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Structural Simulation Analysis of the Developed Hybrid of *Momordica angustisepala* Fiber and Breadfruit Seed-Shell Particles Composites Bolted Flanges

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Abstract

In order to examine the mechanical behavior of a natural composite bolted flange made of *Momordica angustisepala* fiber (MAF) and breadfruit seed-shell particles (BFSAp), this study suggested a multiscale finite element (FE) analytical technique. Based on their properties which includes, light weight, superior strength-to-weight ratio, improved fracture toughness, fatigue and tensile properties, increased corrosion resistance in harsh environments, and other qualities, composite materials are always desired and widely used in the manufacturing sector. Based on the experimental findings, it was observed that The linear structural analysis of the developed bolted flange with sustainable materials shows that the high values of the Von Misses stress of 85.9355 MPa and 42.9677 MPa obtained in this study at 5.1 MPa and 10.2MPa internal pressure applied was attributed to the stiffness and strength obtained in this composite which resulted to high toughness obtained by the reinforcement that give a minimum factor of safety of 2.99318 ul and 1.49659 ul at 5.1 MPa and 10.2MPa internal pressure applied respectively. The tensile strength and factor of safety obtained are within the recommended standard for bolted flange application.

***Keywords**: Mechanical strength, Composite, Finite element method, Momordica angustisepala fiber (MAF), breadfruit seed-shell particles (BFSAp)*

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1. Introduction

Composite materials have been essential to the development of contemporary technology and the building of the first structures throughout human history. Composites have affected our daily existence. A composite material with the desired properties is what the technique aims to achieve [1]. The limitations of single reinforcement composites and polymers in the areas of high hardness values, wear resistance, thermal resistance, and fire resistance have been addressed in recent years by the development of hybrid composites [2]. Due to these restrictions, polymer materials cannot be used to manufacture pipelines, naval equipment, bolted flanges, or automotive components [2]. Among the current work on hybrid composites is the mixing of specific and fibers in the fabrication of composites materials. The hybrid composites offer numerous advantages such as strong tensile, flexural strength, elastic, impact energy, thermal stability, abrasion and wear resistance [3].

A promising natural fiber for the development of polymer composites is *Momordica angustisepala* fiber (MAf) [4]. The fibers are available in many African nations, including Ghana, Benin, Cote Divoire, Nigeria, and Cameroon [3]. The fibers are extracted from the MA stem by smashing them and then washing them to get rid of contaminants [4]. Commercial amounts of it are cultivable. The MA fibers are utilized as a local bathing sponge in Africa [5]. In Nigeria, Achigan-Dako [6] used MA as a traditional medicine, and Atuanya et al [7] characterized the MAf for potential application in the creation of polymer composites. Their results indicated a tensile modulus of 2-4.4GPa and tensile strength of 35-57.93MPa.

A brake disc made of waste aluminum beverage cans, carbon nanotubes obtained from rice husk (CNTs-derived RH), and periwinkle shell nanoparticles (PWSnp), Braide *et al* [8,9,10] created a hybrid of aluminum composites and carbon nanotubes. The brake disc's compressive strength is 410 MPa,

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and its maximum stress during the braking operation is 15.8402 MPa, according to the experimental results.

The strengthening and damage effects of adding a reinforcing phase to hybrid reinforced aluminum matrix composites are analyzed using a finite element model, and the work presented in this paper can be used as the basis for future micro mechanism analysis and optimal design of hybrid reinforced composites.

2. Materials and Methods

2.1 Materials

The *Momordica angustisepala* used in this study was bought from a local market in Nsukka, a major town in Anambra State, Southern Nigeria, and the bread fruit ashes was obtained as a waste came from Awka market, Anambra State, which is in Southern Nigeria.

2.2 Method

2.2.1 Chemical treatment of MA fibers

The fibers were washed with acetone for 48 hrs and oven-dried at 75 ℃ for 5 h [11, 12]. The cleaned fiber bundle was preserved in glass containers. To produce hydroxylated fibers, the cleaned fibers were steeped in an 80 ml sodium hydroxide solution, heated to 105 ℃ for three hours, and then rinsed with distilled water and 5% HCl solutions before being dried in an oven set at 75 ℃ [13,14]. To functionalize the silane, prepare 2 milliliters of aminopropyltriethoxysilane (APS) in 100 milliliters of ethanol. Using a magnetic stirrer set at 250 rpm, the mixture was stirred thoroughly for a minute. After being immersed in this solution, the fibers are activated using the temperature and duration indicated in Table 1. The fibers were washed with deionized water and dried.

Table 1 Processing parameter with their coded values

S/N	Variables	Upper level	Lower level
1	Temperature (A)(℃)	150 (+ 1)	75 (− 1)
2	Holding time (B) hr	6 (+ 1)	1 (− 1)

2.2.2 Breadfruit Seed-Shell (BFS) Processing and Characterization

Preceding to the development of the composites, the breadfruit seed-shell (BFS) was used. After three days of sun drying, the breadfruit seed shell was ground into a fine powder in a ball mill (see Figure 1). The planetary ball was positioned eccentrically in relation to the ball milling grinding jars. The moving wheel was set in the opposite direction as the grinding jars, with a ratio of 1 to 2.5 or 1 to 3. The graphite crucible containing the ball-milled powder was put in a muffle electric furnace. For five hours, the furnace was heated to 1000 degrees Celsius.

In accordance with ASTM E2651 standard protocol, the MICROTAC Bluewave Particle Size Analyzer (Figure 2) was used to analyze the powder sample's size after heating. Following particle analysis, a 63µm size (refer to Figure 3) was adopted in the study of [13].



Figure 1: Photograph of the ball mills



Figure 2: Microtrac Bluewave Particle Size Analyser.



Figure 3: Photograph of Breadfruit seed-shell ash particles (BFSAp) of 63µm

2.2.3 Production of the Composites

Using the Taguchi Orthogonal array of L9, the hybrid composites for optimization were produced by the hand-laying approach, as indicated in Tables 2–3. The composition ranges utilized in Tables 2-3 were completed in compliance with the industry standards for the creation of hybrid composites for bolted flanges and pipelines [14]. Prior to production, the MAf treated with aminopropyltriethoxysliane (OH-APS) was matted, cut, weighed, and placed into a wooden mold with an aluminum foil covering the floor.

Table 2: Process parameters and their values at a different level

Process Parameter Designation	Process Parameters	Level 1	Level 2	Level 3
A	Wt% Breadfruit ash	10	20	30
B	Wt% MAf	10	20	20
C	Curing Temperatures(°C)	50	100	150
D	Curing Time(hrs)	1	2	3

Table 3: Process parameters and their values at a different level

Exp. No.	Randomized Run order	A(wt%)	B(%)	C(°C)	D(hrs)
S1	3	10	10	50	2
S2	7	10	20	100	4
S3	5	10	30	50	6
S4	1	20	10	100	6
S5	4	20	20	150	2
S6	6	20	30	50	4
S7	9	30	10	150	4
S8	2	30	20	50	6
S9	8	30	30	100	2
Control					

The BFSAp was well combined with the epoxy. The mixture was stirred with a 200 rpm magnetic stirrer to create a uniform mixture. After adding the hardener and stirring the mixture once more, the slurry was poured into the matted fiber mold. Air trapped inside the mold was removed during production using a 50mm diameter roller. With this approach, a variety of compositions were created, as shown in Table 2. Following the instructions in Table 3, the samples were taken out of the mold and thermally cured after the composites had been cured inside for twenty-four (24) hours. After that, the samples were divided into several test samples using a mechanical bench saw.

2.2.4 Production of the Bolted Flange

Flange joints are designed with guidance from handbooks according to criteria set up by standards from The American Society of Mechanical Engineers (ASME) or the European Committee for Standardization (CEN) (ASME (2010e). ASME Code for Pressure Piping B31.1), flange of diameter of 279.4 mm (11 inches), 8 number of bolts, 19.5 mm (¾ inches) diameter of bolts, 22.35 mm (0.88 inches), diameter of bolt hole, 234.95 mm (9-1/4 inches) bolt circle, and 127 mm (5 inches) normal pipe size was used in the production of the bolted flange with the optimum composite formulation.

The bolted flange was made using the hand laying method. Using this technique, the epoxy resin, MAf, and BFASp were applied to the mold to create the heads, cylindrical, and attachment. The catalyst promoter system was used to cure the material at room temperature. In Figure 4, the production process is shown. Each ply is applied one at a time, as shown in Figure 4, being careful to adhere to the suggested orientation and prevent air bubbles from leaking into the resin. Between each ply, the resin is applied using a brush or a pistol. Details of the production are explained as follow:

Step 1: Formation of the Female/Male mould:

In order to create the mold, the metal flange pattern was first coated with petroleum jelly, which served as a releasing agent. The petroleum oil was removed from the pattern by exposing it to sunlight. After the paint was dry, epoxy glue was repeatedly applied to the pattern's wall. Fiber was put around the pattern's wall at the same time that the resin was being applied to the wall. This was carried out repeatedly until the pattern, which subsequently served as a mold for the prototype, produced the required wall thickness. Following curing, the flange was taken out of the mold-forming cured pattern. These processes were respectively followed when producing both male and female mold.

Step 2: Production of the Composite Flange

The exterior wall of the male mold and the interior wall of the female mold were repeatedly coated with petroleum oil. To dry, both male and female molds were placed in the sun. After the petroleum oil on the male mold dried, epoxy resin was repeatedly applied to both the interior and exterior walls of the female mold.

Fiber was put around the walls of the male and female molds at the same time that the resin was being applied to both walls. This was done repeatedly until both molds had the required wall thickness, at which point they were combined to create a single flange unit. After curing, the male and female molds were separated from the cured composite flange.



Figure 4: Production of the Flange in process

It is evident from Figure 5 that the produced flange has a good surface finish free of defects, voids, and porosity. This was explained by the strong bond between the epoxy resin and the reinforcement.

The weight of the developed composite flange is 0.45 kg, whereas the weight of the steel-made metallic flange is 9.5 kg on a weight comparison. This led to the conclusion that the produced composite flange might be used to create a lightweight flange that could lower the overall weight of the construction and transportation.

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Figure 5: Produced Flange

3. Results and Discussion

3.1 Tensile Strength of the Treated MAf

The tensile strength result obtained for the OH-APS treatment on the MAf is as shown in Table 4. The fibers' tensile characteristics showed notable and significant improvements. After soaking for three hours at 150°C, the treatment improved the fiber's strength to 202.5 N/mm², which was significantly higher than the untreated fiber's 108.85 N/mm². Following OH-APS treatment, the MAf's elastic modulus increased. Following OH-APS treatment at 150°C and 3 hours of soaking, high values of 4354.09 N/mm² were observed, which indicates a significant improvement in the stiffness of the fibers compared to the untreated fibers' 3101.42 N/mm². However, greater tensile characteristics were attained in all of the treatment conditions listed in Table 4 compared to the untreated fibers.

The results obtained in Table 5 was transformed into a signal to noise(S/N) using the average values of the tensile strength. The Taguchi quality index of larger the better (Equation 4.4) was used in this work. Design expert 9.0 and Minitab 16.0 software was used for the analysis.

3.2 Stress Analysis of the Bolted Flanges

The oil and gas sectors are very interested in the mechanization of bolted flange stress analysis because it provides a window for flange acceptance or rejection during production. In this work, Autodesk software was used to simulate the bolted flange created from BFSAp and MAf. Figure 6 shows the bolted flange prototype that was used for the stress analysis. Components of pipe flange joints are homogenous, isotropic, and elastic in nature. Different properties and materials are listed in Table 6, and the material is as per ASTM standards, and these properties are used for finite element analysis. The flange is subjected to an internal pressure of 5.1 MPa and 10.2 MPa as per the pressure rating recommended for ASME Class 300 with a flange diameter of 11 inches (279.4 mm).

Table 4: Matrix Design for Calculating the Regression Co-efficient and ANOVA

S/No	X_O	A	B	AB	Tensile strength (N/mm^2)	Elastic modulus (N/mm^2)	%E	%W.A
75T-3t	1	-1	-1	+1	157.378	3982.93	25.42	2.01
150T-3t	1	+1	-1	-1	202.5	4354.09	24.45	1.05
75T-6t	1	-1	+1	-1	160.55	5160.00	26.37	1.45
150T-6t	1	+1	+1	+1	168.73	3729.42	23.056	2.08
Untreated					108.85	3101.42	21.056	3.78

Table 5: Results obtained from the tensile test

Exp. No.	**Randomized Run order**	**A (wt%)**	**B (%)**	**C (°C)**	**D (hrs)**	**Tensile strength MPaT_1**	**S/N ratio**	**Elastic modulus (MPa)**	**% Elongation**	**Energy to break (N.m)**
S1	3	10	10	50	2	108.9	40.74	3101.4	30.08	484.17
S2	7	10	20	100	4	112.68	41.04	27.81.1	27.96	507.44
S3	5	10	30	50	6	111.19	40.92	1854.65	29.22	501.48
S4	1	20	10	100	6	124.19	41.88	3300.47	33.92	584.93
S5	4	20	20	150	2	130.48	42.31	3626.34	27.44	468.87
S6	6	20	30	50	4	123.04	41.80	3395.99	26.09	432.83
S7	9	30	10	150	4	145.70	44.39	5160.55	37.77	687.18
S8	2	30	20	50	6	135.81	43.85	3840.09	34.87	598.24
S9	8	30	30	100	2	140.21	44.09	3729.99	31.62	566.90
Control						77.31		1731.94	13.8	122,71

Table 6: Mechanical Properties used for the Input

Items	Young Modulus (GPa)	Poisson ratio (γ)	Stress (MPa)	Materials
Flange	5160. 55	0.25	147.34	Polymer composites
Bolts	32271	0.3	345.65	A36 grade Steel
Gasket (2mm thickness)	512.00	0.21	17	ZW660 graphite

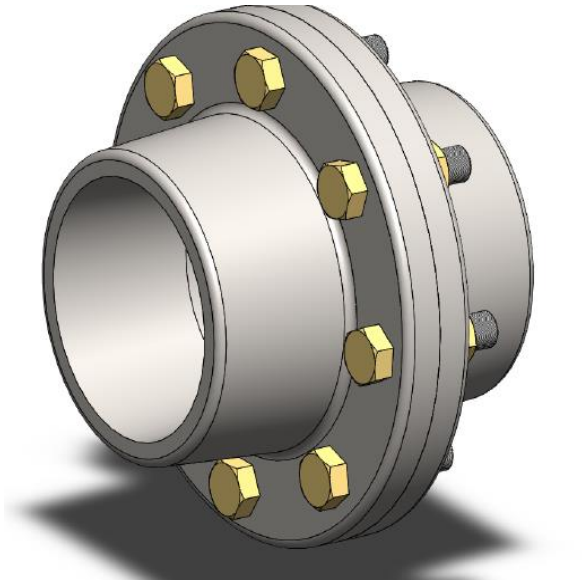


Figure 6: 3D photo of the flange, bolts and gasket of 2.00mm thickness

The boundary condition applied was the restraining of the displacement in the x and z directions and support at the center location in y-displacement (Figure 6). For the meshing, an average element size of 0.1 fraction model diameter and 0.05 shells, a 60° maximum turning angle, a 1.5 grading factor, and 0.2 minimum element sizes were used. The flanges are free to move either in the radial (X) or tangential (Z) direction; this provides flange rotation and the exact behavior of stress in the flange and bolt. Symmetry conditions are applied on both sides of the gasket, the bolt cross-sectional area, both sides of the flange ring, and the attached pipe. A nominal preload, i.e., 30% of the strength of the bolt, was chosen to perform stress analysis.

The simulation involves the modelling of the bolted flanges under the internal pressure to determine the stress, deformation, strain, and factor of safety of the materials. This force has been converted to an equivalent pressure load and applied uniformly in the axial direction at the end of the pipe. The working pressure load is applied over all elements of the internal surfaces of the pipe and the gasket.

The deformation of the bolted flanges under internal pressure, which inludes the gasket, flange, and bolt, is displayed in Figures 8-11. An internal pressure of 5.1 to 10.2 MPa was applied to the inner of the bolted flanges. The maximum deformation occurs at the point of application of the pressure; this could be attributed to the fact that bending of the flanges may happen, which should have kept the internal pressure and the sealing tights. High deformation of bolts and washers was observed due to high gasket compression as a result of bending of the flanges

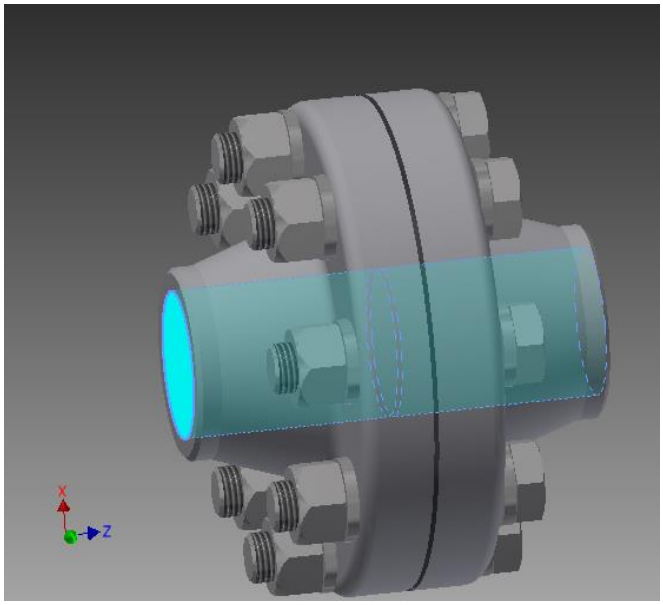


Figure 7: 3D photo of the bolted flange under the action of internal pressure.

Table 7: Stress Analysis of the Simulation

	5.1MPa		10.2MPa	
	Min.	Max.	Min.	Max.
Volume	7885850 mm^3		7885850 mm^3	
Von Mises Stress	0.0271534 MPa	85.9355 MPa	0.0135767 MPa	42.9677 MPa
1st Principal Stress	-7.78147 MPa	68.5634 MPa	-3.8907MPa	34.2817MPa
3rd Principal Stress	-36.8246 MPa	6.41309 MPa	-73.6491 MPa	12.8262 MPa
Displacement	0 mm	0.114167 mm	0 mm	0.228333 mm
Safety Factor	2.99318 ul	15 ul	1.49659 ul	15 ul

The Von Misses stresses and strain are displayed in Figure 8, the values of the Von Misses stress ranges from 0.0271534 MPa to 85.9355 MPa and 0.0135767 MPa to 42.9677 MPa at 5.1MPa and 10.2MPa pressure respectively. This was used to determine the yielding of the materials in question. It was observed in Figure 7 that the lower the internal pressure has the higher von misses stress which is close to the maximum strength of the materials.

The first principal and third principal stress values were obtained and displayed in Figures 9-10. It was observed that the values of the first principal stress range from -7.78147 MPa to 68.5634 MPa, -3.8907 MPa to 34.2817 MPa, and that of the third principal stress from -36.8246 MPa to 6.41309 MPa and -73.6491 MPa to 12.8262 MPa at 5.1 MPa and 10.2 MPa internal pressure applied, respectively.(refer to Table 7)

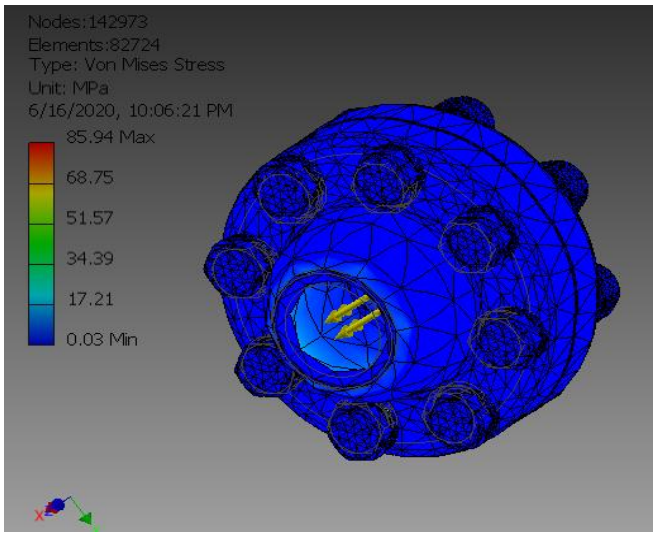


Figure 8a: Von Misses stress at internal pressure of 5.1MPa

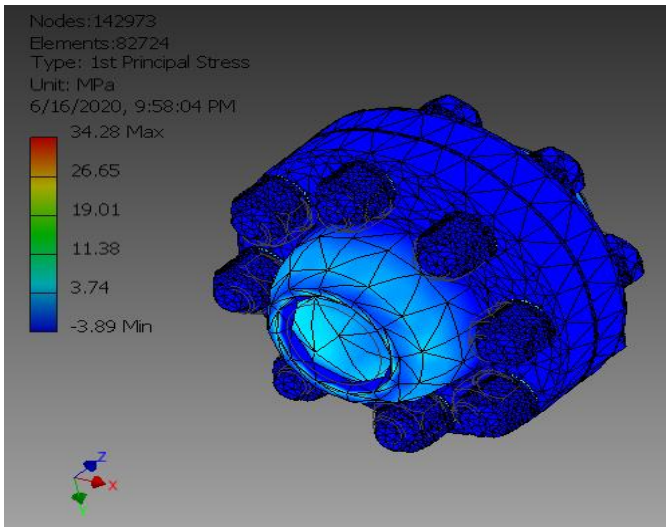


Figure 9b: First principal stress at internal pressure of 10.2MPa

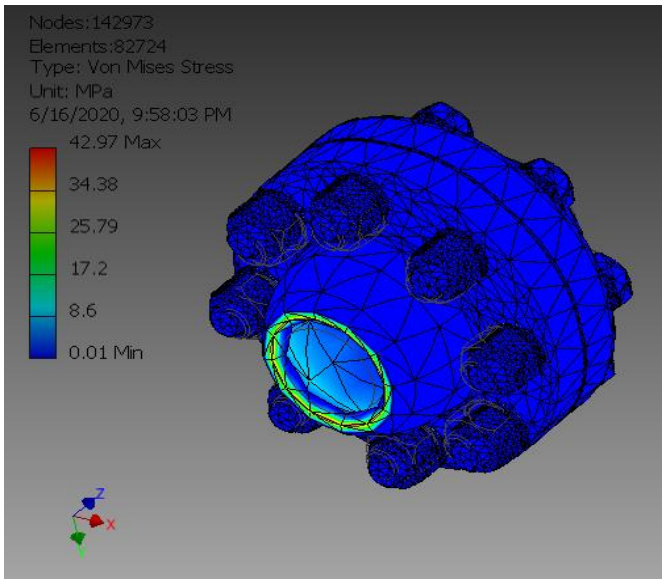


Figure 8b: Von Misses stress at internal pressure of 10.2MPa

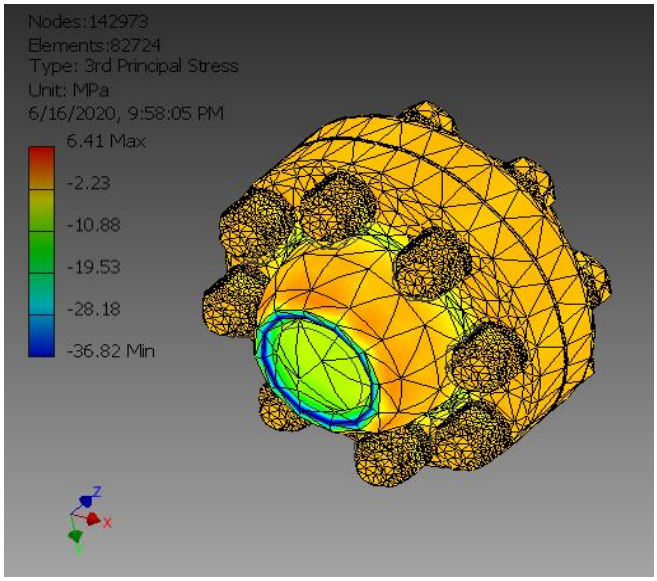


Figure 10a: Third principal stress at internal pressure of 5.1MPa

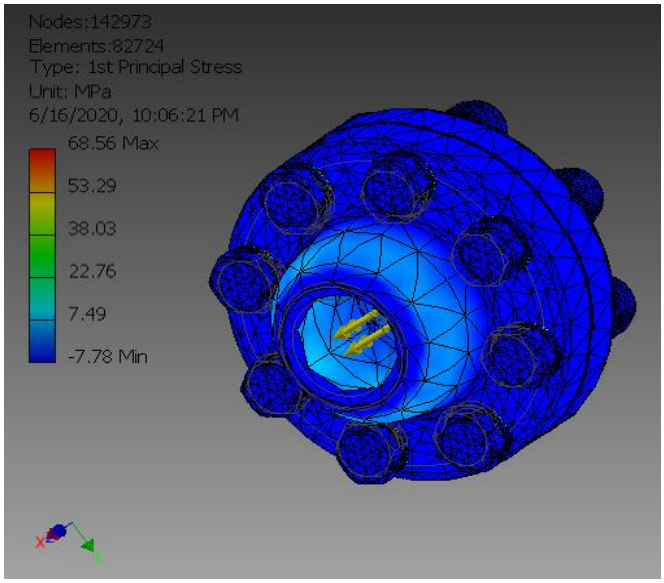


Figure 9a: First principal stress at internal pressure of 5.1MPa

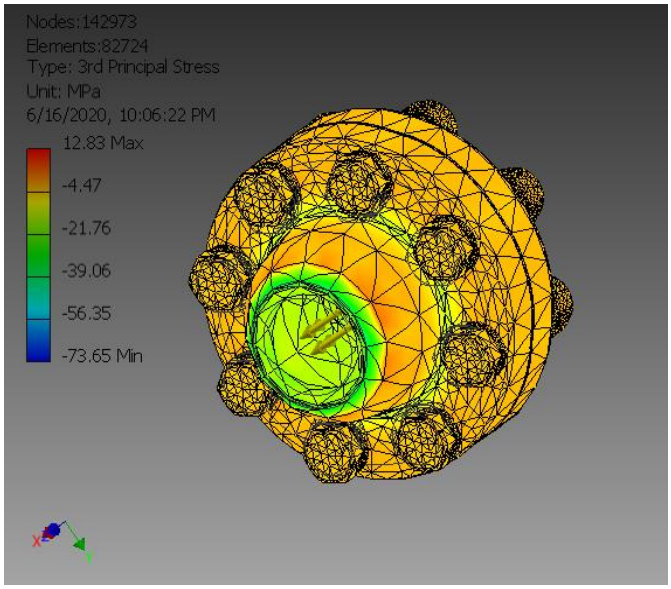


Figure 10b: Third principal stress at internal pressure of 10.2MPa

Maximum displacement values of 0.114167 mm and 0.228333 mm (refer to Figure 11), while a factor of safety of 2.99318 ul to 15 ul and 1.49659 ul to 15 ul (refer to Figure 12) were obtained in this stress analysis of the composite bolted flange at 5.1 MPa and 10.2 MPa internal pressure applied, respectively (refer to Table 6). The higher the applied pressure, the more the displacement and lower the von Mises stress and factor of safety. The higher deformation observed at higher internal pressure of 10.2 MPa was attributed to greater force, which tends to stretch the bolted flange apart.

The linear structural analysis of the developed bolted flange with sustainable materials shows that the high values of the Von Misses stress of 85.9355 MPa and 42.9677 MPa obtained in this study at 5.1 MPa and 10.2 MPa of internal pressure applied were attributed to the stiffness and strength obtained in this composite, which resulted in high toughness obtained by the reinforcement that gives a minimum factor of safety of 2.99318 ul and 1.49659 ul at 5.1 MPa and 10.2 MPa of internal pressure applied, respectively. The tensile strength and factor of safety obtained are within the recommended standard for bolted flange applications [14, 15].

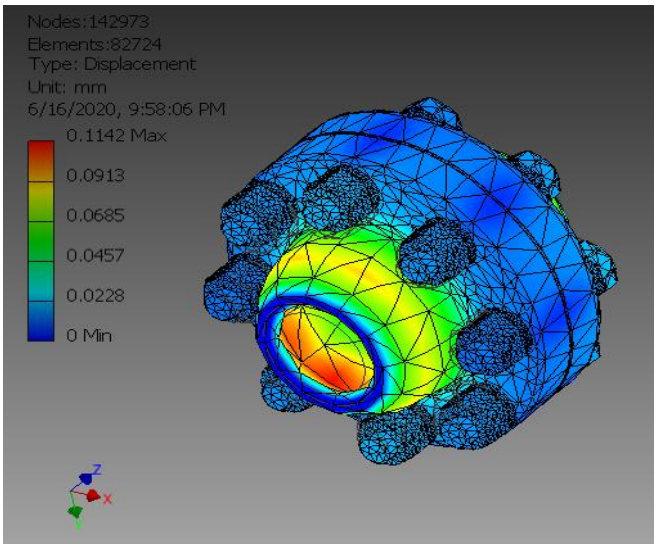


Figure 11a: Displacement at internal pressure of 5.1MPa

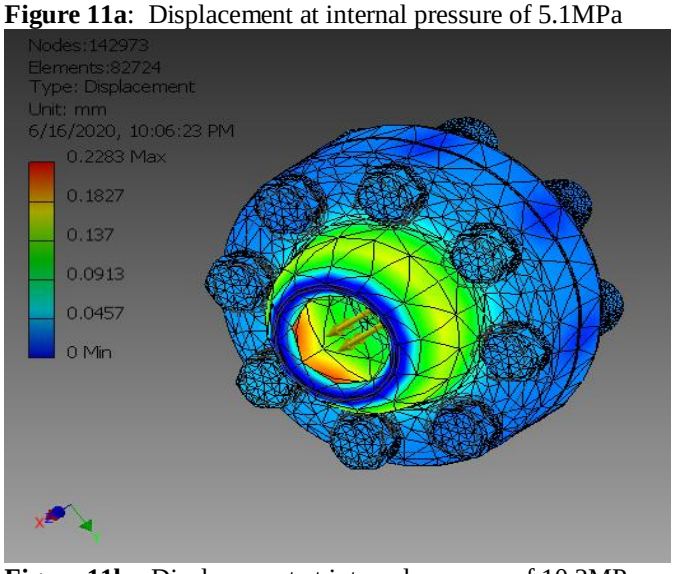


Figure 11b: Displacement at internal pressure of 10.2MPa

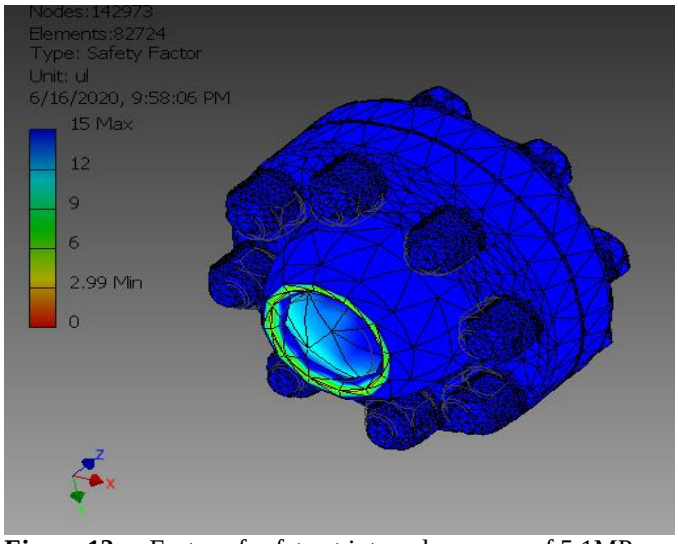


Figure 12a: Factor of safety at internal pressure of 5.1MPa

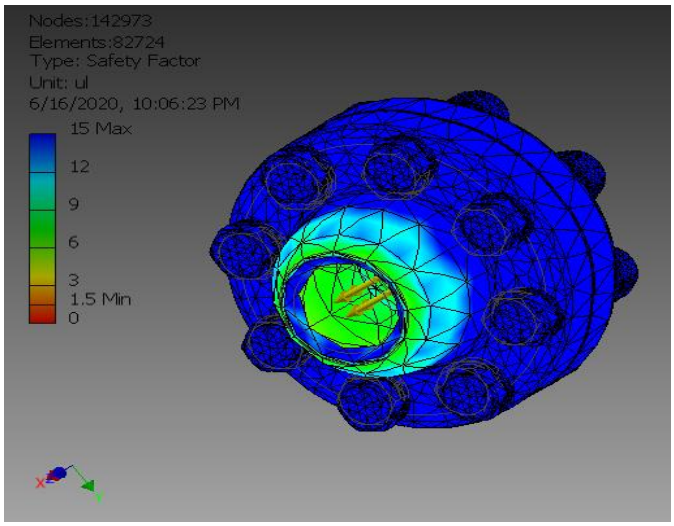


Figure 12b: Factor of safety at internal pressure of 10.2MPa

4. Conclusion

The study provided new information regarding the structural performance of a newly developed composite bolted flange for oil and gas applications. MAf and BFSAp as new materials for bolted flange applications have been established. From the observation of the linear structural analysis, the value strength and factor of safety obtained are within the recommended standard bolted flange application. The current study has yielded some important information about the development of Epoxy- MAf-BFSAp hybrid composites for bolted flange application. In the course of the investigation, recommendations and new areas of research have been identified. Corrosion problem of a metallic bolted flange can be reduced using the developed composite. [16, 17, 18].

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Author Contributions

All the authors contributed to the development of the work. All authors read and approved the final manuscript.

Competing interests
The authors declare no competing interests.

Data Availability
The authors confirm that the data supporting the findings of this study are available within the article.

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