COMPARATIVE STRESS EVALUATION OF ABS PLASTIC AND PVC PLASTIC FOR HIGH PRESSURE APPLICATIONS USING FINITE ELEMENT SIMULATION APPROACH

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ABSTRACT

In this paper, comparative stress evaluation of ABS plastic and PVC plastic for high pressure applications using finite element simulation approach was successfully investigated. Two Plastic slab models of 16mm by 16mm wide with thickness of 2mm were created using Autodesk Inventor with an assigned material for each being ABS and PVC plastics respectively. Each of the plastic model was imported to Finite Element Analysis software where stresses were evaluated, using fixed constraints under a load of 10N. Results showed that the Von Mises stress for Polyvinyl Chloride (PVC) and that of Acrylonitrile Butandiene Styrene (ABS) Plastic Slabs was found to be 1.11MPa for both under the stated simulation conditions. It suggested that failure of the two plastics due yielding would have equal chances and more noticeable in Acrylonitrile Butandiene Styrene Plastic due to its lower yield strength. Furthermore, 1st and 3rd principal stresses were found to be 1.505 MPa and 0.735MPa respectively, which indicated that the Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastics would fail due to tensile stress rather than compressive stress under high pressure applications. Tensile strength improvers should be added during manufacturing of both plastics to ensure safety and reliability of usage. Study showed that the maximum stress induced was found to be 0.8511MPa, for both plastics. Since the ultimate tensile strengths for Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastics were not exceeded, it suggested that the plastic model design was not over stressed and therefore, safe. This result also indicated that the two plastics have equal application areas or could be used interchangeably. Maximum displacement of 0.005443mm for both plastic slabs, suggested that the two plastics might be used in high pressure areas where rigidity is of paramount.

Keywords: *ABS plastic, PVC plastic, Simulation, High pressure, Stress*

INTRODUCTION

Polyvinyl Chloride (PVC) plastic has a wider application in all kinds of pipes and tiles, especially in plumbing pipes, and is mostly recyclable. This kind of plastic should not come in contact with food items when ingested as it can be harmful. According to Kamweld (1958) polyvinyl chloride (PVC) is hard, rigid when not plasticized, good chemical resistance, long term stability, good weathering ability and low gas permeability.

In accordance with Society of Plastic Industry, Acrylonitrile Butandiene Styrene (ABS) is considered under miscellaneous types of plastic not defined by the other six codes. Polycarbonate and Polylactide are included in this category. ABS is a polymer plastic that has wide range of uses in engineering sector. This type of plastic is difficult to recycle. ABS is used in baby bottles, compact discs, and medical storage containers.

The applications of both Acrylonitrile Butandiene Styrene and Polyvinyl chloride in engineering sectors, especially in fluid and food processing machineries; has prompted researchers to investigate stress response behaviors of these types of plastics. It is on this note, researchers aimed to study comparative stress evaluation of ABS plastic and PVC plastic for high pressure applications using finite element simulation approach.

According to Adebisi et al., (2011) as cited in Ibrahim and Sanni (2023) maintained that the use of plastic in packaging has become more prevalent for soft beverages and table water, taking the role of the biodegradable materials that were once commonly used in Nigeria to wrap a variety of meals.

Onyenobi et al., (2022) contributed that finite element simulation approach of plastic involves the use of simulation to predict and understand stress, deformation and displacement of plastic under load or pressure applications with fixed constraints. Finite element simulation uses finite element method, which is a numerical technique that cuts the structure of the plastic into several elements and then reconnects the elements at point called nodes.

METHODOLOGY

The researchers created plastic slab models of 16mm by 16mm wide with thickness of 2mm using Autodesk Inventor with an assigned material for each being ABS and PVC plastics respectively. Each of the plastic model was imported to Finite Element Analysis software where stresses were evaluated, using fixed constraints under a load of 10N. Results were recorded and reported as shown below.

MESHING

Meshing was used to divide the plastic slab into section with nodes of 2060 and elements of 1153. Increasing the number of elements, means more computations and more mathematical formula for the element. Hence, the more precise the results would be. Mesh settings used is shown below. **See Fig 3.0.**

Table 1: General objective and settings:

Design Objective	Single Point
Study Type	Static Analysis
Last Modification Date	6/1/2024, 2:08 PM
Detect and Eliminate Rigid Body Modes	No

Table 2: Mesh settings:

Avg. Element Size (fraction of model diameter)	0.1
Min. Element Size (fraction of avg. size)	0.2
Grading Factor	1.5
Max. Turn Angle	60 deg
Create Curved Mesh Elements	Yes

Table 3: Mechanical Properties of Material for PVC Plastic

Name	PVC Plastic	
General	Mass Density	1.29 g/cm^3
	Yield Strength	40 MPa
	Ultimate Tensile Strength	40 MPa
Stress	Young's Modulus	0.709 GPa
	Poisson's Ratio	0.41 ul
	Shear Modulus	0.251418 GPa
Part Name(s)	Part1	

Table 4: Physical Properties of Material for ABS Plastic

Name	ABS Plastic	
General	Mass Density	1.06 g/cm^3
	Yield Strength	20 MPa
	Ultimate Tensile Strength	29.6 MPa
Stress	Young's Modulus	2.24 GPa
	Poisson's Ratio	0.38 ul
	Shear Modulus	0.811594 GPa
Part Name(s)	Part1	

Operating Conditions

Table 5 : Force

Load Type	Force
Magnitude	10.000 N
Vector X	-10.000 N
Vector Y	0.000 N
Vector Z	0.000 N

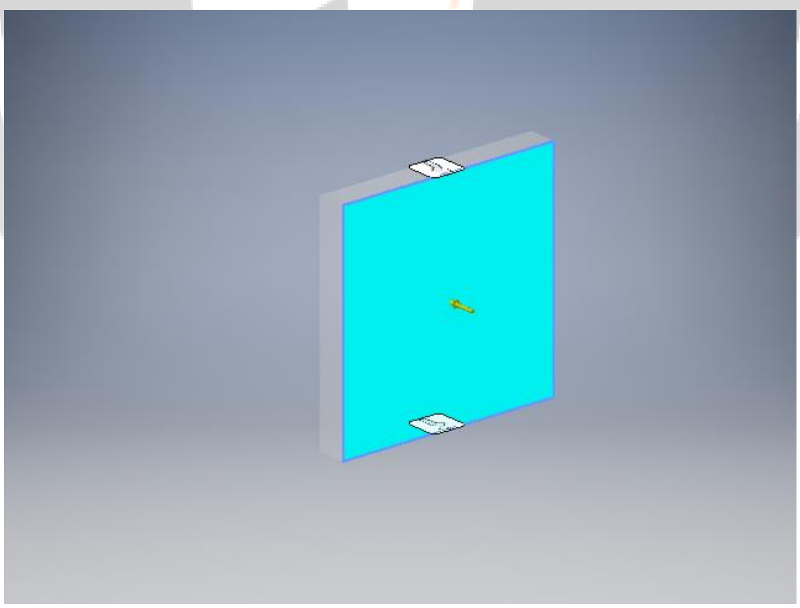

Fig 1.0(a): Polyvinyl Chloride Plastic Slab with Constraints and Force

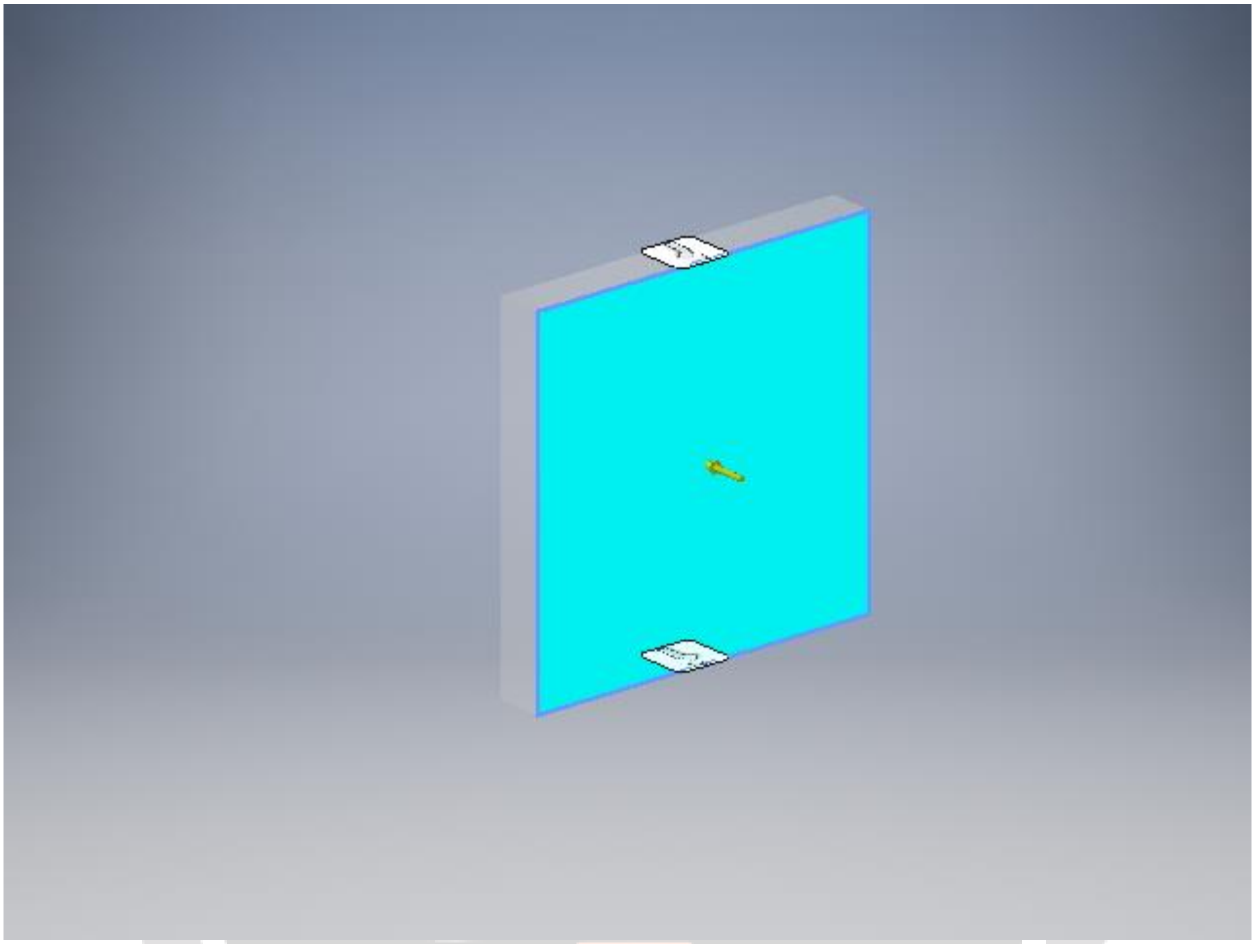

Fig 1.0(b): Acrylonitrile Butandiene Styrene Plastic Slab with Constraints and Force

EQUATIONS

The stress components in an element are given as below.

$(\sigma_x)_n = \frac{E}{(1+v)(1-2v)}[(1-v)a_n + ve_n] \ldots\ldots(1)$ (Onyenobi et al., 2022)

$$(\sigma_y)_n = \frac{E}{(1+v)(1-2v)}[va_n + (1-v)e_n] \ldots\ldots(2)$$

$$(\tau_{xy})_n = \frac{E}{2(1+v)}(b_n + d_n) \ldots\ldots(3)$$

$$v = Poisson's\ ratio, E = modulus\ of\ elasticity$$

The displacement field is shown below.

$$a_n = \frac{\partial u_n}{\partial x} \ldots(4)$$

$$e_n = \frac{\partial v_n}{\partial y} \ldots(5)$$

$$b_n + d_n = \frac{\partial u_n}{\partial y} + \frac{\partial v_n}{\partial x} \ldots.(6)$$

$$v \text{ and } u \text{ are velocity components of } x \text{ and } y$$

Von Mises Stress can be given as below.

$$Von - mises\ stress = \sqrt{\sigma_x{}^2 - \sigma_x\sigma_y + \sigma_y{}^2} \ldots. (7)$$

Total bending moment acting on the slab due to loading from fixed constraints is given as below

$$M = (-Px_1 - Px_2) \text{ kN-mm} \ldots. (8)$$

RESULTS

The following results were gotten when simulation was run in finite element software.

Table 6: Reaction Force and Moment on Constraints

Constraint Name	Reaction Force		Reaction Moment	
	Magnitude	**Component (X,Y,Z)**	**Magnitude**	**Component (X,Y,Z)**
Fixed Constraint:1	10 N	10 N	0 N m	0 N m
		0 N		0 N m
		0 N		0 N m

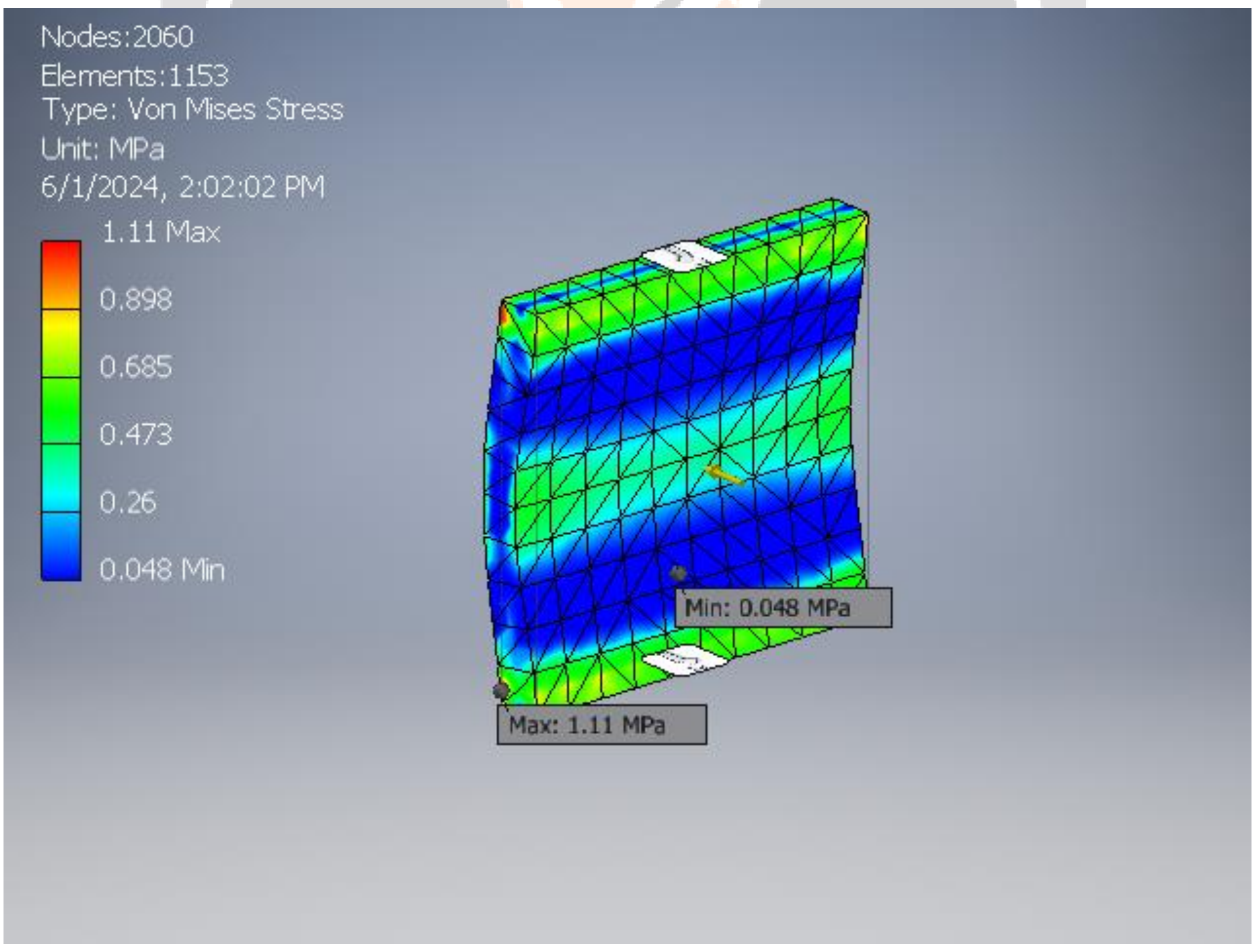

Fig 2: Von Mises Stress for Acrylonitrile Butandiene Styrene Plastic Slab

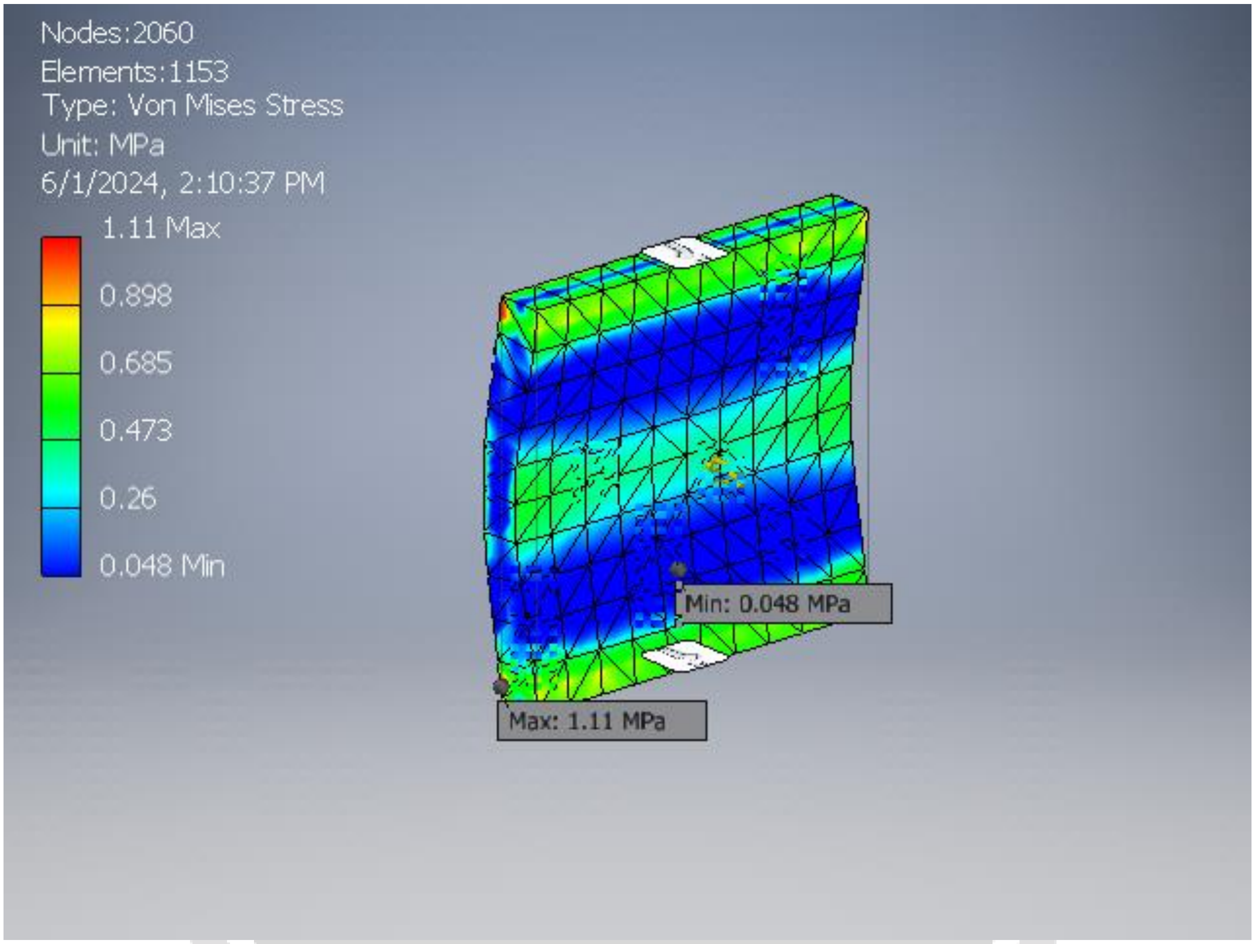

Fig 3: Von Mises Stress for Polyvinyl Chloride Plastic Slab

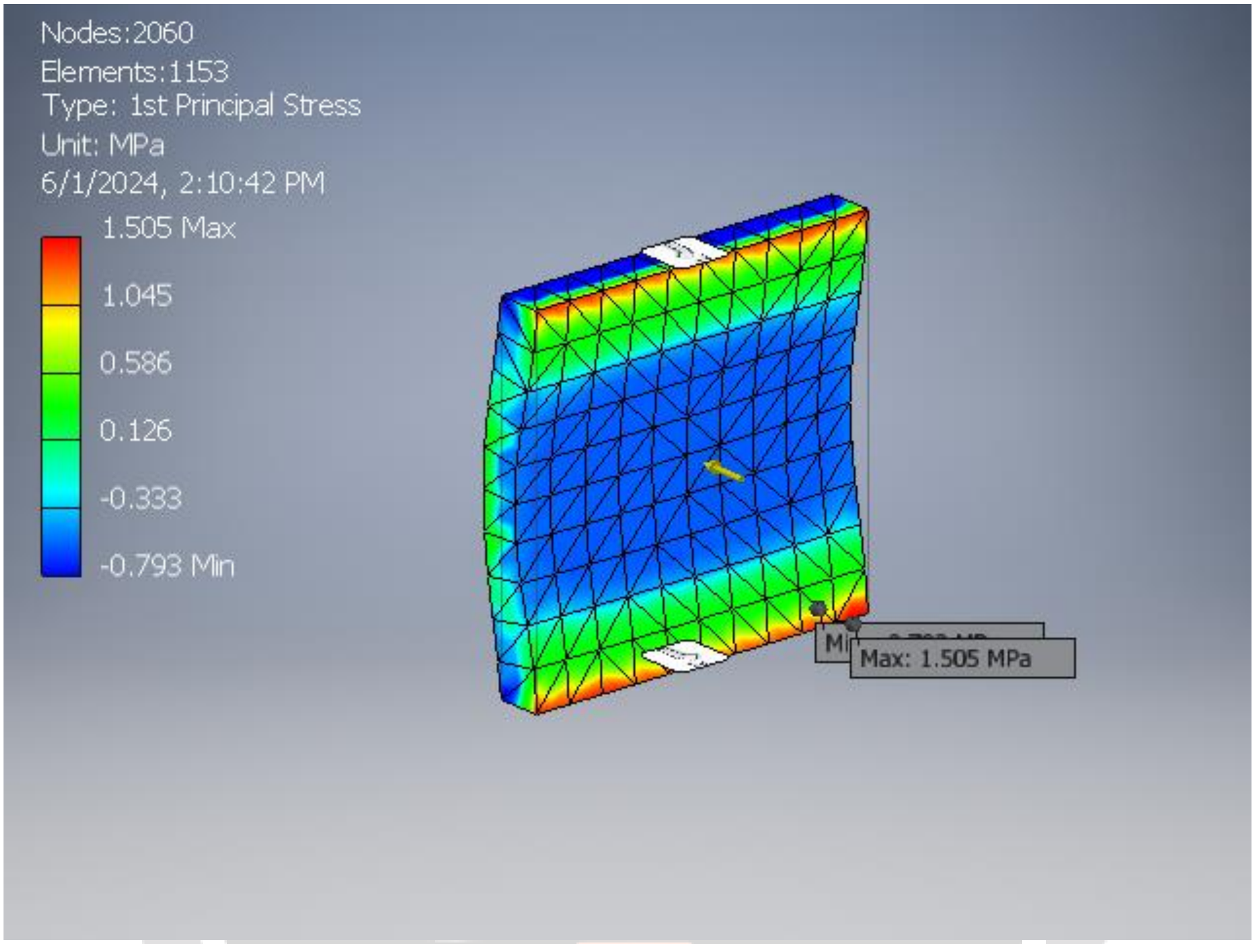

Fig 4: 1st Principal Stress Same for both Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastic Slab

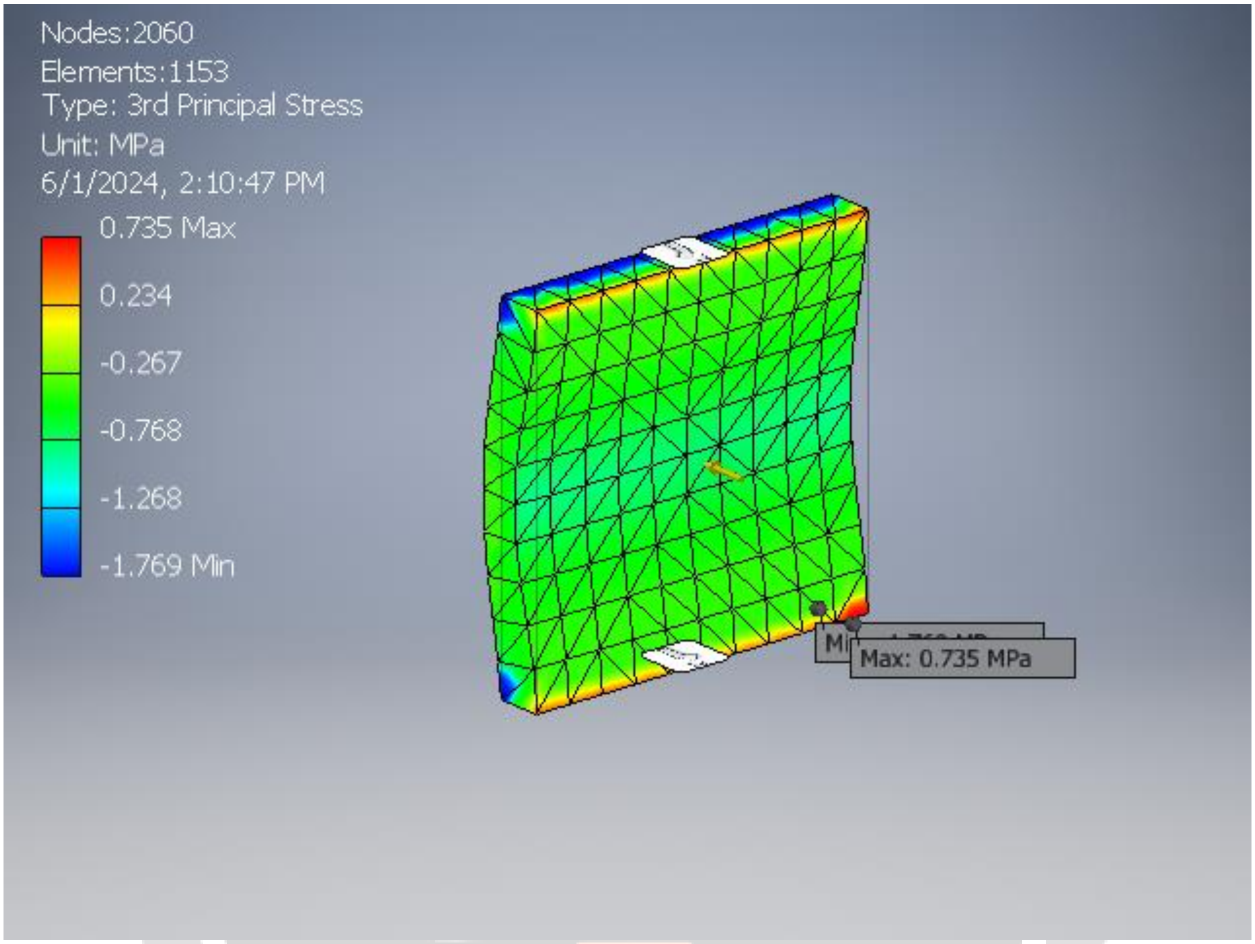

Fig 5: 3rd Principal Stress Same for both Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastic Slab

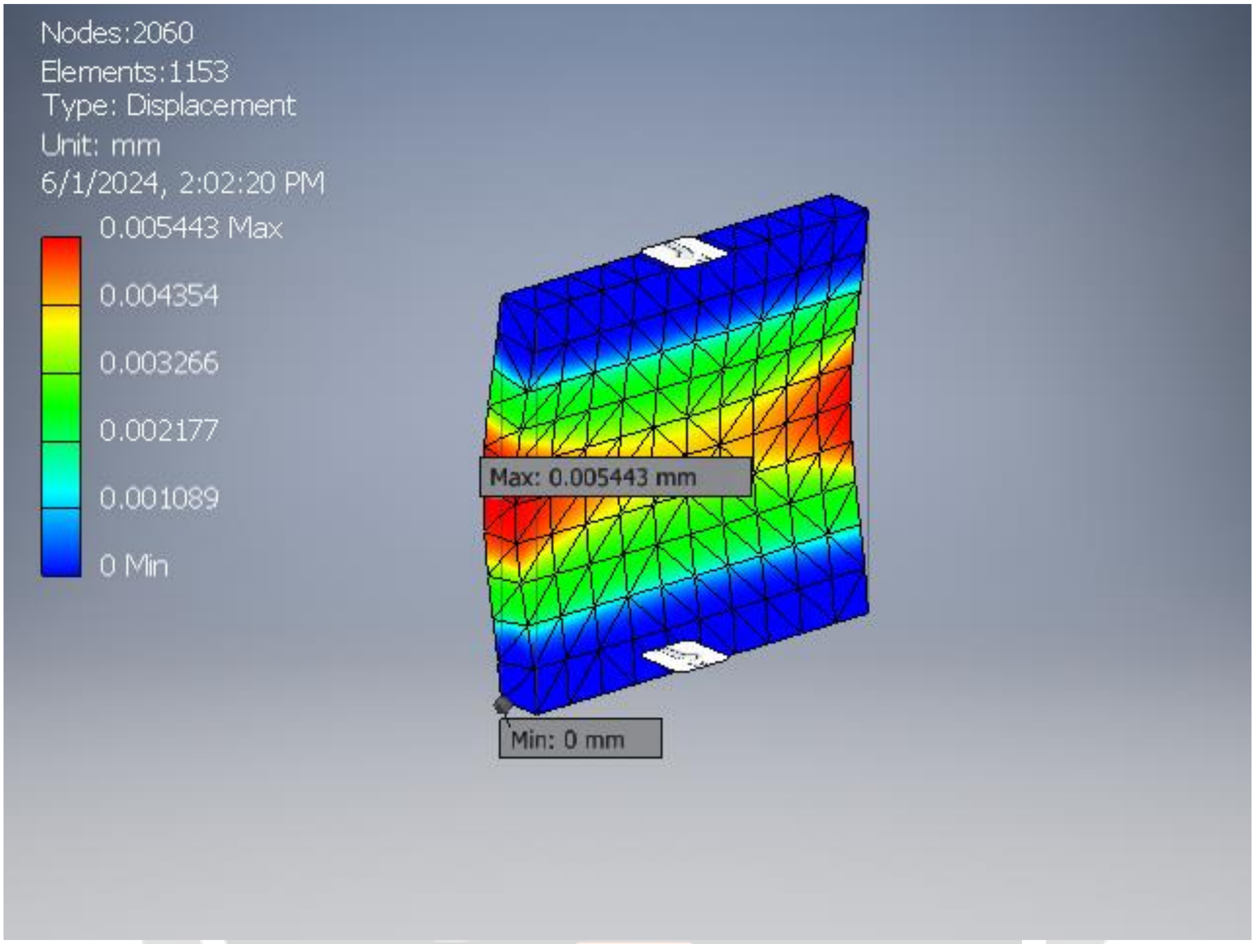

Fig 6: Maximum Displacement Same for both Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastic Slab

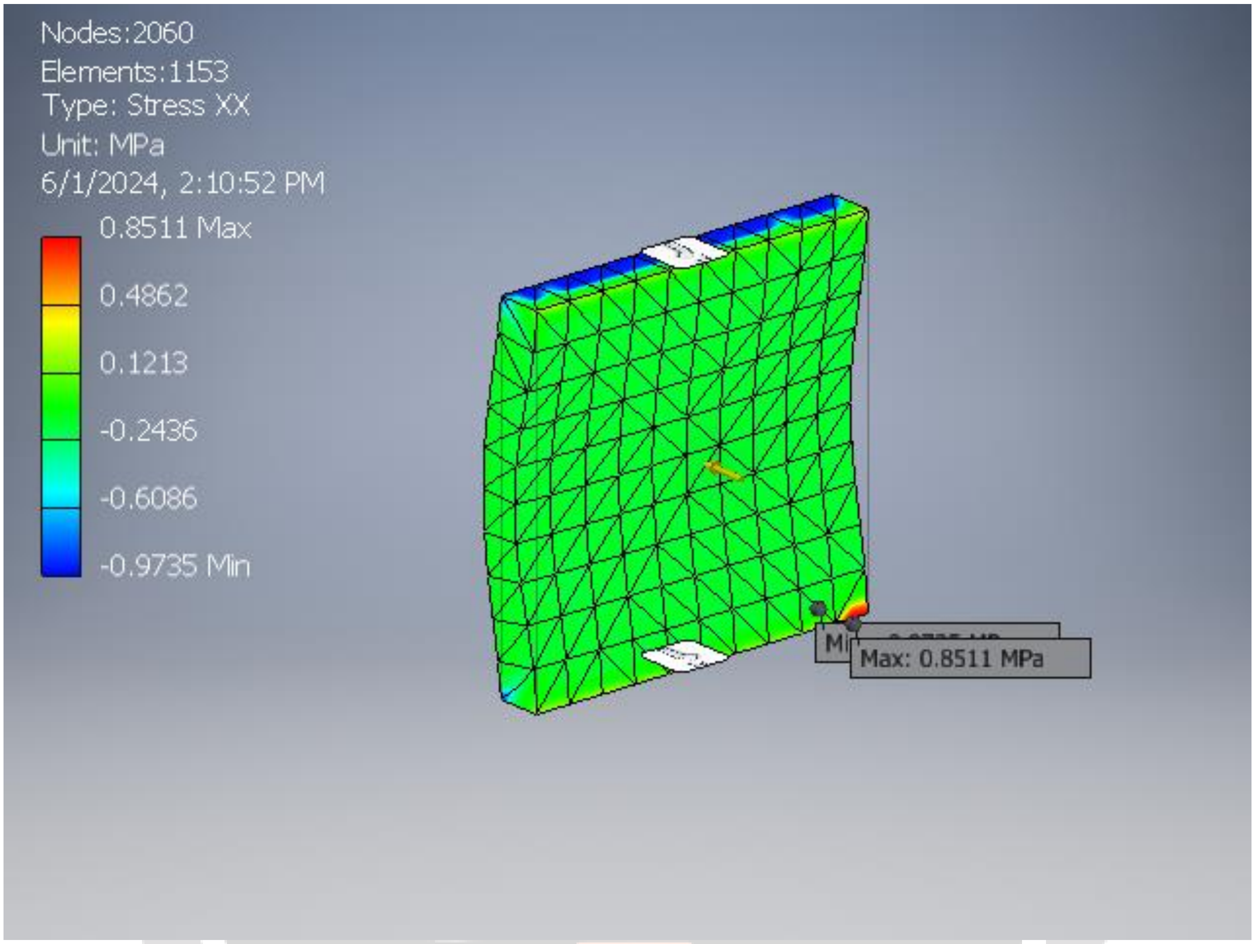

Fig 7: Maximum Stress Same for both Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastic Slab

DISCUSSION

Comparative stress evaluation of ABS plastic and PVC plastic for high pressure applications using finite element simulation approach was successfully achieved.

Plastic slab models of 16mm by 16mm wide with thickness of 2mm was created using Autodesk Inventor with an assigned material being ABS and PVC plastics; according to **Fig 1 to Fig 2**. Each of the plastic models was imported to Finite Element Analysis software for simulation and stresses were evaluated, using fixed constraints under a load of 10N.

According to **Fig 2 and Fig 3**, result showed that the Von Mises stress for Polyvinyl Chloride was found to be 1.11MPa and that of Acrylonitrile Butandiene Styrene Plastic Slab was also 1.11MPa. Since, yield strength of the assigned materials were 40MPa and 20MPa respectively, it suggested that failure of the two plastics due yielding would have equal chances and more noticeable in Acrylonitrile Butandiene Styrene Plastic.

According to **Fig 4 and Fig 5**, the 1st and 3rd principal stresses were found to be
1.505 MPa and 0.735MPa respectively. These results indicated that induced stress due to tensile loading is higher and more noticeable at the loaded points. Therefore, the Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastics would fail due to tensile stress rather than compressive stress under high pressure applications. Tensile strength improvers should be added during manufacturing of both plastics to ensure safety and reliability of usage.

It was observed that the maximum stress induced was found to be 0.8511MPa, for both plastics. Since the ultimate tensile strength for Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastics were 40MPa and 29.6MPa respectively, the design was not over stressed and therefore, safe. This result also suggested that the two plastics have equal application areas or could be used interchangeably, according to **Fig 7**.

Fig 6 showed that the maximum displacement was observed to be 0.005443mm for both plastics respectively. This result suggested that the two plastics showed lower displacement, hence might be used when rigidity is of paramount.

CONCLUSION

The results from the study showed that Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastics showed similar stress behavior properties and could be used for high pressure applications where tensile loading is less predominant. In addition, the two plastics could be answerable to areas where rigidity property is important.

RECOMMENDATIONS

The following recommendations are suggested based on the study:

1) For high pressure applications of Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastics, tensile strength improvers should be added during plastic manufacturing to improve reliability.
2) Polyvinyl Chloride and Acrylonitrile Butandiene Styrene Plastics should be used in areas where rigidity property plastic is important.
3) This research could also be done in future using different plastic geometric sections and other advanced software for generalization.

REFERENCES

Ibezim, J, M., Nkwor, C, A., Efosa, O., Ekanem, O, A., & Ewurum, T,I.(2024). Determination of Natural Frequency Of Vibration And Deformation of Centrifugal Pump Open Impeller For Performance Improvement. Iconic research and engineering journal, 7(10).

Ibrahim, G.W & Sanni, E. O. (2023). Development of a Waste Plastic Bottles and Tin Cans of Plastics Shredding Machine. *In the Proceedings of the 4th International Conference, The Federal Polytechnic, Ilaro, Nigeria in Collaboration with Takoradi Technical University, Takoradi, Ghana 3rd – 7th September, 2023. University Auditorium, Takoradi Technical University, Takoradi.*

Khurmi, R.S & Gupta, J.K. (2014). *Strength of Materials.* New Dehi: Khanna Publishers.

Kamweld, I. (1958). Plastic Welding. Newton Ma, 02561. Retrieved 8th June, 2024 from www.researchgate.net

Mohamed, N., Moey, L.K., Ibrahim, A.A.,Yazdi, M.H. & Merdji, A. (2022). Stress Analysis of Various Designs of Centrifugal Pump Impellers Using Finite Element Method. *Journal of Engineering and Technological Advances7(1).*

Onyenobi, C.S., Emeh, G., Azodoh, K.A., IKenga, E., Anyanwu, U., Ekekwe, S.& Ewurum, T.I. (2022). Finite Element Analysis of Centrifugal Pump Impeller Model for Performance Improvement. *International Journal of Research in Engineering and Science,11(10).*

Olewuezi, E.C., Gaven, D. V., Oparanozie, G.U., Ahaotu, R. O., & Ewurum, T.I. (2022). Linear Regression Modeling of Induced Stress and Displacement along a Pipeline Due to Fluid Weight: Matlab Approach. *International Journal of Advances in Engineering and Management 4(7), pp. 684-689.*

Rajput, R. K. (2008). *Strength of Materials.* New Dehi: S. Chand Technical Publishers.

Samadhan, G. M & Laxmikant, M. G. (2015). Analysis of Steel I-Beams with Rectangular Web Openings: Experimental and Finite Element Investigation. *Journal of Engineering Structures and Technologies.*http://www.researchgate.com

Yi Zhu, W & Tim. (2007). Finite Element Analysis of Structural Steel Elliptical Hollow Sections in Compression. *School of Civil Engineering Centre for Advanced Structural Engineering.* http://www.civil.usyd.edu.au