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(Research Article)

Production and Thermal-Structural Analysis of Welding Face Shield from Plantain Fibers Reinforced Polymer Matrix Composites

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Abstract

Composites have been widely used in engineering research since the increased interest in fibers and resins. This paper describes a polymer matrix that is supported by a low-cost plantain fiber-welding face shield system and thermal-structural analysis. A manual scraper process was used to extract the fibers from the plantain pseudostem and the hand lay-up molding process was used. Polyesters and resins have been successfully processed without heat or pressure to cure, so no heat has been released. Ansys 14.0 software tool was used to examine the thermal and structurally developed welding face shield. The welding face shield was developed, and the polymer matrix bonding between the fibers was found to be excellent and showed no signs of delamination or debonding. The findings of the analysis indicate that the average temperature distribution is within the correct range at a radiative temperature of 80 ^oC. The maximum total heat flux distribution of 25236 W/m^2 has a minimal effect which shows that the insulation properties of the composite do not allow the effects of the welding temperature to penetrate the material and thus protect the user's face from the heat. The results of the stress analysis show that the maximum von misses stress distribution of 1.551E5 Pa is lower than the maximum main stress distribution of 1.8551E5 Pa at a radiative temperature of 80 ^oC, which means that the force is suitable for working conditions. The maximum total deformation of 4.1104E-5 m at a radiative temperature of 80 ^oC suggests that its strength is sufficiently high to withstand the stress factor in the working condition based on the fiber effect because it is less than the maximum directional deformation of 4.3862E-5 m. The composite welding face shield made from plantain fiber has a lighter weight compared to traditional materials and is durable and suitable for welding processes.

Keywords: Composite, plantain fiber, polymer materials, production, thermal-structural analysis, welding face shield.

1. Introduction

Cellulose-based natural fibers are an alternative to synthetic fibers as a reinforcement for polymeric materials due to environmental and technological advantages [1-3]. Facts that waste natural fibers have advantages of low density, low cost, good thermal properties, improved specific strength, biodegradability, environmentally friendly nature and can be used as a substitute for glass fibers during composite production to meet individual requirements [4-6]. This ensures a good combination of mechanical properties and thermal and insulating protection [7-9]. The high cost of synthetic fiber and asbestos fiber health risks necessitated the discovery of natural fiber [10-11]. Due to their high specific strength, Plantain fibers can be used as a replacement for glass fibers as reinforcement in composite manufacturing [12-14]. Plantain fiber composite's mechanical properties are superior to traditional materials' properties and are used as the material of choice for several structural and non-structural industrial applications [15-17].

With the growing global energy crisis and environmental risks, natural fiber reinforced polymer composites and their application in impact-loading equipment design have attracted more research interest due to their potential to serve as an alternative to artificial fiber composites [18-19]. Plantain demand in Africa is projected to be more than 50% of world production [20-21]. Nigeria is one of the largest production plantain countries in the world and is estimated that more than 15.07 million tons of plantain are produced annually in Nigeria [20]. Plantain fiber can be easily obtained from plants that are made as waste after the fruit has matured. In comparison, plantain grows to a mature size in just 10 months, while wood lasts for at least 10 years [20]. The use of fiber-reinforced polymers (FRPs) is increasing in the aerospace and automotive industries due to their inherent advantages over conventional materials. Increased use is reported not only in the above-mentioned applications but also in many other technical applications, in particular where high strength and rigidity are

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required but the low component weight [22-24]. Classical FRP composites, however, face difficult re-use and recycling problems, mainly due to the compounding of miscellaneous, usually very stable fibers and matrices [25-27]. An alternative option is the construction of composite materials made from renewable resources, including production technologies that are economically and environmentally acceptable.

The designer is always interested in estimating the fault stress of the material that he wants to use in his design, and the most important characteristics that require consideration for most engineering components include mechanical properties (strength, rigidity, specific strength and stiffness, fatigue and durability, and influence of high or low temperatures on these properties), corrosion susceptibility and degradation, wear-resistance and frictional properties, special properties, molding and/or other methods of fabrication and the total costs attributable to the selected material and manufacturing route [28-29]. The thermal conductivity of the fibrous insulation is a combination of conduction, convection and radiation by porous material [8-9],[30]. The initial analysis is needed to determine the suitability of thermal insulation for the development and use of new materials. The apparent thermal conductivity is a good predictor for assessing the suitability and potential scope of application for prospective insulating material [31-32]. The rapidly expanding thermal insulation industry has dominated synthetic materials such as mineral fiber, fiberglass, foam and polystyrene for decades [33-34]. However, the non-biodegradability of such materials has contributed to environmental issues, as retrofitting, refurbishing, reconstruction and upgrading of existing buildings have seen an increasing amount of discarded disposable insulation content [7],[35].

Numerous investigations have been conducted into the potential of natural fibers as composite reinforcements [36] and, in several cases, the result has shown that natural fiber composites possess good rigidity, but do not achieve the same level of strength as composite fibers [2],[19]. Oladele et al.[37] reported that the fiber/matrix plays a significant role in composite micromechanical behavior. According to OSHA [38], welding raises a range of well-known and subtle health and safety hazards. Increasing industrial accidents caused by improvements in technological progress in the automotive sector need an innovative approach to automotive safety measures. Appropriate welding face safety equipment is used to avoid possible damage to welders due to radiant energy during such dangerous activities. In this study, polyester and plantain fibers were used as matrix and reinforcement materials in the manufacture of natural composite materials. To achieve cost-effectiveness and maximum strength while maintaining the previously established properties, this composite was used to produce a welding face shield and its thermal-structural analysis.

2. Materials and Methods

2.1 Materials: Materials used in the conduct of this research are polystyrene foam, calcium carbonate powder, epoxy resin and hardener, strawboard, log water-based binding agent, clear tooling gel coat, polyester laminating resin, cobalt derivative accelerator, black pigment, 2 inches paintbrushes, universal mold release wax, polyvinyl alcohol, chopped strand mat fibers, resin–unsaturated polyester resin, the catalyst–Methyl Ethyl Ketone Peroxide (MEKP), accelerator–cobalt naphthenate, reinforcer–plantain fiber, mold release agent–silicon wax (mirror glaze), other fillers calcium carbonate, Gelcoat–resilient isophthalic gel coat, and styrene monomer.

2.2 Equipment: An already finished mold, weighing balance, mixing bowl, cutting/grinding machine, hack-saw blade, iron rolling, sandpaper/emery cloth, tensometer, wedged, and a rubber mallet.

2.3 Plantain fiber extraction and chemical treatment: The fiber content used in this analysis is plantain fiber. It was extracted from plantain pseudostem using a manual scraper [21],[39]; it was prepared and treated with the following liquids: mercerization, silane, and acidic or hydroxide to create the most hydrophobic fiber. The fibers were washed so that several chemicals could be used on the surface to enhance their interfacial properties.

2.3.1 Plantain fiber matting and reinforcement: This includes dimensional stability, that is, the processing of fiber strands in matt shapes, making them more compact for easy handling and serving as reinforcing materials. Initially, the plantain fibers were chopped stranded in 500 m lengths and divided into single strands. The PVA (Poly Vinyl Acetate) binder was then applied to the flat, smooth surface of the floor where the already chopped stranded fibers were uniformly and randomly distributed. Water was sprinkled on the fibers and beaten to ensure adequate wet-out of the PVA. This process is known as fiber impregnation and has been done to obtain a uniform thickness. Subsequently, the reinforced fiber mat was sun-dried for about 24 hours.

2.4 Methods:

2.4.1 Mold fabrication procedure: A commercially available welding shield was used as a guide for the creation of a design. The scale and form have been implemented using a foam cutting tool; polystyrene foam has been cut into forms roughly identical to the shape of the face shield. A sanding pad covered with rough sandpaper was used to sand and refine the form of the foam pattern. After hours of meticulous sanding, the design resembled the facial shield being emulated but without the viewing screen area in relief, this viewing area was built using a strawboard and a log water-based sealing agent to seal the porosity of the strawboard surface using a much-smothered surface until it was flawless.

The pattern of the strawboard was glued to the polystyrene foam pattern in the correct position as in the commercial face shield. The edge around the polystyrene pattern was surrounded by straw and held securely in place. A mixture of calcium carbonate and log sealing agent was formulated for a puffy electoral district and was used as a filler to secure the straw lip around the edge of the polystyrene pattern as well as the corners of the strawberry pattern glued to the polystyrene pattern. The system was allowed to dry out completely. The rough edges and spots were sanded smoothly. A 2:1 combination of epoxy resin and hardener has been used to cover the entire surface of the polystyrene foam as well as the pail attachment, and the system has been completely repaired. To add grain to the surface, a further round of epoxy resin was added, but this time it was applied with a piece of foam in a touch and raise motion leaving a mark on the smooth surface. On full curing; the pattern was ready for use in the preparation of the mold.

2.4.2 Mold lamination procedure: The lamination of the mold was carried out first by washing the mold with dry rags, avoiding dust and water, and then by adding the wax to the mold several times over the surfaces of the mold. Polyvinyl alcohol (PVA) has been applied using a brush. On drying, Gelcoat, a special mold-specific polyester resin formula, was moved with appropriate quantities of catalyst and accelerator and applied evenly over the surface of the pattern, allowed to be partially cured, then mixed with laminating resin and used to wet three (3) layers of woven strand matt plantain fibers over the gel load layer. The system had been allowed to cure for a whole day. The next step was the de-molding, which consists of extracting the pattern from the laminated mold. This was done by pulling the pattern or the laminate out of the mold. The mold was trimmed using an angle grinder and was ready to fix a well-concentrated fiber on the laminate point of view and was ready to be used to make a face shield.

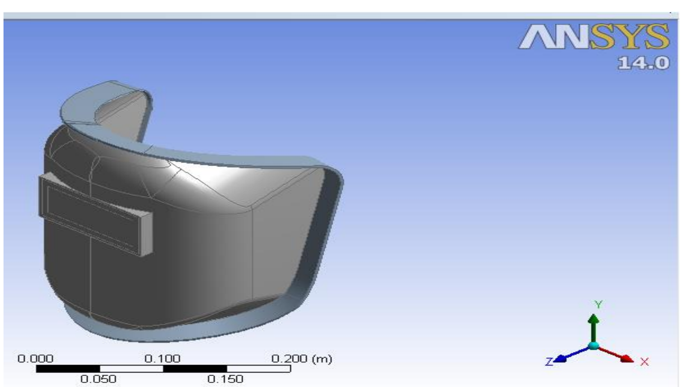


Figure 1. A 3-D Model of a Plantain Fiber Reinforced Polyethylene Welding Shield

2.4.3 De-molding and surface finishing processes: De-molding is the removal of the laminate from the mold after it has been allowed to be installed. Immediately after the de-molding process, post-cure treatment is followed. This involves all treatments given to the molded component to correct errors or defects introduced in the work during molding or de-molding operations. These include the use of a grinding machine to properly trim the protruding fibers and then sandpaper to achieve smooth corners; drilling holes with a hand drill on the laminate to make fasteners as in commercial welding shields; and spraying the laminate with black coloured paint for uniform orientation.

2.5 Thermal and structural evaluation: Ansys 14.0 software tool was used for the thermal and structural analysis of the welding face shield produced from plantain fiber reinforced polymer matrix. Table 1 shows the properties of Polyethylene and plantain fiber.

2.6 Performance Test: Tensile testing was performed on the produced face shield in accordance with the ASTM D3039 Standard Method using a Universal Testing Machine. The loads of 200N to 1800N at the interval of 200 was applied to the face shield. The area and length of the specimen are 50 mm^2 and 75 mm respectively.

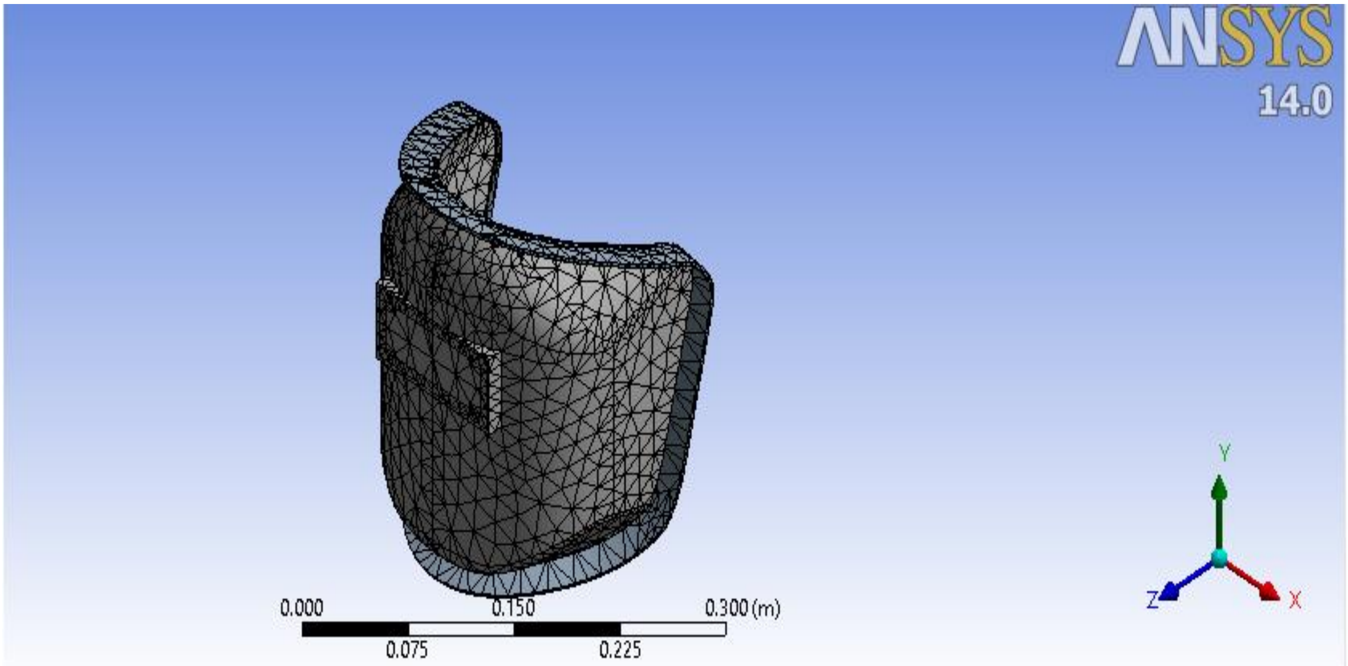
Table 1. Properties of Polyethylene and Plantain Fibers

Polyethylene	
Parameters	Values
Density	930-960 kg/m^3
Tensile Strength	(2.07-4.48)E7 Pa
Young's Modulus	(6.21-8.96)E8 Pa
Poisson Ratio	0.418-0.434
Compressive Strength	(1.97-3.19)E7 Pa
Vicker's Hardness	(5.3-8.53)E7 Pa
Maximum Service Temperature	90-110 °C
Minimum Service Temperature	-123 - -73.2 °C
Thermal Conductivity	0.403-0.435 w/m°C
Working Temperature	80 °C
Plantain Fibers	
Density	750-950
Tensile Strength	529-914 MPa
Young's Modulus	27-32 GPa
Specific Young's Modulus	20-24 GPa
Specific Tensile Strength	392-677 MPa
Failure Strain	1-3 %

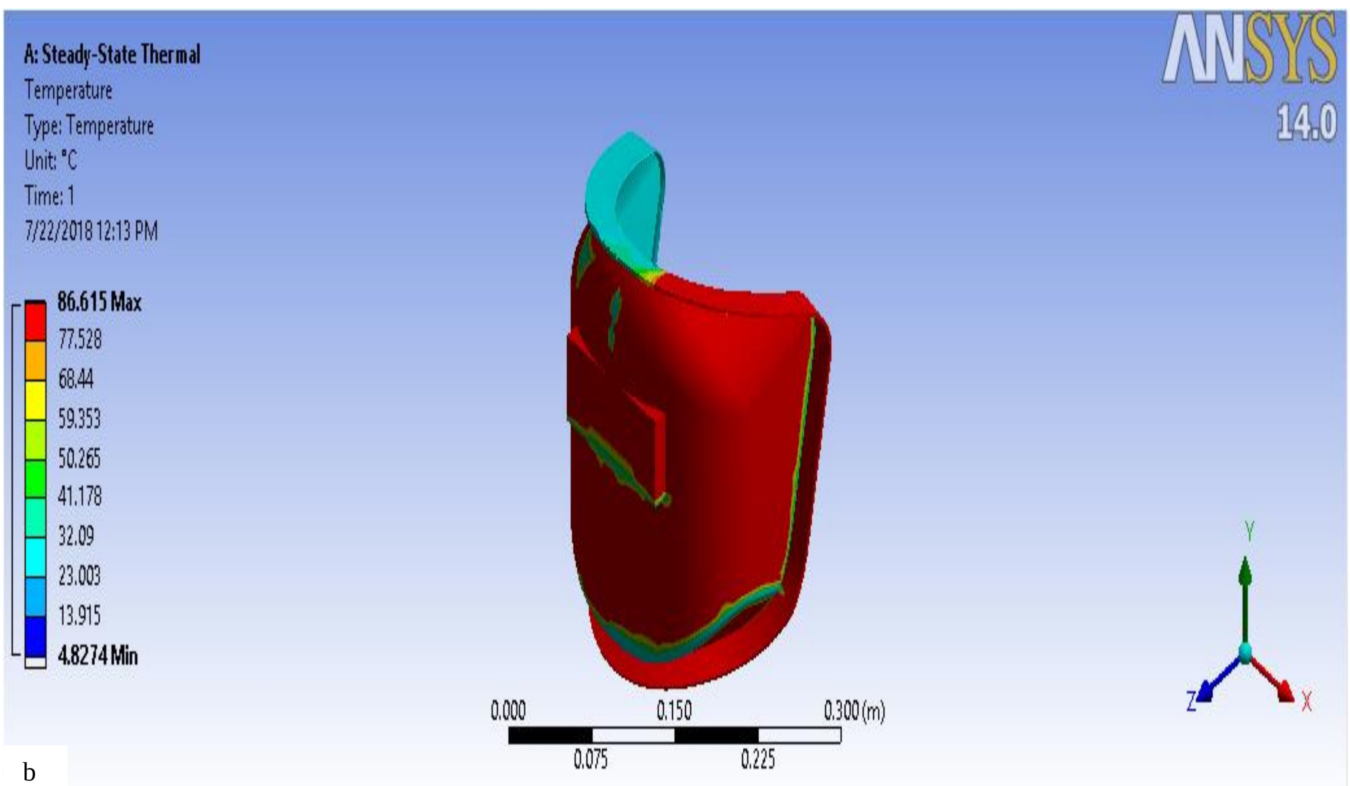
3. Results and Discussion

The results of the thermal-structural analysis of the Polyethylene welding shield reinforced with plantain fiber are shown in Figures 2, 3, 4 and 5.

Figure 2a is a 3-D mash model showing the mash configuration of a plantain fiber reinforced Polyethylene welding shield, whereas Figure 2b is a 3-D configuration of a plantain fiber reinforced Polyethylene welding shield showing a temperature distribution within an appropriate range at a radiative temperature of 80 °C. Figure 2 is a temperature distribution of the result of the boundary conditions used, the insulation properties of the composites could not allow the effect of the welding temperature on the other side of the material, and therefore the user's face is protected from heat.

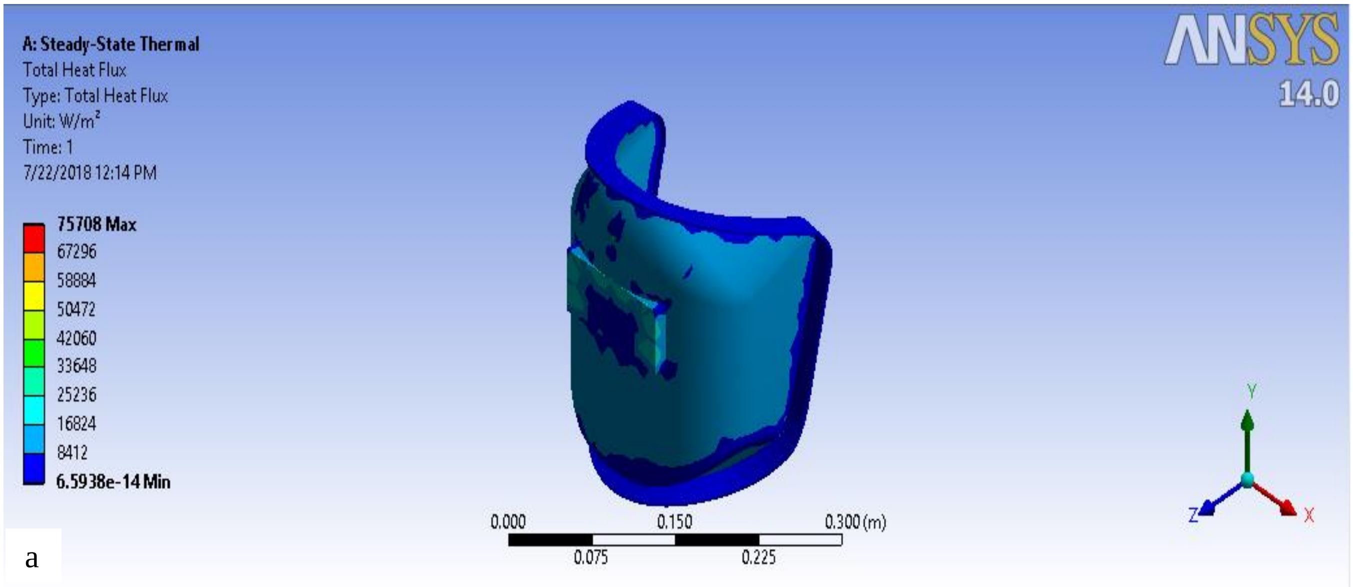


(a)

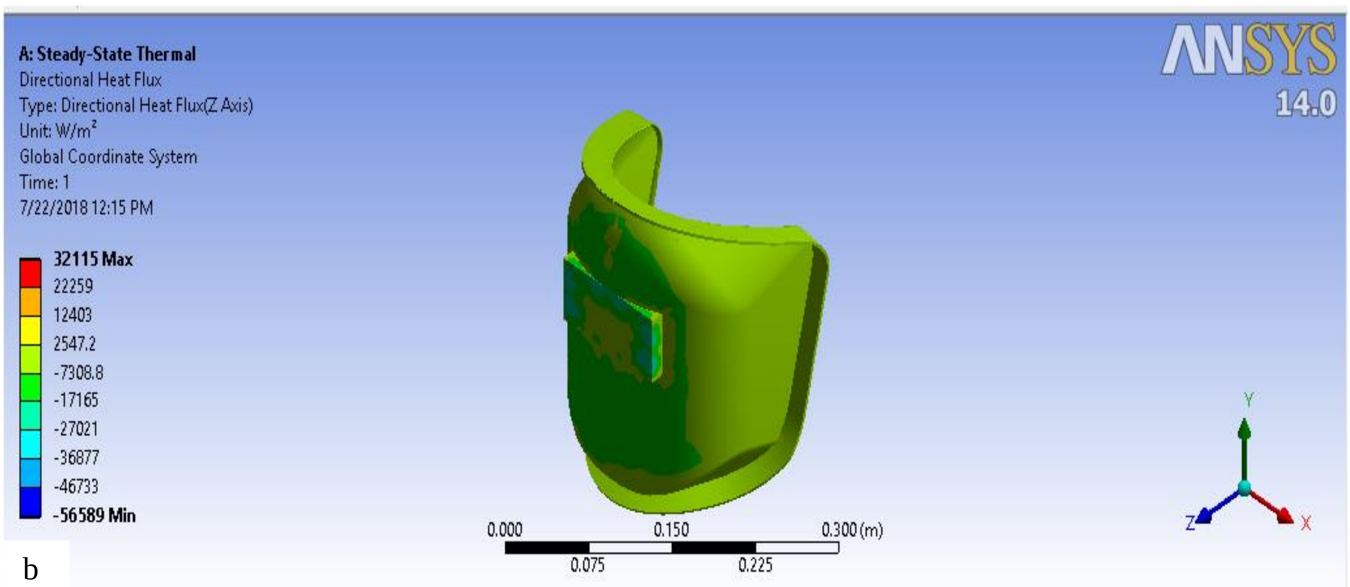


(b)

Figure 2. A 3-D Model (a) Mesh (b) Temperature Distribution



(a)

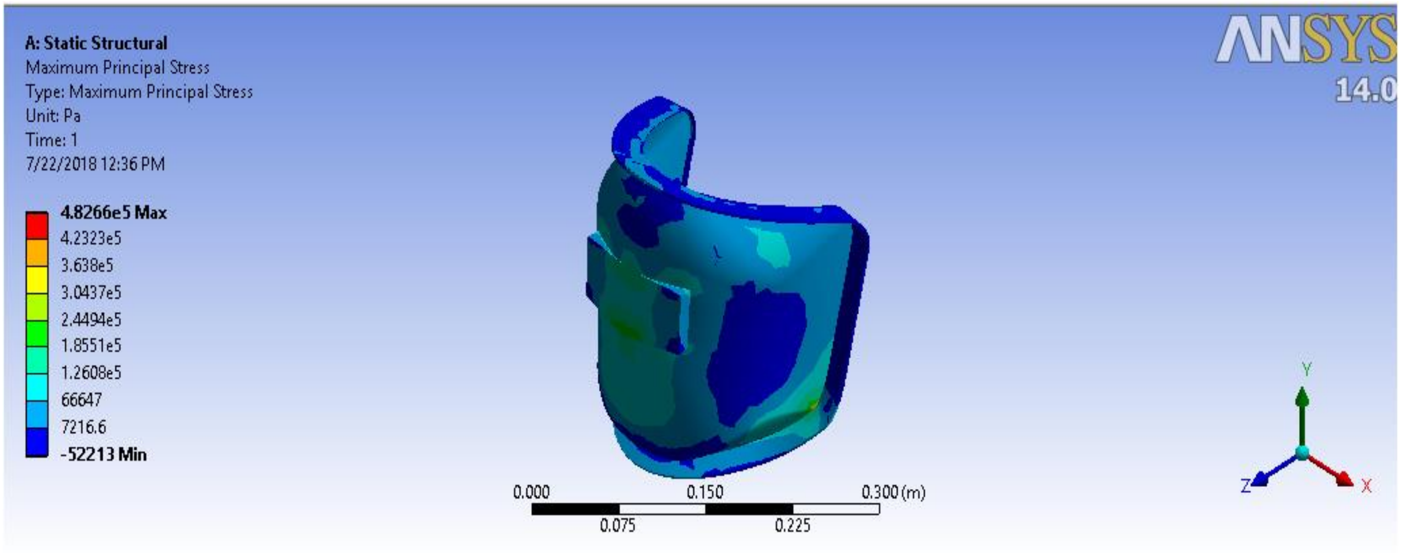


(b)

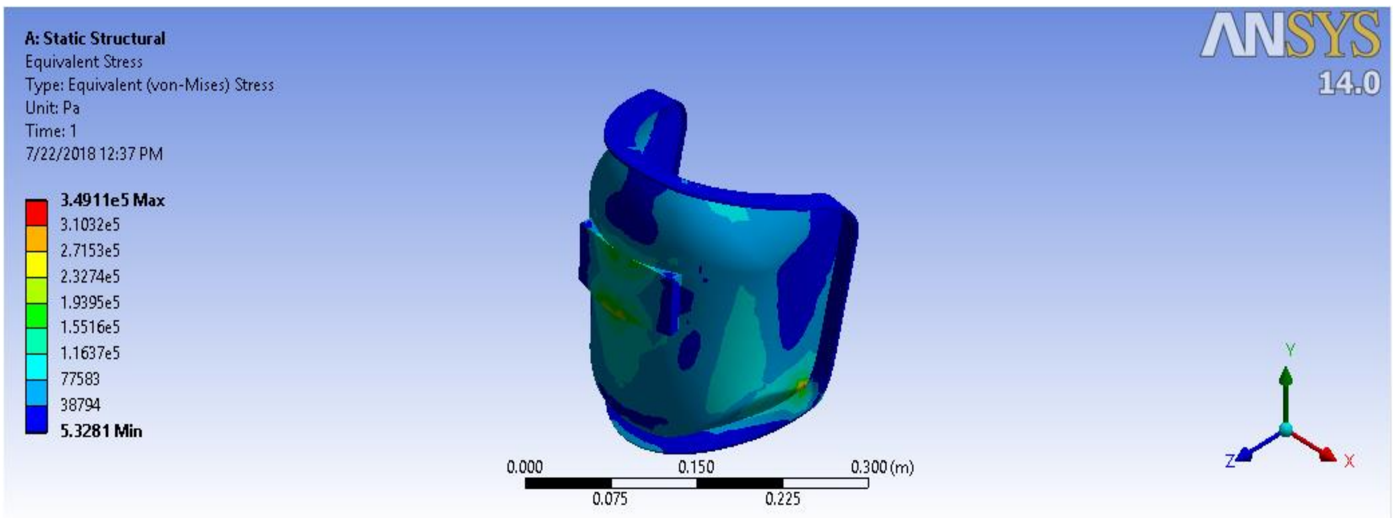
Figure 3. A 3-D Model (a) Maximum Total Heat Flux (b) Minimum Heat Flux

The effect of the heat flux is a function of the temperature distribution and therefore, from Figure 3, the total effect of the heat flux distribution is minimal due to the insulating properties of the composite. Thus, the user is protected from the heat that would have affected his face, making his manufacturing work terrible for him. Figure 3a shows the maximum total heat flux distribution of 25236 W/m^2 at a radiative temperature of 80 °C. The directional heat flux, to a certain degree, defines the strength of the heat in a particular direction, hence the directional heat flux distribution on the face shield is small. In Figure 3a, the impact on the material of the face shield is x-rayed and gives a clear indication that the user's face will be protected, lower than the total distribution of the heat flux. Figure 3b shows the minimum spatial thermal flux distribution of -17165 W/m^2 from the z-direction showing the welding flame effect at a radiative temperature of 80 °C.

The purpose of the structural analysis is to assess the impact of the load on it, which decides its reliability and usability under an unregulated situation where it is haphazardly maintained. The protection in relation to harm will be guaranteed under the load applied. Figure 4 shows the main stress effect, which shows a minimal effect.



(a)



(b)

Figure 4. A 3-D Model (a) Maximum Stress Distribution (b) Maximum von misses Stress Distribution

Figure 4a shows the maximum main stress distribution of 1.8551E5 Pa at a radiative temperature of 80 ^{o}C, with thermal-structural coupling indicating its strength in working conditions. Figure 4b shows the average von misses stress distribution of 1.5516E5 Pa lower than the main stress at a radiative temperature of 80^{o}C, thermal-structural coupling suggesting that the pressure at the working condition will be sustainable. The stress of the von misses is used to visualize the effect of the loads on the composite face mask to see areas that are most stressed to identify areas that are likely to fail. Failure is inevitable in the areas most stressed, hence Figure 4b shows the distribution of stress when loads are applied.

Directional deformation shows the direction the body will fail to follow. Directional deformation in Figure 5 is minimal and has no major effect on the object. Figure 5a shows the maximal directional deformation of 4.3862E-5 m at a radiative temperature of 80 ^{o}C, the thermal-structural coupling indicating its intensity is strong enough in a working condition based on the fiber effect. Figure 5b shows the maximum total deformation of 4.1104E-5 m at a radiative temperature of 80 ^{o}C, the thermal-structural coupling suggesting its strength is strong enough to withstand the stress factor at the working condition based on the fiber effect as it is less than the directional deformation. Maximum deformation is small as the values are marginal with a maximum value of 9.2483E-5 m. The effect is therefore insignificant. These findings are summarized in table 2. While figure 6 shows the photographs of the produced face shield.

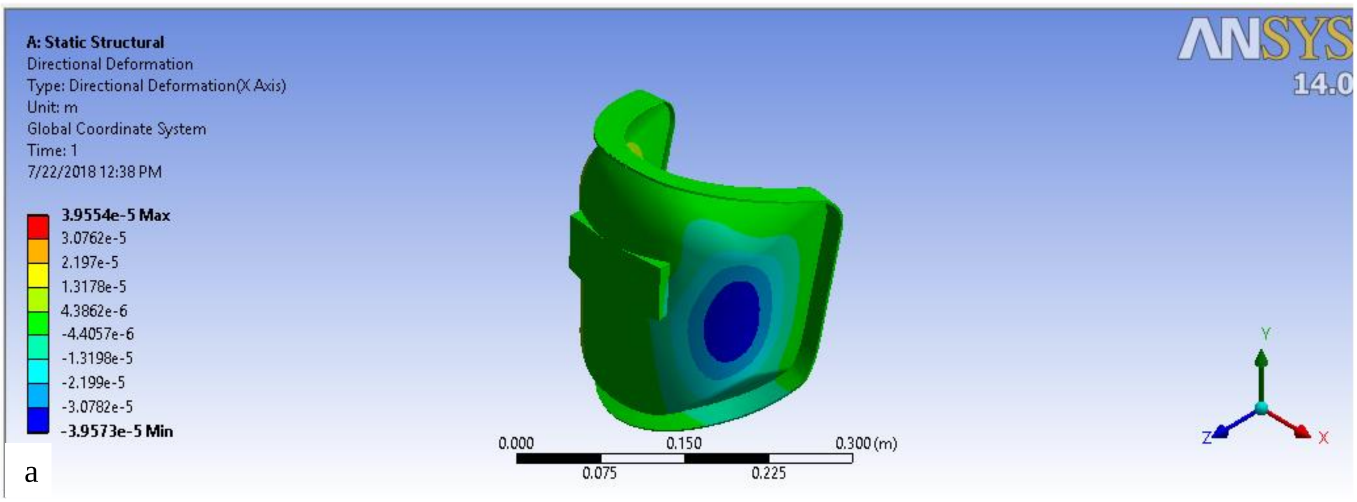
Table 2. Thermal-structural Analysis of the Welding Face Shield

At a radiative temperature of 80 ºC	
Maximum total heat flux	75708 W/m^2
Minimum total heat flux	6.5938E-14 W/m^2
Maximum directional heat flux	32115 W/m^2
Minimum directional heat flux	-56589 W/m^2
Maximum principal stress	4.8266E5 Pa
Minimum principal stress	-52213 Pa
Maximum von mises stress	3.4911E5 Pa
Minimum von mises stress	5.3281E5 Pa
Maximum directional deformation	3.9554E-5 m
Minimum directional deformation	-3.9573E-5 m
Total deformation	9.2483E-5 m

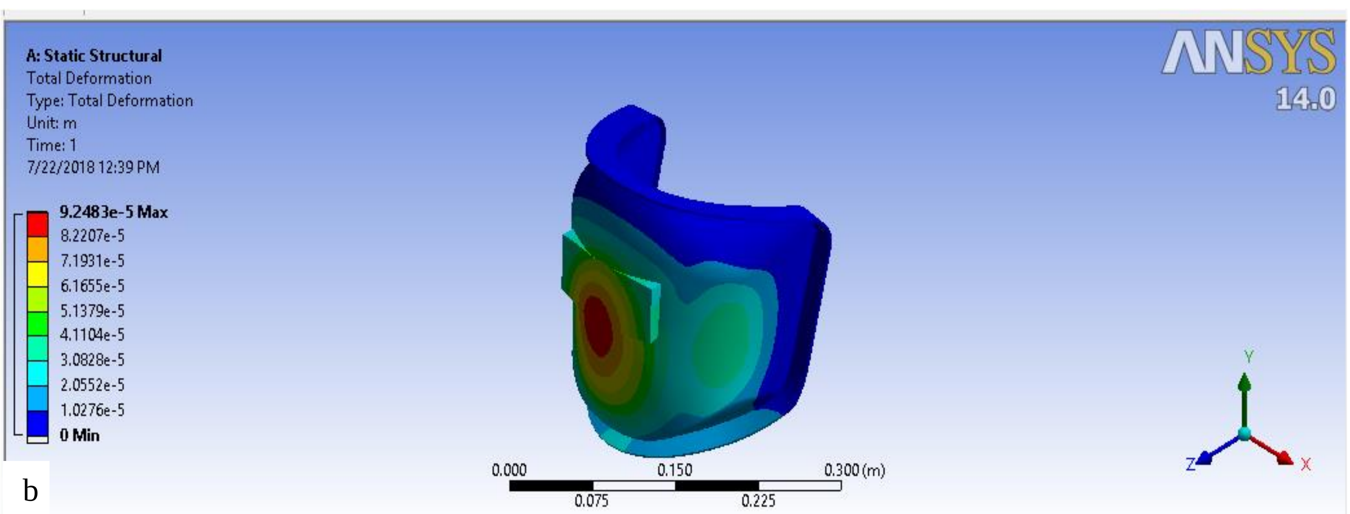
Table 3. Experimental and FEA Results

SN	Maximum Stress	Result	Unit
1	Experimental stress	3.2E5	Pa
2	Von mises stress	3.4911E5	Pa
3	Principal stress	4.8266E5	Pa

The tensile test result shows a maximum stress of 3.2E5 Pa at a load of 1600 N, while at a load of 1800 N, the specimen fails the tensile test with a stress of 3.6E5 Pa. The comparison of experimental and FEA results is shown in Table 3. Table 3 shows that the principal stress exceeds both the von Mises and experimental results, implying that the specimen will not fail at this maximum stress. Von Mises stress is also greater than the experimental stress, indicating that the specimen will not fail, confirming the result of the tensile test at 3.6E5 Pa, which is greater than von Mises stress.



(a)



(b)

Figure 5. A 3-D Model (a) Maximum Directional Deformation (b) Maximum Total Deformation

Figure 6. Photographs of Produced Face Shield

4. Conclusions

Study of design, thermal-structural analysis and production of welding face shields using natural fiber to ensure cost-effectiveness. The welding shield, which has undergone a series of thermal-structural analyses of the efficiency and performance of the mechanical properties, has shown excellent results. It was found that the bonding between the fibers in the polymeric matrix was excellent and showed no signs of delamination or debonding. The composite laminate has been exposed to different weather conditions and has been checked for fatigue and cracking throughout. The results of the thermal-structural analysis of the plantain fiber reinforced Polyethylene welding shield indicated that the insulation properties of the composite resist the effect of the welding temperature and also showed that the total heat flux distribution effect is minimal due to the insulating properties of the composite. In addition, the face shield provides a clear indication that the user's face will be protected as the spatial heat flux distribution is lower than the overall flow distribution.

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