 implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully 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 the prospect, and let it drop at that. Make a decision as to whether each premise is supported or 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 an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of 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 other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

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.

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 Above 200 words	No specific data with ambiguous information 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

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