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The Amount of Excess Weight from the Design of an Armored Vehicle Body by Using Composite Materials Instead of Steel

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ABSTRACT

In this paper, the amount of excess weight resulting from the design of a mathematical model composed of composite materials will be calculated and compared with a mathematical model of an armored steel structure. Five different models were designed, one of which is made of steel, the other part is made of composite materials, and a section of steel and composite materials, and then tested for resistance to stresses and compared the weight of each structure with that of the steel component by taking the maximum stress as a basic criterion for weight comparison. The results showed that the best model was the second model fiberglass, where the percentage of weight loss was compared to the steel model (73.77%), in addition to the wall thickness (62 mm) and the wall thickness of the steel model with which the comparison was (60 mm), but the displacement is (7. 24 mm), and in the steel model it is (1.827 mm). The best model compared to steel in terms of resistance to maximum stress, less displacement and less weight was the model consisting of steel with carbon fiber and its thickness was (47 layers& 57 mm, 2 layer & 10 mm steel and 45 layer & 45 mm carbon fiber), and the percentage of weight loss compared to the first mathematical model (60.96%). The results of this research may be a key to obtaining alternative materials for traditional materials in the manufacture of armored hulls, aircraft and ships, and it has a lower weight.

1. INTRODUCTION

Composite materials are described with high strength, stiffness, and low density as contrasted with bulk materials, permitting the weight reduction in the Vehicle's parts, and can oppose a high ballistic force because of their high strength to weight proportion [1]. Composite armor layer ordinarily made out of various material layers that comprise of fiber overlays, rubbers, ceramics, metal, and so on. The design factors of composite armor are most frequently limited to the material determination, layer thickness and layer request [2]. Among the regular composite materials are fiber strengthened polymer, and ceramic, they are not just described with stiffness and high strength to weight proportion properties, yet besides offers different properties, for example, flexural strength; high sturdiness; high hardness; firmness; damping property; thermal dependability; and protection from wear; corrosion; fire; and impact as well as low density. These wide scopes of features were enabled the composite materials to find r applications in automobile, construction, mechanical, aviation, marine, biomedical, and present-day defensive layer [3]. Composite material performance is dominating relies upon the assembling strategies and their constituent components, subsequently, fiber functional properties as well as assembling procedures that have been applied to design and manufacturing the composite material are significant needs to be studied to figure out their optimization qualities for the necessary application [3]. The design strategy complexity nature of sun-based vehicle fiber strengthened composite structure was examined, and repaid by fitting their mechanical attributes and optimizing the overall load of the vehicle [4]. The normal fiber with glass half breeds was embraced to improve the mechanical properties over utilizing regular fiber alone [5]. A reinforced vehicle configuration was read for characterizing the prerequisites relying upon to perform the various task execution, the structural stages for various courses of action, a protection dangers determination for various pieces of the fuselage, just as execution test. The ballistic assessment relying upon the weakness capacities was concentrated by non-including insurance for an individual. It was indicated that conservative arrangement which empowers personal transfers and conveying the joined overwhelming weapons or a crucial reasonable was conceivable by the adaptability of the design [6]. An exploratory and numerical methodology was investigated for deciding the productivity of the ballistic defensive layer framework that has been made from ceramic and metal against a 40.7-gram steel shot. It was inferred that the simulation technique applied right now was a good design tool and valuable for optimizing lightweight armor that has been made from ceramic and metal [7]. The advanced design process was proposed for a composite armor, dependent on testing and simulation. It was demonstrated that the crossbreed material design that has been utilized for the ceramic layer gave an extra design variable besides, size, thickness, and materials. It has likewise appeared through physical and virtual prototyping that the performance of the improved ballistic could be accomplished through the procedure of the design [2]. Characterization and recognition of the ballistic harm of ground vehicle armor panels produced using composite material were performed by a computed tomography imaging approach of an ultrasonic guided wave. A guided wave of incredible potential has appeared for the location and mapping of the damage that has been happening in composite panels [8]. An experimental and numerical investigation of armor produced using the composite system for ballistic protection was introduced. The composite system was fabricated from Al_2O_3 ceramic mounted on the hitting face and backed with high strength steel. The system demonstrated a higher degree level of ballistic performance, which could overcome a 7.62*54 armor-penetrating projectile [9]. The mechanical properties including (impact, hardness, and tensile) of an epoxy lattice composite material strengthened with a particle of TiO_2 and a short irregular glass fiber of (3% wt, 6% wt, and 9% wt) weight portion were considered. The outcomes uncovered improvement in mechanical properties with an increase in the division weight rate [10]. Hexagonal honeycomb cores of a sandwich panel produced from a glass fiber strengthened polymer was made by an adhesion method. Three methods twisting trial of the panels with three sorts of glue (thermosetting resin, plastic steel epoxy, and polyomino-amide- biphenyl-A resin) were accomplished to examine the bending stress. It was concluded that the honeycomb sandwich panel stress with all the three adhesives was more than that for Kalisahak28 lightweight undercarriage [11]. Carbon and glass fiber strengthened composite were mechanically tried for tensile (at different temperatures and strain rates), impact and flexural (at different strain rate). The carbon fiber strengthened polymer test results demonstrated a superior tensile, impact, and flexural properties than that of glass fiber strengthened polymer [12]. Interlayer and interlayer mixture composite were explored for compressive and tensile properties. The results demonstrated that better tensile strength was recorded than compressive strength. The results also uncovered that strength and modulus were increased with an increase in the substance of carbon fiber, and the compressive values were marginally changed [13]. The multi-scale investigation law of ceramic composite was determined based on periodically boundary displacement conditions, and a dynamic model has been created by utilizing the constitutive law of the adjusted Mohr-Coulomb. The stress-strain results revealed that the agent volume component mechanical properties were influenced by the volume portion and microstructure arrangement [14].

In this research, the amount of excess weight produced from the design of mathematics models composed of composite materials will be calculated and compared to a mathematic model for an armored body made of steel. This is due to the importance of weight in armored vehicles, as it affects all components of the armored vehicle when designing the engine, transmissions, tires ... and others, as well as its effect on the speed of the armor.

The remainder of this paper is organized as follows: Section 2. Materials and model analysis, section 3. Results and discussion, section 4. Conclusions, acknowledgment, and references.

2. MATERIALS AND METHODS

A five-dimensional finite element model was constructed to simulate the influence test in ANSYS 15.0, Figure 1 shown in the models. The impact force was comparable to the impact force of a projectile on an armored structure and was projected in the middle of the designed models and its value was (120 KN).

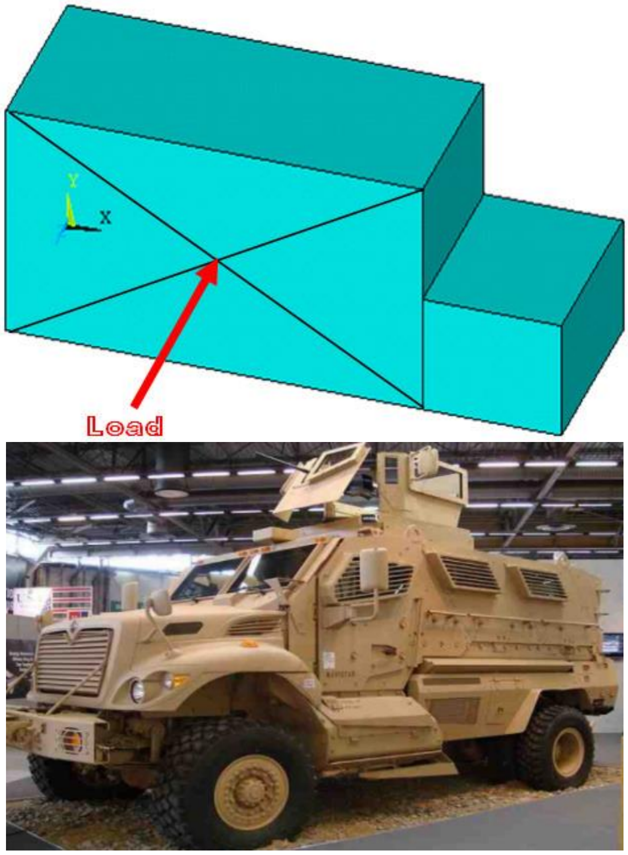


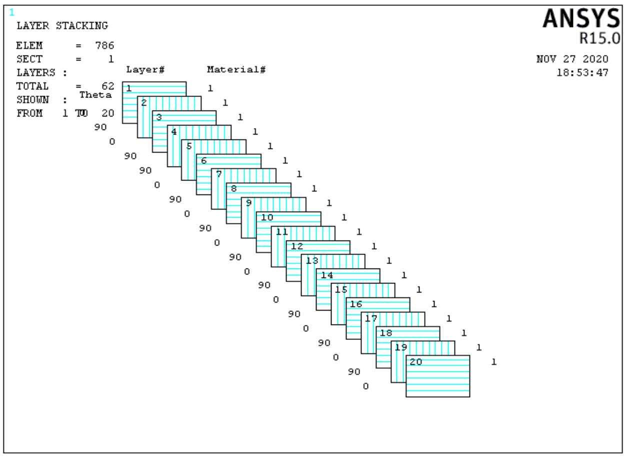
Figure 1. Solid shell geometry

Numerical simulations are performed based on the lab conditions used in the practical test of impact testing where we consider the shape and geometry of the sampling process and boundary conditions. We will focus on two main aspects of this procedure. Modeling and calculating the failure voltage. Simulations were performed using ANSYS (15.0) constructors.

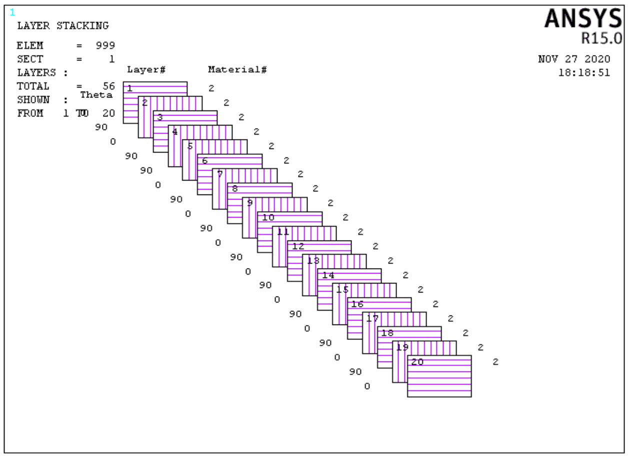
Five models are designed from different materials to compare the deformations and stresses that affect them. The models selected are steel, carbon fiber, S-shaped fiberglass, carbon fiber with steel, and fiberglass with steel models. Symbols for the fiberglass and carbon fiber model were chosen as shown in Figure 2.

Five mathematical models were designed, the first model is made of steel, the second model is made of carbon fiber, the third model is made of glass fiber, and the fourth model is made of carbon fiber and steel. The fifth model is made of fiberglass and iron.

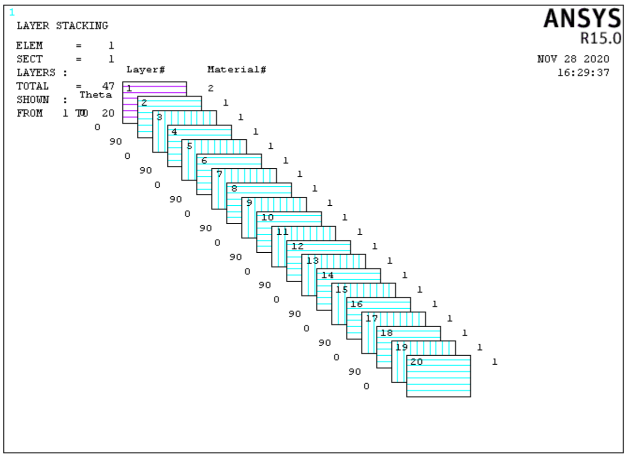
Table 1 appears the specifications for the materials used in the model structures, Table 2 shows the elastic properties of carbon- and fiberglass, and Table 3 shows the specifications used for drawing test samples and the symbols for materials used in all tests.



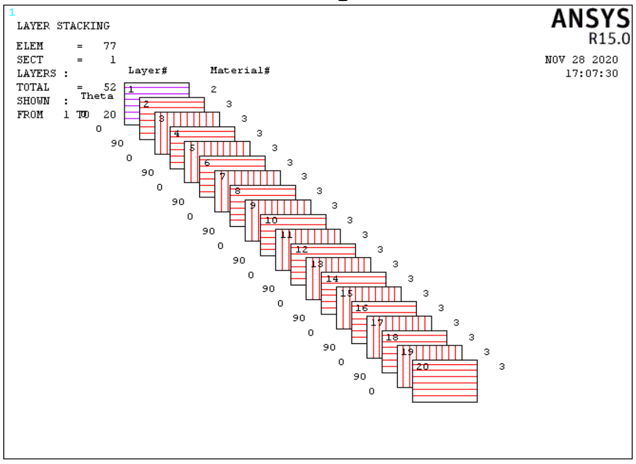
A- Carbon fiber



B. Fiberglass



C. Carbon fiber & steel



D. Fiberglass & steel

Figure 2. Codes of models

Table 1. The mechanical and thermal specifications of the materials used [15-18]

Model	Materials		Density, ρ, Kg/m^3	Thermal Conductivity, W/m. k	Modulus of elasticity, E, GPa	Passion ratio	Height, (cm)	Width, w, (cm)	Thickness, t, (cm)
M1	Steel		7800	50.2	210	0.3	200	520	5
M2	Carbon fiber	Carbon, 55%	1800	0.17	230	0.3	200	520	---
		Epoxy, 45%	1200	0.23	3.5	0.3			
M3	Fiberglass	Glass, 55%	2500	0.8	87	0.2	200	520	---
		Epoxy, 45%	1200	0.23	3.5	0.3			
M4	Carbon fiber& Steel	Carbon 55%	1800	0.17	230	0.3	200	520	---
		Epoxy 45%	1200	0.23	3.5	0.3	200	520	---
		Steel	7800	50.2	210	0.3	200	520	---
M5	Fiberglass& Steel	Glass 55%	2500	0.8	87	0.3	200	520	---
		Epoxy 45%	1200	0.23	3.5	0.2	200	520	---
		Steel	7800	50.2	210	0.3	200	520	---

Table 2. The different stresses of the composite materials used [18]

Material	E_{ii}, MPa	G_{ii}, MPa	μ_{ij}	μ_{ji}
Carbon fiber	E_{11}=91600	G_{12}=11540	μ_{12}=0.26	μ_{21}=0.110
	E_{22}=38700	G_{13}=2750	μ_{13}=0.30	μ_{31}=0.028
	E_{33}=8590	G_{23}=1070	μ_{23}=0.30	μ_{32}=0.067
Fiberglass	E_{11}=26600	G_{12}=5030	μ_{12}=0.17	μ_{21}=0.150
	E_{22}=23300	G_{13}=1140	μ_{13}=0.52	μ_{31}=0.062
	E_{33}=10760	G_{23}=950	μ_{23}=0.53	μ_{32}=0.245

Table 3. Specifications of codes, models, and type of elements for mathematical models in ANSYS 15.0

No.	Material	Code	Model	Density, Kg / m^3	Type of Element
1	Steel Model - 1	[0]	Linear, (Isotropic)	7800	Solid 187 Geometry, 10 Nods, 3-D Modeling
2	Carbon fiber Model - 2	[0/90/0/90/0/90/0/90/0/90/0/90/0/90l0l90/ 0/90/0/90/0/90/0/90/0/90/0/90/0/90/0]s	Linear (Orthotropic)	1650	Shell (3D 4node 181)
3	Fiberglass Model - 3	[0/90/0/90/0/90/0/90/0/90/0/90/ 0/90l0l90/0/90/0/90/0/90/0/90/0] s	Linear Orthotropic)	1814	Shell (3D 4node 181)
4	Carbon fiber& Steel Model - 4	[0/0/90/0/90/0/90/0/90/0/90/0/90/0/90/0/ 90/0/90/0/90/0/90/0/90/0/90/0/90/09/0/90/0/90/0/ 90/0/90/0/90/0/90/0/90/0/90/0]	(Orthotropic)	1650	Shell, (3D 4node 181)
			(Isotropic)	7800	Solid 187, 10 Nods
5	Fiberglass & Steel Model - 5	[0/0/90/0/90/0/90/0/90/0/90/0/90/0/ 90/0/90/0/90/0/90/0/90/0/90/0]s	(Orthotropic)	1814	Shell, (3D 4node 181)
			(Isotropic)	7800	Solid 187, 10 Nods

Table 4. Results of simulation test first model

NO.	Type of test	Displacement (DMX), mm	Maximum value (SMN), MPa	Minimum value (SMX), MPa
1	δ_x	1.827	- 144	136
2	δ_y	1.827	- 151	145
3	δ_z	1.827	- 39.6	28.5
4	τ_{xy}	1.827	- 10.4	10.4
5	τ_{yz}	1.827	-5.4	6.37
6	τ_{xz}	1.827	- 4.88	5.6
7	First Principal Stress	1.827	- 39.4	145
8	Second Principal Stress	1.827	- 144	136
9	Third Principal Stress	1.827	-152	28.4
10	Stress Intensity	1.827	0.004	147
11	Von Mises Stress	1.827	0.003	143

Table 5. Results of simulation test second model

NO.	Type of test	Displacement (DMX), mm	Maximum value (SMN), MPa	Minimum value (SMX), MPa
1	δ_x	7.24	- 114	115
2	δ_y	7.24	- 109	110
3	δ_z	7.24	0	0
4	τ_{xy}	7.24	- 55	55.8
5	τ_{yz}	7.24	-1.42	1.42
6	τ_{xz}	7.24	- 93.3	93.1
7	First Principal Stress	7.24	0	143
8	Second Principal Stress	7.24	- 46.5	46.6
9	Third Principal Stress	7.24	0	142
10	Stress Intensity	7.24	0.001	143
11	Von Mises Stress	7.24	0.001	136

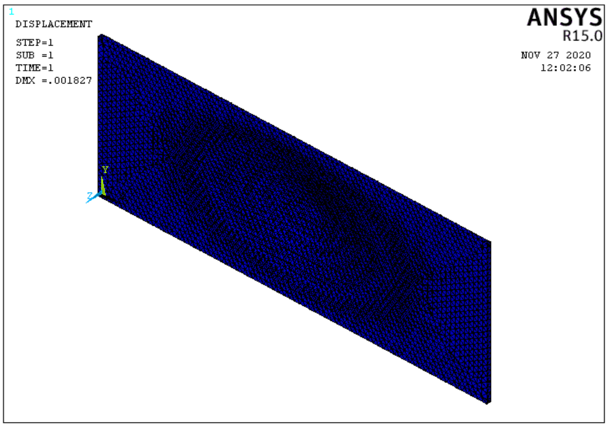
3. RESULTS AND DISCUSSION

The first model was designed consisting of steel, and a section was taken on the side of the armored body, which was with dimensions (*520 * 200 * 50 mm*) and its weight was calculated to compare it with the weight of other models consisting of other materials, and the model was installed from all sides and a load of (*150 KN*) was placed in the middle of this model to know the amount of deformation and stresses Influencing the armored structure.

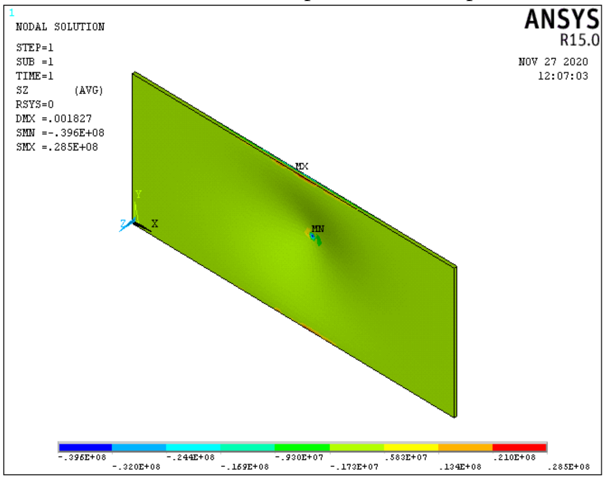
Table 4 and Figure 3 show the results of these tests using the ANSYS -15.0 program.

The second mathematical model, consisting of carbon fibers, was built with the same width and height as the first model, but the thickness was changed by changing the number of layers until an equal intensity stre ss was obtained as in the first model consisting of steel, and after multiple tests by changing the thickness of the walls, the required thickness was obtained, which was (*62 mm*) and the number of its layers (62) and after that the weight of the designed structure, which is made of carbon fiber, was calculated (1063.92 Kg). Table 5 and Figure 4 show the results of these tests using the ANSYS -15.0 program.

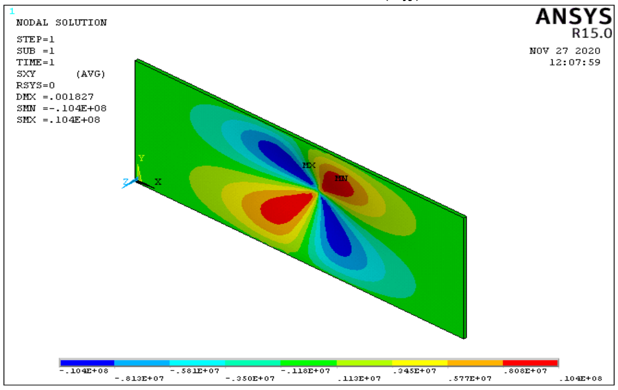
The third mathematical model, consisting of fiber glass, was built with the same width and height as the first model, but the thickness was changed by changing the number of layers until an equal intensity stress was obtained as in the first model consisting of steel, and after multiple tests by changing the thickness of the walls, the required thickness was obtained, which was (56 *mm*) and the number of its layers (56) and after that the weight of the designed structure, which is made of fiber glass, was calculated (1056.47Kg). Table 6 and Figure 5 show the results of these tests using the ANSYS -15.0 program.



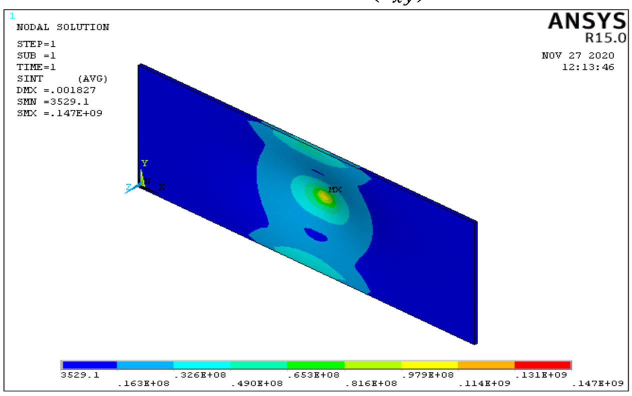
A. Deformation Z- displacement component



B. Normal stress (σ_x)



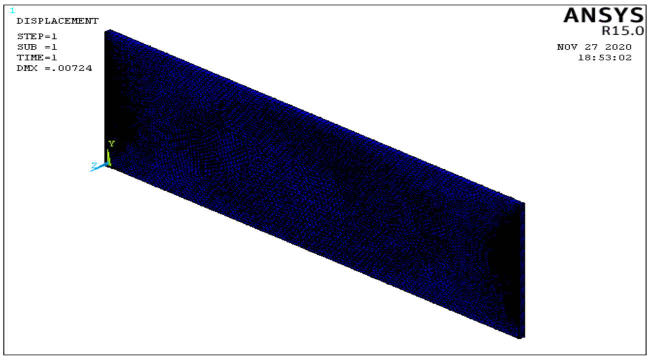
C. Shear stress (τ_{xy})



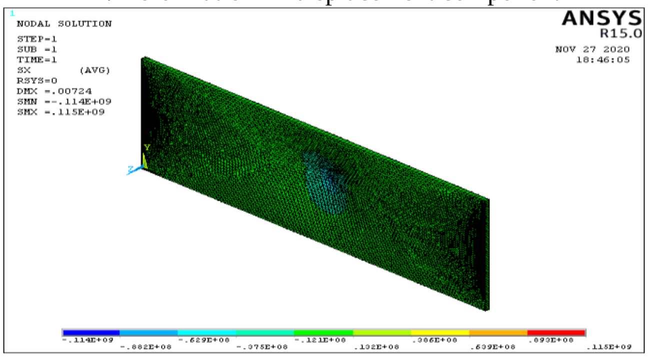
D. Stress intensity ($\sigma_{max.}$)

Figure 3. Results of the simulation test of the first model

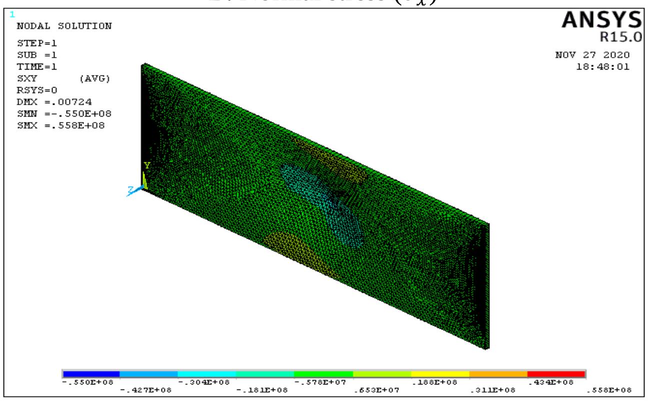
The fourth mathematical model, consisting of Steel and Carbon fiber, was built with the same width and height as the first model, but the thickness was changed by changing the number of layers until an equal intensity stress was obtained as in the first model consisting of steel, and after multiple tests by changing the thickness of the walls, the required thickness was obtained, which was (55 *mm*) and the number of its layers (47) and after that the weight of the designed structure, which is made of fiber glass, was calculated (1583.4Kg). Table 7 and Figure 6 show the results of these tests using the ANSYS -15.0 program.



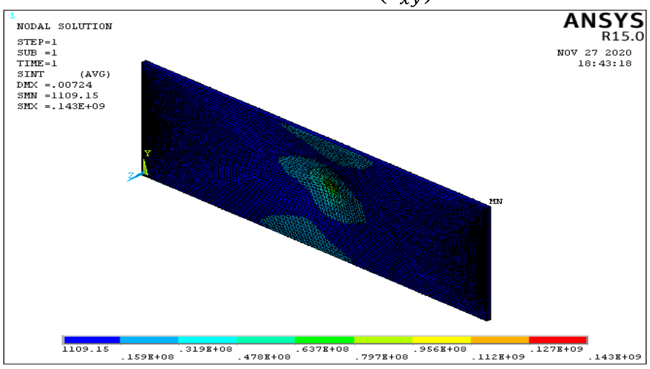
A. Deformation Z- displacement component



B. Normal stress (σ_x)

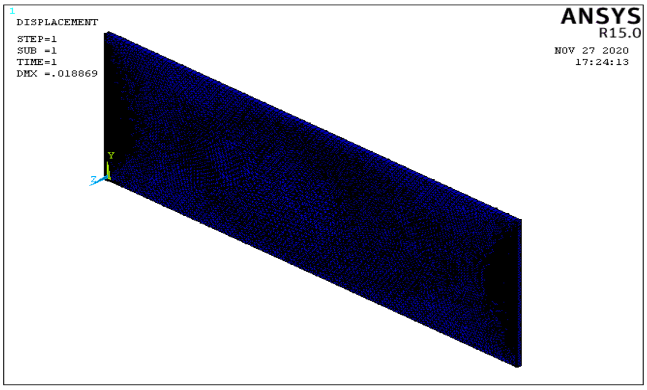


C. Shear stress (τ_{xy})

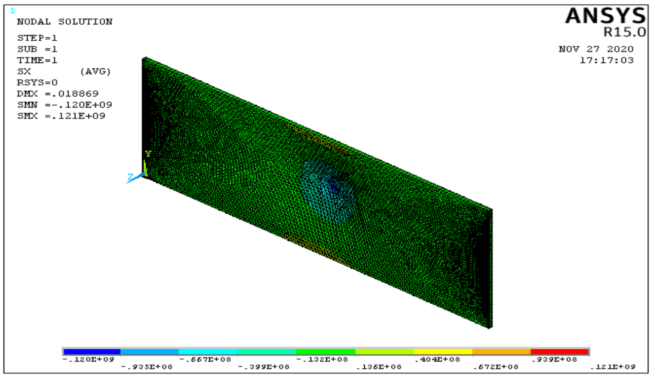


D. Stress intensity ($\sigma_{max.}$)

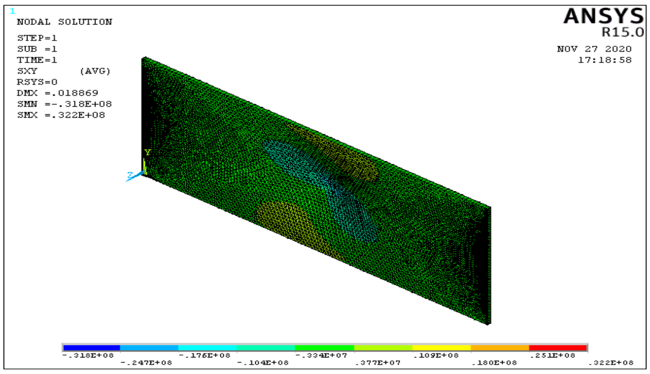
Figure 4. Results of the simulation test of the second model



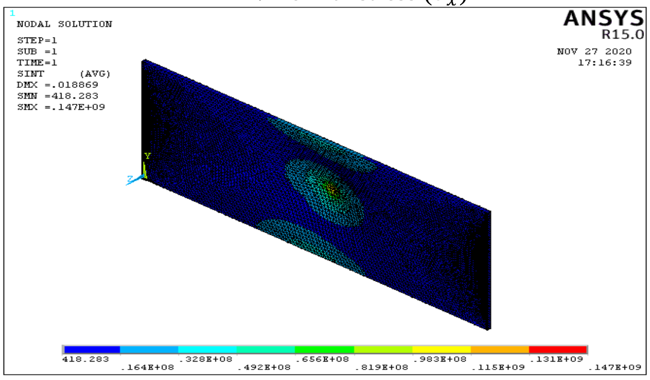
A. Deformation Z- displacement component



B. Normal stress (σ_x)



C. Shear stress (τ_{xy})



D. Stress intensity ($\sigma_{max.}$)

Figure 5. Results of the simulation test of the third model

Table 6. Results of simulation test third model

NO.	Type of test	Displacement (DMX), mm	Maximum value (SMN), MPa	Minimum value (SMX), MPa
1	δ_x	18.869	- 120	121
2	δ_y	18.869	- 128	128
3	δ_z	18.869	0	0
4	τ_{xy}	18.869	- 31.8	32.2
5	τ_{yz}	18.869	- 55.7	55.2
6	τ_{xz}	18.869	- 51.1	51.1
7	First Principal Stress	18.869	0	147
8	Second Principal Stress	18.869	- 92.5	92.3
9	Third Principal Stress	18.869	- 147	0
10	Stress Intensity	18.869	0.0004	147
11	Von Mises Stress	18.869	0.0004	128

Table 7. Results of simulation test fourth model

NO.	Type of test	Displacement (DMX), mm	Maximum value (SMN), MPa	Minimum value (SMX), MPa
1	δ_x	3.909	- 130	130
2	δ_y	3.909	- 147	147
3	δ_z	3.909	0	0
4	τ_{xy}	3.909	- 16.9	16.9
5	τ_{yz}	3.909	- 27.5	27.6
6	τ_{xz}	3.909	- 24.9	24.8
7	First Principal Stress	3.909	0	147
8	Second Principal Stress	3.909	- 130	130
9	Third Principal Stress	3.909	0	147
10	Stress Intensity	3.909	- 0.005	147
11	Von Mises Stress	3.909	0.005	139

The fifth mathematical model, consisting of Steel and Fiberglass, was built with the same width and height as the first model, but the thickness was changed by changing the number of layers until an equal intensity stress was obtained as in the first model consisting of steel, and after multiple tests by changing the thickness of the walls, the required thickness was obtained, which was (60 mm) and the number of its layers (52) and after that the weight of the designed structure, which is made of fiber glass, was calculated (1754Kg). Table 8 and Figure 7 show the results of these tests using the ANSYS -15.0 program.

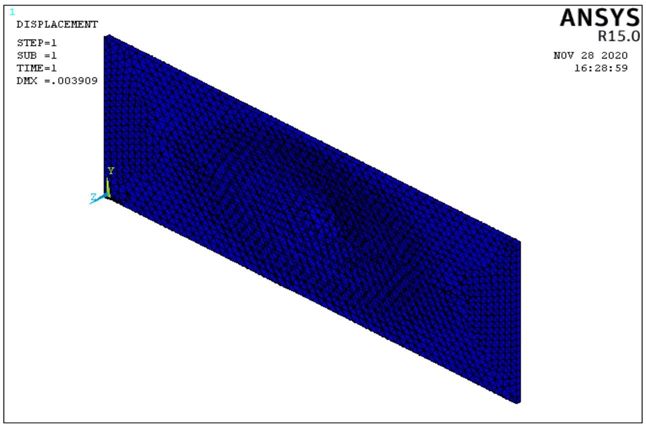
Table 9 shows the results of the five models' tests using a program ANSYS 15.0. The table shows the weight difference between the five models, and the percentage of decrease in weight compared to the weight of the steel frame.

The results in Table 9 show the following:

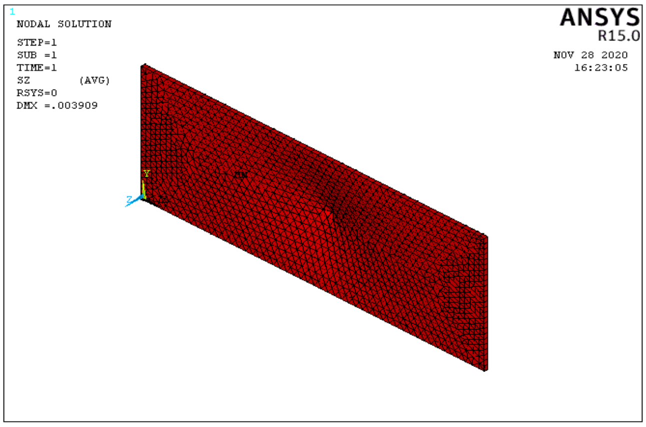
When comparing the second model, which is made of carbon fiber, with the first model, which is made of steel, we note that the percentage of weight loss was (73.77%), which is the highest reduction rate, but the thickness of the structure was composed of (62 layers) and (62 mm), and the displacement was (7.24) while the displacement in steel was (1.827). In the third model, which is made of carbon fiber, the percentage of weight loss in relation to the weight in the first model, which is made of steel, was (73.45), and the number of layers was (56) and the thickness of the frame (56 mm), and the displacement was very high as it reached (18.896 mm), which is the highest displacement in the five mathematic models. In the fourth model, consisting of two layers of steel and the thickness of each layer (5 mm) and (45) a layer and thickness (45 mm) of carbon fiber, the percentage of decrease in weight compared to the weight of the first model was (60.96%), and the displacement was very appropriate, reaching (3.909 mm). In the fifth model, which consisted of an outer layer and an inner layer of steel, and between the two layers (50) layers of fiberglass, the percentage of weight loss compared to the weight of the first model was (56.76), and the displacement was (3.792).

Table 8. Results of simulation test fifth model

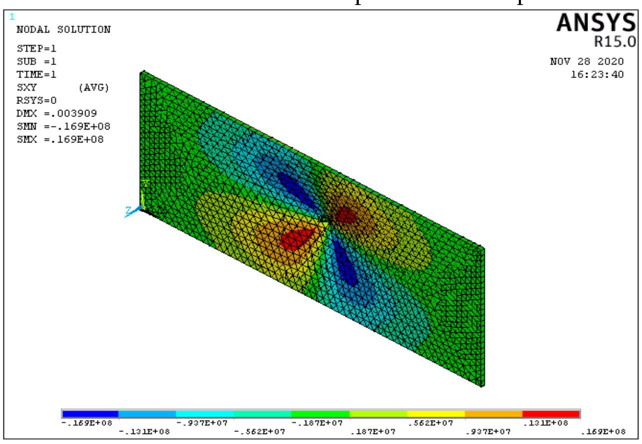
NO.	Type of test	Displacement (DMX), mm	Maximum value (SMN), MPa	Minimum value (SMX), MPa
1	δ_x	3.792	- 127	128
2	δ_y	3.792	- 143	144
3	δ_z	3.792	0	0
4	τ_{xy}	3.792	- 16.3	16
5	τ_{yz}	3.792	- 37.3	37.2
6	τ_{xz}	3.792	- 30.3	30.2
7	First Principal Stress	3.792	0.004	145
8	Second Principal Stress	3.792	- 126	127
9	Third Principal Stress	3.792	0	143
10	Stress Intensity	3.792	0.005	145
11	Von Mises Stress	3.792	0.005	137



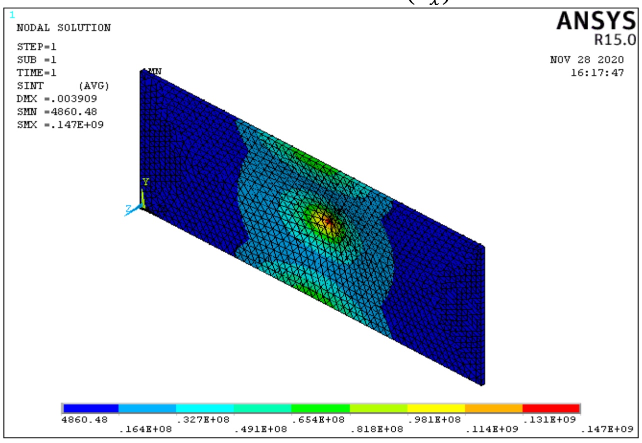
A. Deformation Z- displacement component



B. Normal stress (σ_x)

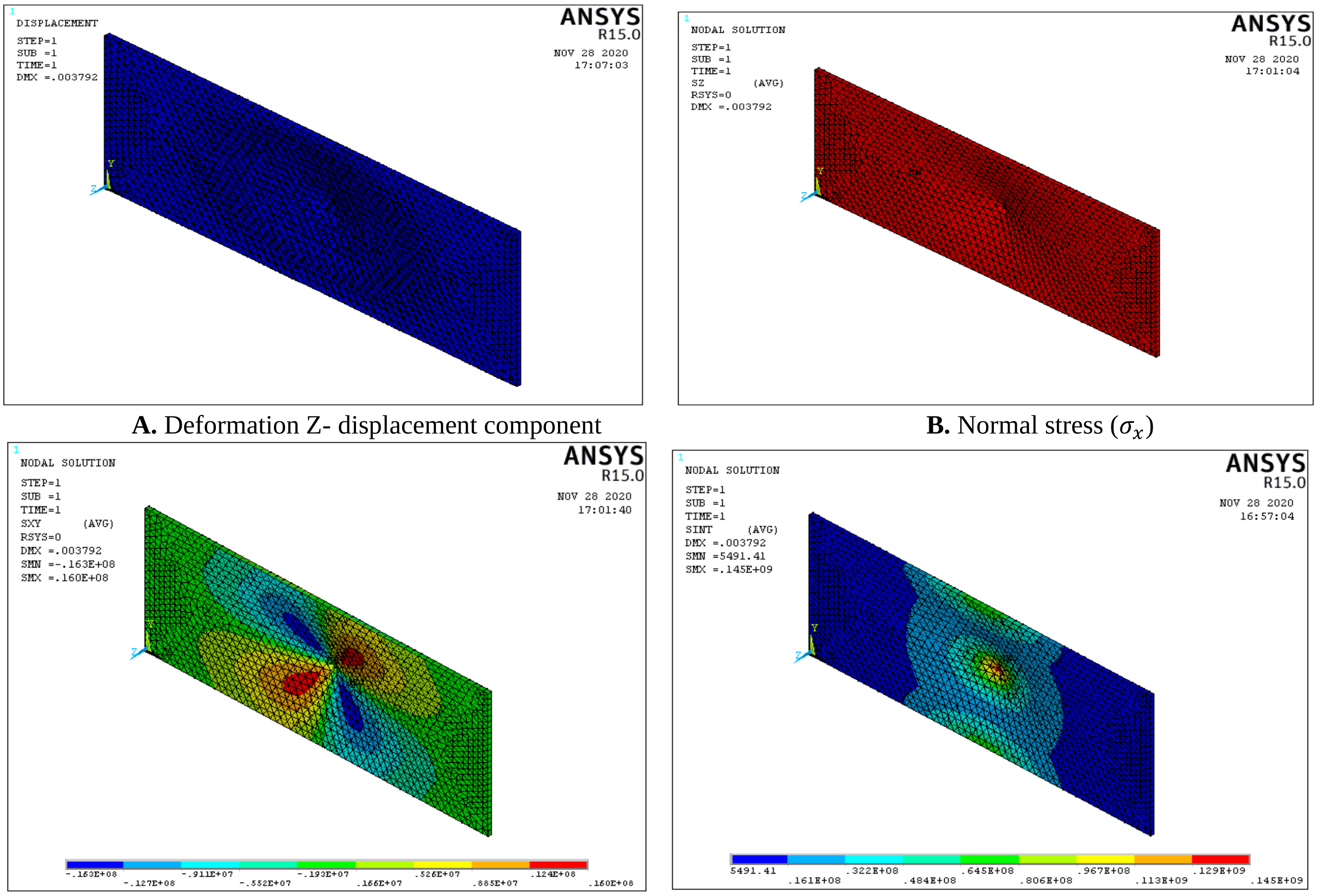


C. Shear stress (τ_{xy})



D. Stress intensity ($\sigma_{max.}$)

Figure 6. Results of the simulation test of the fourth model



A. Deformation Z- displacement component

B. Normal stress (σ_x)

C. Shear stress (τ_{xy})

D. Stress intensity ($\sigma_{max.}$)

Figure 7. Results of the simulation test of the fifth model

Table 9. The results of the five models' tests using

Model	Materials		Density, ρ, (Kg/m³)	Deformation, (mm)	Intensity stress, (MPa)	Von Mises Stress, (MPa)	Height, (mm)	Number of layers	Width, w, (mm)	Thickness, t, (mm)	Volume of wall, (m³)	Weight, (Kg)	The percentage of weight loss in relation to steel%
M1	Steel		7800	1.827	147	143	200	1	520	50	0.52	4056	---
M2	Carbon fiber	Carbon, 55% Epoxy, 45%	1650	7.24	143	136	200	62	520	62	0.6448	1063.92	73.77
M3	Fiberglass	Glass, 55% Epoxy, 45%	1814	18.896	147	128	200	56	520	56	0.5824	1056.47	73.85
M4	Carbon fiber & Steel	Carbon, 55% Epoxy, 45%	1650	3.909	147	139	200	45	520	45	0.104	1583.4	60.96
		Steel	7800	---	---	---	200	2	520	10	0.468		
M5	Fiberglass & Steel	Glass, 55% Epoxy, 45%	1814	3.792	145	137	200	50	520	50	0.104	1754	56.76
		Steel	7800	---	---	---	200	2	520	10	0.52		

4. CONCLUSIONS

Composite materials have distinctive properties since their invention in the last century, and there is a lot of research that has studied the improvements of these materials and make them more effective in engineering, technological and industrial applications. There are many types of fiber reinforced materials that are classified as natural and synthetic fibers, as the fibers provide more rigidity and resistance to various stresses. Mathematical models made of composite materials were used in this research, and it was concluded that the use of composite materials in the manufacture of various structures, including the structures of armor, is of great importance in reducing the weight of armor, and it has resistance to different stresses similar to that of steel. It is evident from analyzing the results and making the necessary calculations that the best model is the second model, which is composed of carbon fibers, where the weight of the structure in it reached (1063.92 kg), and the percentage of weight reduction compared to the first model, which was made of steel (73.77%), and the intensity of stress in it (143 MPa) and displacement (7.24), despite from the fact that the lowest weight was in the third model, which is made of fiber class, and its value (1056.47 kg) and the displacement in it was very high, reaching (18.896 mm). From other results, the least number of layers for the armored hull was adopted in the fourth model, which consisted of steel and carbon fiber, as the number reached (47) layer and the percentage of weight reduction compared to the first model was (60.96%) and displacement (3.909 mm).

5. RECOMMENDATIONS FOR FUTURE STUDIES

Knowledge in material and process selection and active part size definition is crucial in the conceptual design of the composite body structure of the future. Since high volume, manufacturing processes for structural composite are under constant development it must be continuously monitored to improve the results from the presented framework, and the following study can be done:

First, finding alternative materials that have a resistance similar to steel, are environmentally friendly, and have a lower weight than steel.

Second, conducting practical and applied tests and comparing them with the obtained theoretical results.

Third, the use of sports models made of other materials as an alternative to steel, for example ceramics, and their comparison with the resistance of steel.

Fourth, studying the resistance of these materials in terms of thermal insulation and sound insulation, as well as their resistance to weather conditions and fires.

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