A FEA-BASED FEASIBILITY STUDY ON THE REPLACEMENT OF STUDENT WOODEN DESKS AND CHAIRS WITH A PLASTIC ARM CHAIR.

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Abstract

Deforestation increases the amount of CO_2 gas in the atmosphere and is also a permanent destruction of forests. According to the United Nations' Food and Agriculture Organization (FAO), approximately 18 million acres of forest are lost each year. Thus, regulations have been placed on forests' clearance because the loss of forests causes global warming. Having identified the severe effects of greenhouse gases on the earth, this paper focuses on finding an alternative material for furniture manufacturing in order to reduce deforestation. With wooden furniture prices increasing due to the regulations limiting deforestation, the effect being significant in the education sector, plastics are studied as the alternative material to classroom wooden furniture. Instead of having a desk and a chair, the furniture is designed as a single combined plastic arm chair to save material. A Finite Element Analysis (FEA) is carried out on the selected polycarbonate arm chair using Solid Works, and it is observed that the maximum stress that the arm chair can be subjected to is less than that at which polycarbonate alloy (ABS-PC) fails. Hence, it is possible to replace classroom wooden furniture with cheap and easy to maintain polycarbonate arm chairs.

Key Words:

deforestation, global warming, furniture, FEA, ABS-PC

1. Introduction

'Go Green' is the motto that has been echoing in our streets and nations ever since the kick-off of the 21st century. Due to studies being carried out by meteorologists, a need has arisen for there to be strict regulations on the destruction of vegetation, that is the cutting down of trees. This is because trees play a crucial part in reducing the greenhouse gas, carbon dioxide (CO_2) emitted in the atmosphere through the process of photosynthesis. Amongst the six most common man-made greenhouse gases, CO_2 is the most abundant and is responsible for 85 percent of human-produced greenhouse gases in the U.S. (Bradford, 2015).

Background Information

According to the Merriam Webster dictionary 2016, wood is a porous and fibrous structural tissue that is found in the stems and roots of trees and other woody plants. It has found considerable use in the furniture industry because of its inexpensiveness, strength, durability and high compressive strength.

However, the inexpensiveness of obtaining wood comes at a cost to the environment. Trees have to be cut down and this deforestation, according to Nature Geoscience, contribute between 6-12% of all the annual global carbon dioxide emissions. NASA predicts that if the current deforestation levels proceed, the world's rainforests may be completely finished in as little as 100 years (NASA, 2017). Other causes of deforestation besides timber harvesting include land creation and fuel, but are insignificant compared to deforestation through timber harvesting. According to Michael Daley, an associate professor of environmental science at Lasell College, the number one problem caused by deforestation is the impact on the global carbon cycle. Greenhouse gases can force climate change if produced in large quantities (Daley, 2015). In 2012, CO_2 accounted for about 82 percent of all U.S. greenhouse gas (EPA, 2017). Trees help, as according to Greenpeace, 300 billion tons of carbon, 40 times the annual greenhouse gas emissions from fossil fuels, is stored in trees. The deforestation of trees not only lessens the amount of carbon stored, it also releases carbon dioxide into the air. This is because when trees die, they release the stored carbon. According to the 2010 Global Forest Resources Assessment, deforestation can cause a billion tons of carbon to be released into the atmosphere per year. It is the second largest human-caused source of carbon dioxide to the atmosphere, ranging between 6-17% percent (Van der Werf, et al., 2009).

Figure 1.1 Effects of Global Warming

Carbon isn't the only greenhouse gas that is affected by deforestation. Water vapor is also considered a greenhouse gas. Daley (2015) also reports that, "The impact of deforestation on the exchange of water vapor and carbon dioxide between the atmosphere and the terrestrial land surface is the biggest concern with regard to the climate system." Changes in their atmospheric concentration will have a direct effect on climate. Effects of deforestation are quite harmful (Figure 1.1) and there is need for the use of alternative materials in the manufacturing industry, in order to replace wood. This research aims at studying the feasibility of replacing wooden desks and chairs used by students with plastic arm chairs.

Problem Statement

Continuous clearing of forests for timber harvesting results in an increase of CO_2 emissions leading to global warming.

1.3 Aim

To carry out a feasibility study on the potential use of plastics as a replacement for wood in furniture manufacturing.

1.4 Objectives

- Analyse the properties of a selected plastic material used in furniture manufacturing.
- Determine the forces experienced in a normal wooden desk and chair setting.
- Carry out a Finite Element Analysis (FEA) to determine if the plastic would be able to withstand the forces above.

1.5 Methodology

The objectives in this research will be met through the following methods:

1. *Research*- This will be done through the University of Zimbabwe's library and the internet.
2. *Consultation with a furniture manufacturing company*- A student arm chair made from plastic from the company will be taken and analysed using FEA to determine its strength and durability capability in replacing wooden desks and chairs.
3. *FEA* – Which is a computerized method for predicting how a product reacts to real-world forces, vibration, heat, fluid flow and other physical effects. It shows whether a product will break, wear out or work the way it was designed. An example of a FEA carried out on a turbine blade is shown in Figure 1.2, where the red regions represent areas of higher stress levels.

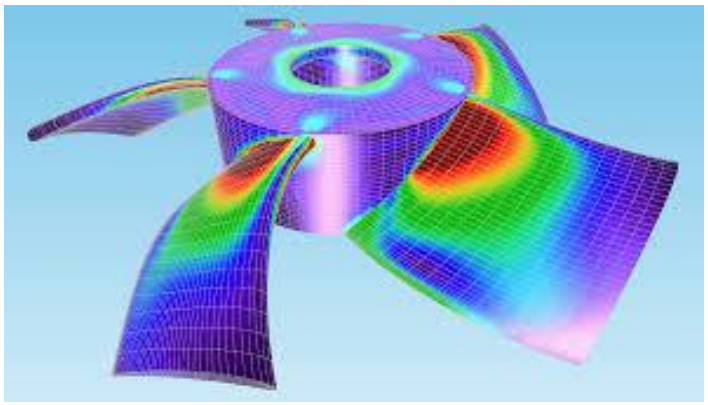

Figure 1.2 FEA on a Turbine Blade

1.6 Justification

Replacing the use of wood will save forests. When forests are degraded, it can set off a devastating chain of events both locally and around the world. Hence saving them will save species extinction, improve the water cycle, prevent soil erosion, improve life quality, and above all reduce emission of greenhouse gases thus reducing global warming. The use of wood in furniture manufacturing also has its disadvantages. Wood is not very stiff and cannot withstand heavy natural calamities. It is fire prone and can be easily damaged. It absorbs surrounding vapor (Shalam, 2013) causing decay through mould and fungi. Wood products require great care and maintenance which is costly.

1.7 Conclusion

Carrying out a FEA will provide the necessary information required for providing alternatives to wood in furniture manufacturing. This will save a lot of trees and as a result save the planet Earth from the harmful effects of global warming.

2. Literature Review

2.1 Introduction

The classroom furniture manufacturing industry is one that has a great potential to blossom in Zimbabwe and many other nations. This is because education is the key to success, and thus will always be a sector that will be supported by governments and various stakeholders. In general, the manufacturing process of classroom desks and chairs basically focuses on student comfort and product durability. In this chapter, various manufacturing materials will be looked at and a comparison will be made so as to bring out the general material preferences.

2.2 Furniture Materials

According Nimeyer S, a professor at the University of Nebraska Lincoln Extension, seven types of materials are commonly used in furniture manufacturing. Table 2.1 shows these materials and summarises the materials' characteristics as well (Niemeyer, 2017).

Table 2.1 Furniture Material Characteristics

Material	Characteristics
Woods	(a) *Plywood* -made of layers of wood glued together with the wood grain at right angles and is often faced with a thin veneer -strong and resists splitting and warping (b) *Solid wood* -generally more expensive but can be refurnished several times. (c) *Hardboard* -made of wood fibres sealed together with adhesives, steam and pressure.
Paper/ Cardboard	Paper -not resistant to heat, moisture, heavy use, scratches and is not easily cleaned. It cannot be refinished or repaired easily, and thus is often used in low-cost furniture.
Metals: Steel, aluminium, copper, brass, bronze, iron	Examples are steel, aluminium, copper and bronze Usually easy to care for but may require the use of protective coatings
Glass	Easy to clean, but however fragile and prone to breaking.
Plastics	Generally strong but lightweight. Some scratch easily and are affected by chemicals or cleaners.
Bamboo and Rattan	Strong due to their weight Water resistant and durable Bamboo is less flexible, which limits its bending capability.
Marble	Marble can break – especially along the veining lines. It can stain from acids, oils, metals, etc.

Figure 2.1 Different Types of Chairs (From left to right-wood, plastic, glass and marble)

2.3 Use of Wood in Furniture

Despite fast coming to depletion and having so many uses other than furniture manufacturing, wood continues to be the most common type of material in furniture manufacturing. This continued use is attributed to the favourable wood properties that make it more preferable when it comes to furniture manufacturing. These properties include:

1. ***Thermal properties***- unlike metals which can expand when exposed to high temperatures, wood is resistant to high temperatures. It also has low heat conductivity which makes it suitable for use in any season of the year.
2. ***Mechanical properties***- these include strength and durability. Wood furniture is resilient and requires very little maintenance; can stand constant abuse, whether it's spills or scratches in the classroom; and can last for generations with minimum care. It has also considerable strength in compression (Record, 1914), which is a favourable property in furniture manufacturing where compressive forces are common (Figure 2.2).
3. ***Comfort***- wood furniture is more solid and therefore offers more solid support and comfort, which is not experienced in plastic or metal furniture.
4. ***Acoustic properties***- absorbs sound and echoes and thus reduces noise in a typical classroom setting.

5. ***Aesthetic appeal***- wood can also immediately bring warmth to sterile surroundings through creating a good look and feel.
6. ***Ease of fabrication*** (Newport, 2010)
7. ***Hardness*** - resistance to indentation (Green, et al., 1999)
8. ***Stiffness***- resists deformation (Mendoza, 2014).

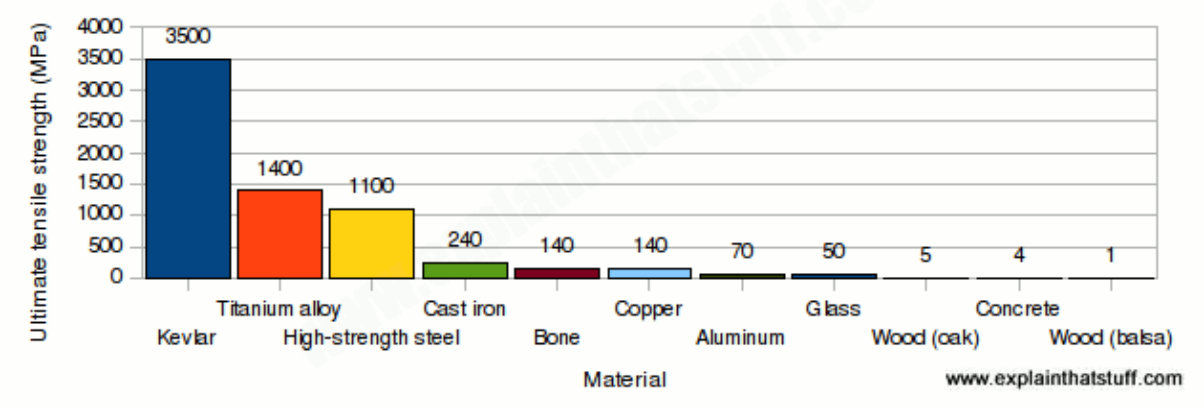

Figure 2.2 Tensile strengths of different materials

9. ***Ease of maintenance***- requires effortless maintenance. Water or dust should not be allowed to settle on the furniture for extended periods.
10. ***Value***- although initial cost of purchase or manufacture may be higher, the benefits will be actually reaped with time (Milker, 2017).
11. ***Modifiable***- wood furniture can be changed over time to give it a second, third or fourth life. By sanding and staining, or painting, it can be refinished to give it a new look.
12. ***Variety***- vast range of colours and tones of wood means that plenty of variety is available for style and look.
13. ***Affordable***- initially the wooden furniture will cost more but in terms of longevity, it will be wise to invest in wood furniture (Clecker, 2017).

2.4 Plastics

Figure 2.3 Plastic Furniture

A plastic is a material consisting of any of a wide range of synthetic or semi-synthetic organic compounds that are malleable and thus can be moulded into solid objects. Their development evolved from the use of natural plastic materials (e.g., chewing gum, shellac) to the use of chemically modified, natural materials (e.g., natural rubber, nitrocellulose) and finally to completely synthetic molecules (e.g., epoxy, polyvinyl chloride).

2.4.1 Classification

Depending on the qualities that are relevant for product design and manufacturing, plastics are classified into four groups. These are:

- ***Thermoplastics and Thermosets*** - Thermoplastics (polyethylene, polystyrene and PVC) do not undergo chemical change in their composition when heated and so can be moulded again and again. Thermosets, or thermosetting polymers, can melt and take shape only once: after they have solidified, they stay solid.
- ***Conductive Polymers*** - Intrinsically Conducting Polymers (ICP) conduct electricity.
- ***Biodegradable Plastics and Bioplastics*** - Biodegradable plastics break down upon exposure to sunlight or ultra-violet radiation, water or dampness, bacteria, enzymes or wind abrasion (Stevens, 2002).
- ***Engineering Plastics*** - Have better mechanical and/or thermal properties than the more widely used commodity plastics (such as polystyrene, PVC, polypropylene and polyethylene).

Figure 2.4 Engineering Plastics

Of the four groups mentioned above, engineering plastics, either thermoplastics or thermosets, are the ones that are used in furniture manufacturing.

2.4.2 Types of Furniture Plastics and Properties

Plastics are used in their solid form to make moulded chairs. Table 2.2 shows the common types of plastics used in furniture manufacturing and their properties.

Table 2.2 Common Furniture Plastics

Plastic Name	Properties
Polypropylene	-higher melting point, fairly strong and durable -easy to add colour to -has the ability to stand up to forces being applied without it deforming in any way (Ryan, 2007).
Polyethylene	-lower melting point than polypropylene but however much sturdier. -is a thermoplastic and can thus be recycled
Polyvinylchloride (PVC)	-low cost -easier to care for and less likely to crack in the same way that many natural leathers will. -resistant to water; lower resistance to sunlight (Crawford, 1981).
Polycarbonate	-is one of the strongest types of plastics available. This means that entire pieces of furniture can be moulded from polycarbonate including the legs, while still maintaining a reasonable amount of strength -slightly more environmentally friendly and is recyclable.
Nylon	-strong material. -low resistance to heat (Brydson, 1975).

2.5 Comparison of Wood and Plastic Materials

While wood has found favourable use as a furniture material, this has led to the serious issue of global warming through deforestation. On the other hand, plastics provide an alternative way to this in that their production requires no cutting down of trees. However, being mostly non-biodegradable, plastics can also cause pollution to the natural environment. Nevertheless, this problem is solvable through recycling the plastic material.

A thorough comparison carried out by the researcher, of plastic and wood materials in furniture manufacturing is shown below (Table 2.3). This comparison was carried out through looking at the advantages and disadvantages of using each type of material in furniture manufacturing.

Table 2.3 Plastic vs Wood

Property	**Wood**	**Plastic**
Cost	-quite expensive	-inexpensive as compared to wood and metal
Weight	-heavy and sturdy, thus it does not easily break	-light weight and can be easily moved around. Thus, it is safe for children environments
Durability	-durable and very resistant to wear -can easily crack when exposed to unfavourable environmental conditions	-also, resistant to wear but to a lesser extent as compared to wood -does not easily break or crack
Longevity	-long lasting, therefore it will eventually cater for the initial high cost	-lacks longevity as it is easily broken by heavy weights
Maintenance	-requires low but regular maintenance, for example, it has need for polishing for shiny surfaces	-requires little or no maintenance
Production	-causes deforestation; long manufacturing processes as compared to plastics	-no deforestation; easy to mould
Pollution	-no pollution, eco-friendly	-mostly non-biodegradable therefore not eco-friendly
Water Resistance	-absorbs moisture therefore it can crack when exposed to moisture	-water proof, does not crack or rust
Safety	-unpolished surfaces can hurt people or damage clothing and other fabric materials	-harmless, rarely any sharp corners and thus it is safe where children are around
Elegance	-requires surface finishes to give it good elegant finishes	-lacks elegance, but however is available in very vibrant colours
Thermal Properties	-good heat conductor, and does not deform when exposed to heat	-can deform(thermoplastic), or degrade(thermosets), when exposed to high temperatures

2.6 Causes of Failure in Classroom Wooden Furniture

Being quite a strong material, failure in wooden furniture is generally caused by improper handling. In a typical classroom environment, scratches made by students damage the furniture. There are cases of bad behaviour (Figure 2.5) whereby the students mishandle the furniture, tip it over, or sit or stand on desks, which can also have a very significant and negative impact on the longevity and proper functioning of the furniture. Bad behaviour also results in scratches and breaking of plastic furniture, with plastic furniture being more prone to breaking as compared to solid furniture. Since wood absorbs moisture quite easily, spillages of beverages on the table can also damage the furniture. This will expose the wood to unfavourable conditions that favour the development of cracks and ultimately lead to failure. However, this effect is one that is absent in plastic furniture, since it is moisture-resistant.

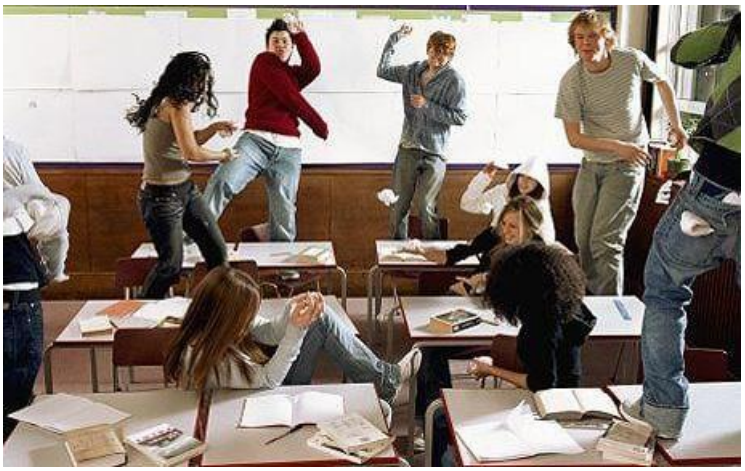

Figure 2.5 Bad Student Behaviour

A study carried out by Adewole and Olorunnisola (2010) indicated that the common causes of failure in Secondary School furniture were mainly poor joining methods and low-grade use of wood in the manufacturing process. For the types of desks and chairs that had wooden legs and back supports, Adewole and Olorunnisola indicated that, "About 41% of the respondents mentioned chair legs while 36.0% mentioned the back, legs and joints as the parts of wooden chairs and desks that are frequently repair. Desk legs were unanimously identified as the most frequently repaired part of the two wooden desks designs. Assessment of 150 pieces of failed Single-User and Multiple-User chairs and desks assembled for repair at about 42% of the schools showed that about 91% of the chairs failed at the joints." The use of wet wood, poor jointing method and poor handling also contributed to the observed failure in the furniture surveyed(Adéwolé & Olorunnisola, 2010). However, the reason why wood has been continuously used for furniture manufacturing is because it is quite resistant to wear as compared to the other furniture materials, and it is now being used together with metal (as legs) to increase its strength. Besides moisture absorption, it functions well and lasts long. But for it to be available, trees have to be cut down, and this has a negative impact on the environment.

Therefore, the researcher focuses on trying to use an alternative material, plastic, to try and replace wood in furniture manufacturing so as to save the woods and reduce global warming. An analysis is going to be carried out to see if plastics can withstand the forces subjected to the wooden furniture in a typical classroom setting using Finite Element Analysis, discussed briefly in the next section.

2.7 Failure Analysis -FEA

In the design of engineering products, components or structures, failure analysis is carried out to determine if the designed product will sustain the forces to which it will be subjected to. In the hope of fulfilling the aim of this project, which is the determination of the feasibility of replacing wooden classroom furniture with plastic furniture, maximum forces that plastic furniture can withstand before failing will be determined. This is done through failure analysis methods, in this case FEA (Bathe, 1996). It is a computerised method that determines when the product is most likely to fail. In engineering, the finite element method was initially developed for structural mechanics. However, it was later realised that the solution could be applied to any and most cases of problems.

3. Methodology

3.1 Introduction

In this chapter, the researcher presents the methods and methodologies used in determining the feasibility of replacing wooden classroom furniture with plastic furniture. The material selection process is done using the data acquired from the literature review of furniture plastics and is presented in detail. Calculations done on determining the forces that must be withstood by the plastic armchair are also presented. Finally, the FEA analysis carried out on the plastic arm chair is presented.

3.2 Plastic Material Selection

Of all the plastics suitable for furniture manufacturing, only four were compared in selecting the most suitable one. The selection process was done looking mainly at the following properties, in their order of importance:

A. Eco-friendliness
B. Cost
C. Mechanical properties
D. Thermal properties
E. Ease of maintenance
F. Comfort
G. Aesthetic properties
H. Ease of fabrication

Since the main aim of the project is to go green and save the earth from global warming, eco-friendliness is a major factor influencing the selection criteria. The other important factors are cost, thermal and mechanical properties and ease of maintenance. These factors are given greater importance over the others mainly because the furniture is to be used in a classroom setting. A classroom setting is one that requires strong but cheap furniture due to its greater importance in education provision. The materials are numbered as follows:

Polypropylene (1); Polyethylene (2); PVC (3); Polycarbonate (4)

3.2.1 Selection Process

Table 3.1 Criterion Weighing

		Material				Material Weight			
Criterion	**Weight**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
A	**9**	4	6	4	7	36	54	36	63
B	**8**	5	5	8	6	40	40	64	48
C	**7**	7	4	4	9	49	28	28	63
D	**6**	7	6	5	7	42	36	30	42
E	**5**	4	5	9	6	20	25	45	30
F	**4**	5	5	5	5	20	20	20	20
G	**4**	8	7	7	3	32	32	28	12
H	**3**	7	6	8	5	21	18	24	15
TOTAL						**260**	**253**	**275**	**293**

Therefore, **polycarbonate** will be used as the manufacturing material.

3.3 Design of Arm Chair

An alloy of polycarbonate, PC-ABS was selected and used for the design of the student arm chair. PC-ABS is a polycarbonate combined with acrylonitrile butadiene styrene (ABS), a common thermoplastic polymer with an approximate glass transition temperature of 105 °C (Raveir, 2013).

Table 3.2 Properties of ABS-PC

Modulus of Elasticity	**2.4GN/m^2**
Poisson's' ratio	**0.3897**
Shear modulus	**862MN/m^2**
Mass density	**1070kg/m^3**
Tensile strength	**40MN/m^2**
Compressive strength	**-**
Thermal conductivity	**0.268W/mK**

The 3-D Solid Works model, is shown in Figure 3.1.

3.4 Calculation of Forces

Considering the case of a college classroom setting, where both adults and children attend, the average human body mass will be considered.

Average body mass $m_{av} = \mathbf{70kg}$

Average weight $W_{av} = m_{av} \times g = 70 \times 9.81 = 686.7N \approx \mathbf{687N}$

Average force exerted by the human arm = **110N** (Xu, 2012).

The forces obtained were applied to the designed arm chair (section 3.3), and a FEA was carried out using Solid Works.

4. Results and Discussion

This chapter presents the results obtained after carrying out a detailed FEA on the designed polycarbonate chair. Conclusions on whether or not plastic can be used a substitute for wood are then made and provided at the end of the chapter.

4.1 Results

Figures 4.1, 4.2, and 4.3 show the results obtained from the FEA procedure.

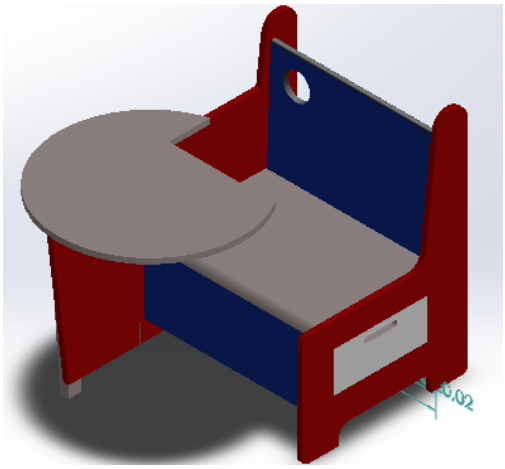

Figure 4.1 Polycarbonate arm chair (3D)

4.2 Discussion

The stress and displacement results obtained from the FEA are as follows:

Maximum von Mises stress $\sigma_v = 4.57 \times \frac{10^5 N}{m^2}$ (Figure 4.1)

Maximum displacement $\delta = 3.389 \times 10^{-1} mm$ (Figure 4.2)

The maximum displacement obtained is very small and can be ignored. This means that the polycarbonate chair will withstand the weight of an average human being without undergoing a noticeable deflection. From Table 3.2, the tensile strength of ABS-PC is $\sigma_t = 4 \times 10^7 N/m^2$. The FEA showed that the maximum stress that can be experienced by the arm chair due to the weight of the human being sitting on it is $\sigma_v = 4.57 \times \frac{10^5 N}{m^2}$. Therefore, since $\sigma_v < \sigma_t$, failure will not occur. This means that the polycarbonate arm chair will be able to withstand the weight of the student without failing.

Thus plastics, in this case ABS-PC, can be used as a substitute for classroom furniture manufacturing, thereby saving the earth's forests from deforestation.

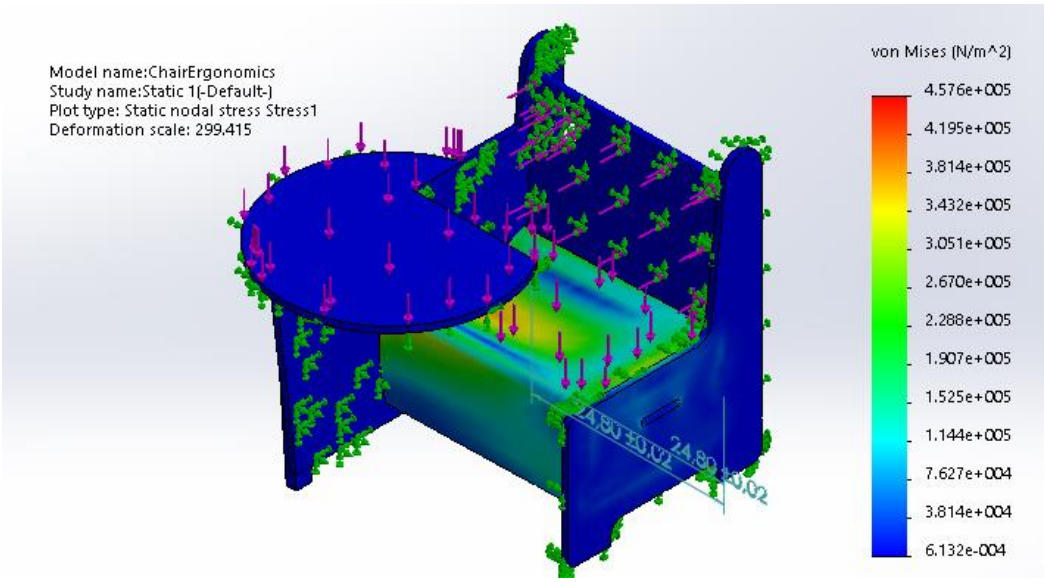

Figure 4.1 von Mises Stress Analysis

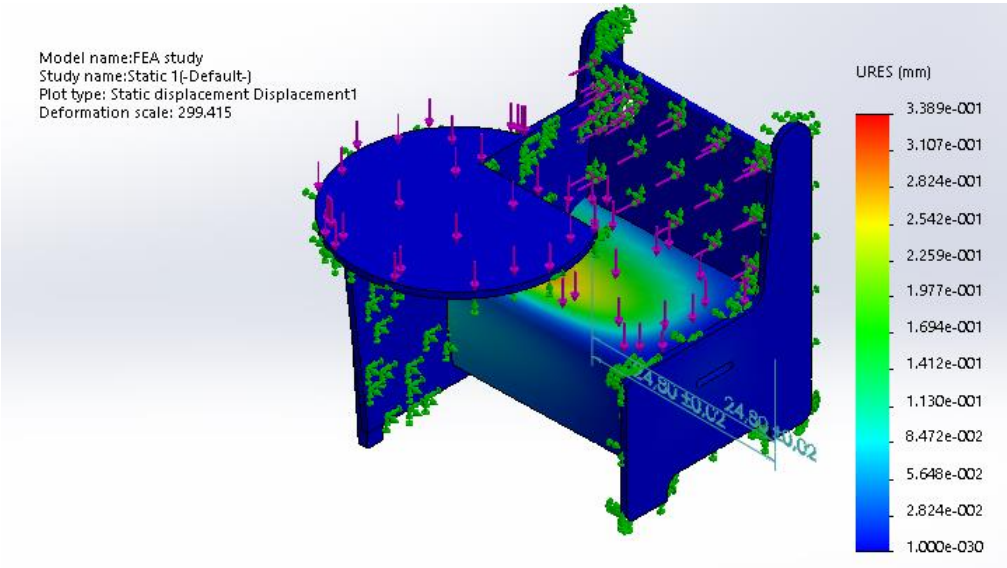

Figure 4.2 Displacement analysis

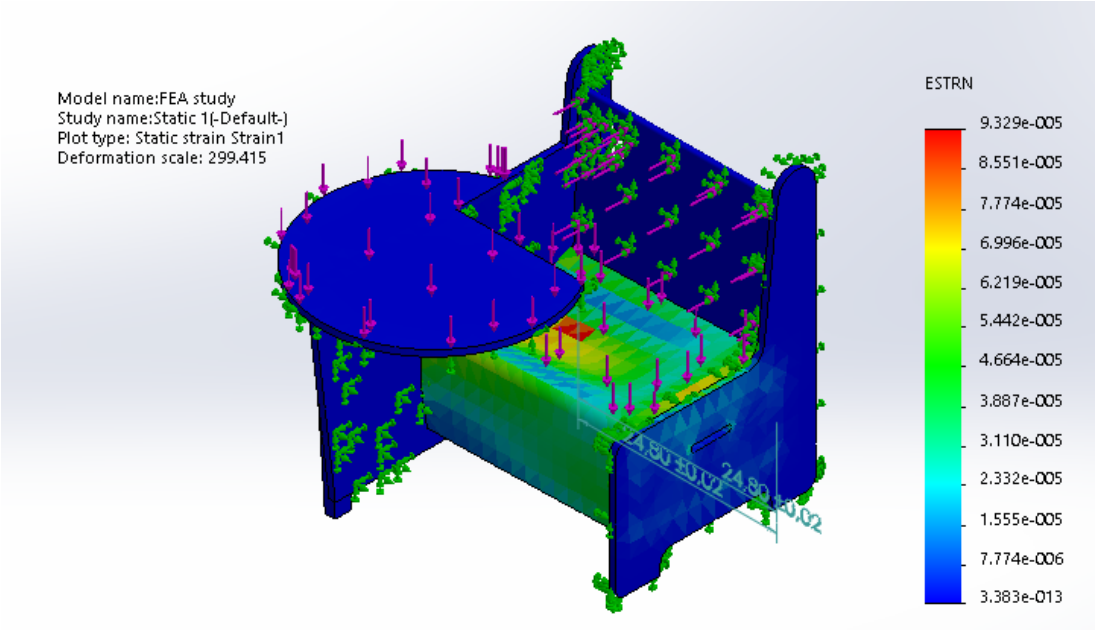

Figure 4.3 Strain Analysis

5. Recommendations and Conclusions

5.1 Recommendations

While it has been concluded that the replacement of wooden classroom furniture chairs with polycarbonate arm chairs is feasible, it can however be noted that wooden furniture remains the strongest as compared to plastic chairs. Hence there is need for reinforcements to be applied to the plastic arm chair in order to try and have it match the strength of wooden furniture. This can be done through heat treatment processes to the plastic that will make it more harder and thus stronger. Other alternative strengthening methods that can be used include the use of metal legs so that the overall force that can be supported by the arm chair is increased.

This study used classroom furniture as a case study. Thus, it is important to note that wooden furniture in homes and other typical setups can also be replaced with plastic furniture if the correct studies of determining the forces setup are done.

5.2 Conclusions

There have been several attempts to try and reduce the amount of wood used in the furniture industry. These include the use of combined desks and chair and also wooden arm chairs. However, it is quite evident that this was not the optimum solution in trying to save the world's forests. Thus, the researcher has presented a solution that, if supported with further research and implemented, will have a tremendous effect on reducing deforestation, and ultimately reducing global warming.

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Authors' Biographies

Rumbidzai Prosper Jera was born in Harare, Zimbabwe in 1994. She is currently a student at the University of Zimbabwe, Harare, studying for a Bachelor of Science Honors Degree in Mechanical Engineering. She did her Advanced and Ordinary level studies at St Mary's High School in Chitungwiza, Harare, where she was involved in a number of engineering and science programs. In the year 2011, she was the secretary for the Science Education in Teacher Training (SEITT) school science club, and later on went to hold the vice-presidency for the club in the years 2012-2013. In 2016, she joined the Zimbabwe Institute of Engineers as a student member. Her current research involves material science, solid mechanics and Finite Element Analysis. Other areas of interest in research and design include aerodynamics, fluid mechanics and manufacturing and engineering management systems.

Doctor Tawanda Mushiri received his Bachelor of Science Honors Degree in Mechanical Engineering (2004-2008) and a Masters (2011-2012) from the University of Zimbabwe, Harare, and a Ph.D. from the University of Johannesburg, South Africa (2013-2017). He also obtained a Certificate with Siemens in Programmable Logic Controllers in the year 2013 where he worked with Scada and Link Programming. His doctorate involved fuzzy logic and automated machinery monitoring and control. Currently, he is a lecturer and Senior Research Associate at the university of Zimbabwe and University of Johannesburg, respectively. In the past (2012-2013), he has also lectured at the Chinhoyi University of Technology, Zimbabwe, lecturing mechatronics courses. He has also been an assistant lecturer for undergraduate students at Chinhoyi University of Technology, tutoring advanced manufacturing technology and machine mechanisms.

Professor Charles Mbohwa is an NRF-rated established researcher and professor in the field of sustainability engineering and energy focusing on green technology, energy and systems. In January 2012 he was confirmed as an established researcher making significant contribution to the developing fields of sustainability and life cycle assessment. He has contributed a chapter to a state-of-the-art book by experts in energy efficiency. In addition he has produced high quality body of research work on Southern Africa. Since 2012 he has worked on sustainability engineering with emphasis on integration of other soft aspects like humanitarian logistics and health care systems. The work also encompasses and integrates energy systems, life cycle assessment and bio-energy/fuel feasibility and renewable energy.