Investigating and Study of Various Composite Materials and Their Counterparts to Replace the Conventional Materials

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Abstract. Composite materials are widely used in no. of industries due to their high performance, light weight and having good strength which is sometimes better than conventional materials. Many research papers are published on different types of composites brackets in the past few years. Referring to those papers and our study we will show the comparative study of different composite and conventional materials. The Bracket is redesigned in CATIA V5 and FEA Analysis is done using Ansys Workbench. Understanding and determining the requirement of thermosetting composite fulfils our requirement. So, we selected carbon fiber and glass fiber as reinforcement and epoxy as a resin. We are using hand-layup method for manufacturing of the component.

Testing of sample is performed on a universal testing machine to get the actual results. Testing is done in Delta Metallurgical Laboratory and Services, is one of the NABL accredited metallurgical testing lab with excellent facilities.

Keywords: Composite material · FEA · Carbon fiber · Glass fiber · Mass Optimization · Brackets

1 Introduction

One of the most promising fields for material development in the twenty-first century is now acknowledged to be composites. As they say, "Necessity is the mother of creativity," composites were created out of the demand for lighter materials with superior mechanical qualities. With the help of this article, we hope to design and create a composite that can replace the majority of automotive parts, particularly the bumper mounting bracket.

In the manufacture of a modern car, metals and alloys such cast iron, steel, and aluminum alloy parts make up more than half of the entire volume (or 65%) while plastic parts make up the remaining 12%. Due to the need for structural rigidity and strength, metals are used to make the majority of auto-motive components, however this increases weight. However, despite their light weight, plastics cannot replace metals since they do not possess the same mechanical qualities. Composites were therefore developed to fill the gap between mechanical strength and light weight. They combine different metal and plastic features like maximum mechanical strength and toughness with varied plastic properties like corrosion resistance and reduced weight. Composite

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materials provide a way to considerably reduce a vehicle's weight while maintaining strength standards.

All industrial sectors have embraced composite materials to a large extent. The fact that composite materials are 25% lighter than steel and 30% lighter than aluminum makes them one of their key draws. Although they weigh roughly one-fifth as much as steel, carbon fiber composites are just as stiff and strong as steel. They also do not rust or corrode like steel or aluminum, and by drastically lowering vehicle weight by as much as 60%, they might significantly improve vehicle fuel economy. Additionally impressive is the composite materials' tensile strength. Impacts that would usually shatter steel can be absorbed by composites. This strength extends to their resistance to corrosion caused by substances like acid rain that would harm alternative metals. For instance, a resin binder system can be employed to improve the composite part's corrosion resistance.

Without using high-pressure equipment, composites can also be molded into a range of intricate shapes. Additionally, because of this, composite parts can be designed to resist bending and be stronger in a specific direction.

2 Literature Survey

William D. Callister, Jr. [1], "Callister's Materials Science and Engineering," The types of composites, including structural, fiber reinforced, and particle reinforced composites, are all addressed in detail in this book. Also takes into account how fiber concentration and orientation affect composite strength. It describes how the composite behaves when subjected to longitudinal and transverse loads. Details of the matrix's many phases, including the matrix and fiber phases. It categorizes matrix materials into carbon-carbon composites, metal composites, ceramic composites, polymer composites, and hybrid composites.

Mr. Pramod Walunje et al. [2], According to the study "Optimization of Engine Mounting Bracket Using FEA," the demand for lightweight materials in automobiles is pushing manufacturers of those items to seek out new materials. Some studies claim that for every 10% decrease in vehicle weight, fuel economy can increase by 4.5 to 6%. Compared to aluminum or grey cast iron, the average magnesium alloy cast item is lighter. The results of the stress study showed that the von-misses stresses for aluminum and grey cast iron are well within the material's yield stress, but they are higher for magnesium (190 MPa), thus that material was not chosen for the bracket. Based on the findings, they came to the conclusion that aluminum is the optimum material for the bracket. They also reduced the aluminum bracket's thickness by 2 mm in order to optimize weight. As a result, they were able to reduce the mass by up to 0.43 kg after choosing the lightweight material aluminum and reducing its thickness by 2 mm.

Mr. A. R. Bunsell and B. Harris [3], Researchers have researched "Hybrid carbon and glass fiber Composites," which are composite materials made of layers of carbon and glass fibers alternately bonded in an epoxy resin. With the alternate layers either unbonded or bonded together, two different forms of hybrids were created. It was thought that by combining two different fiber types in a resin to create a hybrid, it would be possible to produce a material that would combine the benefits of the separate elements while minimizing their drawbacks. The acquired results show that light engineering materials with controlled stress-strain behavior may be made, and their properties can be tailored to fit specific needs. These materials would make it possible to use more expensive parts, such carbon fibers, more widely.

Shama Rao N. [4] et al., For the article "Carbon Composites Are Becoming Competitive and Cost Effective," which also covered the role of numerous advanced technologies in lowering the price of carbon composites, research on economic variables and the condition of composite material manufacturing prices was conducted. Carbon fibre reinforced composites are widely used in many various industries due to their excellent performance, although being more expensive than metals. However, due to recent advancements in composites, carbon composites are becoming more competitive and economical. The reductions in defect and cycle time brought by the introduction of high-end processes are quickening this pace.

Monali Deshmukh et.al. [8], the engine mounting bracket was examined using ANSYS in "Analysis and Optimization of Engine Mounting Bracket." The stresses, deformations, and harmonic responses of the brackets that affect the engine mounting brackets have been identified by the authors. They have also refined the design to lessen the weight of the rib in the engine mounting models. Work had been done using the ANSYS 15.0 Software.

By making several modifications to its form and shape, the engine mounting bracket was optimized. Static and modal analysis for the optimized bracket was done. The maximum stress value for the optimized bracket was determined to be 142.53 MPa, which is greater than the value for the un-optimized bracket but still falls within the safe range. The amplitude for the optimized bracket ranged from 27990 to 29922 mm/s2. A bracket that has been adjusted and is 12.5% less in weight than the original, non-optimized bracket is obtained. Overall costs are decreased and materials are saved as a result. The harmonic response of the redesigned bracket is within a safe range, the authors further established by harmonic analysis. Therefore, the likelihood of a structure operating noisily as a result of its design is reduced.

2.1 Problem Statement

The problem statements formulated as below.

- To investigate and study various composite materials and counterparts to replace the conventional materials.
- To perform FEA analysis and physical testing to determine the strength of conventional and composite materials
- To optimize the design of bracket in terms of strength and weight.

2.2 Paper Objectives

- To solve the problems mentioned earlier, we try to achieve the following objectives
- The composites are lightweight and weighs around 30% lighter than aluminum and 25% than steel. So, the reduction in weight of bracket is possible.
- To try to achieve higher strength as of conventional materials.
- To optimize the bracket in the form of size and shape.

3 Material Selection

New material systems and processes are being created and expanding quicker than ever thanks to technological developments. Metals like steel and aluminium previously dominated product design. The situation has changed. Ignorance of potential provided by new material systems, such as composite material scan, results in decreasing competitiveness and might result in market loss as awareness and customer needs increase.

Cost and energy efficiency are the main factors that influence material choice for the automotive industry. High performance and lightweight materials are prioritised in the aerospace industry. Cost and handling are the driving forces behind consumer items, where performance is not a key component. The athletic goods industry wants materials with great performance and low weight. In the marine industry, lightweight and corrosion-resistant materials are prioritised. There are several potentials for composites technology as a result of this interest in lightweight, high-performance materials. Various industrial sectors can find solutions in composite materials to meet their needs.

4 Understanding and Determining the Requirements

Defining a product's needs, such as its cost, weight, service, performance, etc., is the first stage in selecting a material. A material may have a number of advantages, but certain conditions must be met for the application to work.

The following requirements should be taken into account when choosing materials: Strength, temperature resistance, resistance to chemicals, electrical current, and humidity, and Procedure, Cost, Production rate.

5 Basic Steps in a Composites Manufacturing Process

Fabricating a composite part involves four fundamental steps:

Wetting/impregnation, lay-up, consolidation, and solidification are the order of events. The same four steps are included in all manufacturing procedures for composites, however they are carried out in various ways.

5.1 Impregnation

To create a lamina, fibres and resins are combined in this stage. For instance, during the filament winding process, the resin bath is used to impregnate the fibres. Prepregs that have already been impregnated in a controlled environment by the material supplier are utilised in a manual lay-up procedure. Each layer of fabric in a wet lay-up procedure is wetted with resin using a squeezing roller to ensure adequate impregnation. Making sure that the resin flows completely around all fibres is the goal of this stage. The primary factors influencing the impregnation process are viscosity, surface tension, and capillary action. Thermosets are simpler to wet out since their viscosities fall between 10 e1 and 10 e4 cp.

5.2 Lay-Up

In this stage, composite laminates are created by positioning fibre resin mixes or prepregs at the required angles and locations. By layering the fibre and resin mixture, the required composite thickness is produced up. The mandrel and carriage unit's respective motions during filament winding produce the appropriate fibre dispersion. Prepregs are laid at a precise fibre orientation using either a machine or a manual technique in a prepreg lay-up procedure. In an RTM process, resin is injected into the preform to make the laminate. The preform already has fibre architecture built in, either from a braiding operation or from another machine. This step's goal is to realise the desired fibre architecture as specified by the design. Fiber orientation and lay-up order have a significant impact on a composite structure's performance.

5.3 Consolidation

In this stage, each prepreg or lamina layer is brought into close contact with the others. This procedure makes certain that all trapped air is released from between layers during processing. Getting a high-quality part requires consolidation, which is a crucial stage. Vacuums and dry areas will be present in poorly consolidated portions. Resin flow through porous media and elastic fibre deformation are two critical processes in the consolidation of continuous fibre composites. The applied pressure is shared by the resin and fibre structures during the consolidation process. But first, the resin is the only thing supporting the imposed pressure (zero fibre elastic deformation). When the compressive pressure rises, resins flow out toward the border and fibres undergo elastic deformation. There are many consolidation models, some of which only take resin flow into account and neglect fibre deformation.

5.4 Solidification

Solidification, the last phase, can take as little as a minute for thermoplastics or as long as 120 min for thermosets. During this time, vacuum or pressure is maintained. The procedure can achieve a greater output rate the faster the solidification time. The resin formulation and cure kinetics affect the rate of solidification in thermoset composites. To speed up the resin's cure rate, heat is applied during processing. In thermoset resins, the cross-linking reaction often proceeds more quickly the higher the cure temperature. The least amount of time is needed for solidification in thermoplastics because there is no chemical change during the process. The pace of solidification during thermoplastic processing is influenced by the rate of cooling. When processing thermoplastics, the temperature is dropped to produce a hard product, whereas when processing thermoset composites, the temperature is raised to achieve rapid solidification.

6 Manufacturing Process

6.1 Design and Development

We purchased the Mahindra Bolero Pik up original spare bumper bracket shown in fig No.1 (a) from the dealer. After using measurement techniques to reverse engineer the component shape, the dimensions were recorded and modelled in CATIA, Fig. 1 (b).

(a) (b)

Fig. 1. (a) Actual Bumper Mounting Bracket, (b) CATIA Model

6.2 General Manufacturing Procedure

(1) Cut fiber sheet into pieces of defined dimensions.
(2) Make stirred mixture of polyester or epoxy, hardener, and cobalt (For Glass Fiber-Polyester composite) taking in appropriate quantity.
(3) Take the die for bracket.
(4) Apply gel coat.
(5) Keep fiber sheet inside die cavity.
(6) Apply resin on the fiber sheet.
(7) In this way, repeat procedure 5and 6 until achieved required thickness.
(8) Equally spread the resin and remove the air trapped between each layer.
(9) Kept for socking for some time.
(10) After socking component is ready for further machining processes.

6.3 Glass Fiber Epoxy Composite

E-glass fiber sheets - As a matrix for give strength to component.

Polyester - To provide bounding between fiber sheets.

Polyester resin systems are inexpensive and provide superior corrosion resistance. Epoxies have higher operational service temperatures than polyesters do. For pultrusion, filament winding, SMC, and RTM procedures, polyesters are frequently employed. Thermosetting resins or thermoplastic resins can both be found in polymers. Unsaturated difunctional organic acids react with a dysfunctional alcohol to form unsaturated polyesters. Maleic, fumaric, phthalic, and terephthalic acids are among the ones employed. Ethylene glycol, propylene glycol, and halogenated glycol are some of the alcohols. The range of 30 to 50 weight percent of a reactive monomer, such as styrene, is added for the curing or cross-linking process. Catalysts are now employed in modern techniques to cure polyesters with decreased styrene.

Hardener

The hardener helps to solidify the mixture and enhance mechanical properties by reacting chemically with the resin. The hardener used for polyester resin is Methyl Ethyl Ketone Peroxide (MEKP). Amount of hardener must be 1–2%. Some factors are considered for adding hardener as follows.

(a) (b) (c) (d)

Fig. 2. (a)E-Glass Fiber, (b) Polyester Resin, (c) MEKP Hardener, (d) Cobalt

(1) The thickness of the mat or laminate.
(2) Temperature.
(3) Humidity.

Only mix enough resin and hardener as can be applied within a half hour of combining the two, as the resin will begin to set or become hard after time.

Cobalt
It is used as an additive, to reduce the curing time. It is a promoter or accelerator which increases the rate of curing at room temperature. Its amount must be constrained to 1–2%. It must be added before addition of hardener to the solution of resin. This helps to start chemical reaction between resin and catalyst (hardener) and form a cured solution. Curing is a term in polymer chemistry and process engineering that refers to the toughening or hardening of a polymer material chain, brought about by electron beams, heat or chemical additives (Fig. 2).

6.4 Carbon Fiber Composite

Carbon fiber sheets - As a matrix for give strength to component.

Epoxy - To provide bounding between fiber sheets.

A liquid resin known as an epoxy is one that has multiple epoxide groups, such as the two epoxide groups found in diglycidyl ether of biphenyl A (DGEBA). A three-membered ring with two carbon atoms and one oxygen atom makes up an epoxide group. Along with this initial substance, other liquids are included, such as diluents to lessen its viscosity and flexibil-izers to boost its toughness. The crosslinking reaction known as curing occurs when a hardener or curing agent is added (e.g., diethylenetriamine [DETA]). Cure rates can be managed by carefully choosing hardeners and/or catalysts. Epoxy-based composites function well at both ambient and high temperatures.

(a) (b) (c)

Fig. 3. (a) Carbon Fiber Sheet, (b) Epoxy Resin, (c) Epoxy Hardener (1000 ml)

Hardener

Epoxy floor coating installation, at its most basic, entails mixing an epoxy resin with a hardening agent and letting them react before applying the mixture over a ready-to-use concrete substrate. To improve certain performance characteristics, such as more impact resistance and compressive strength, hardener is applied. Fluids made of epoxy resins have a very long shelf life and are quite stable. They can only properly cure when combined with an epoxy hardener. Without the hardener, the resin would be applied and stay almost perpetually liquid.

A controlled chemical reaction that takes place between precisely calibrated resin and hardener components gives epoxy coatings its high-performance protective qualities, in contrast to paints, which depend on the evaporation of moisture to finally solidify into a thin film. The contractor might only have 15 min to install the combined material after mixing the epoxy finish and hardener. Depending on the chemical composition, thickness, and cure time of the individual formula, the application technique may change (Fig. 3).

7 Analyses Reports

All the CATIA components are imported in Ansys Software and Applying boundary conditions (BC) to Bumper mounting Bracket for different materials and the results were taken for next study (Figs. 4, 5, 6, 7 and 8).

7.1 Boundary Conditions

7.2 Steel Component Results

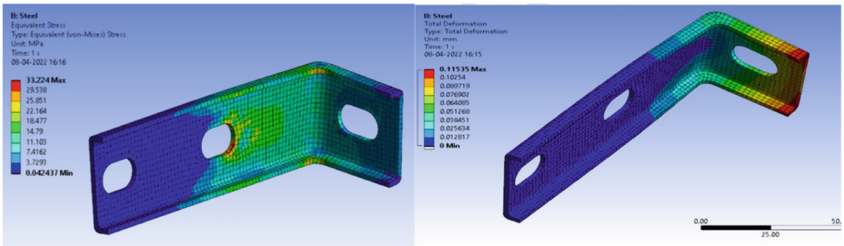
7.3 Carbon Fiber Composites

7.4 Glass Fiber Composite

7.5 Analysis Visualization

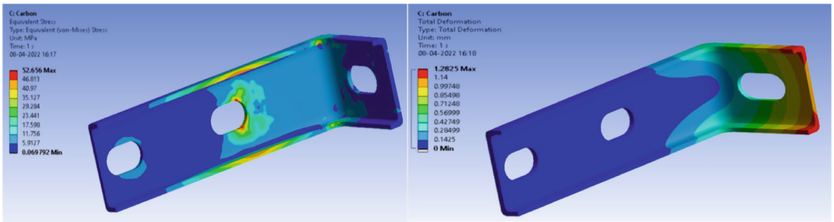
(a) (b)

Fig. 4. (a) BC fixed Support, (b) BC Force Plot



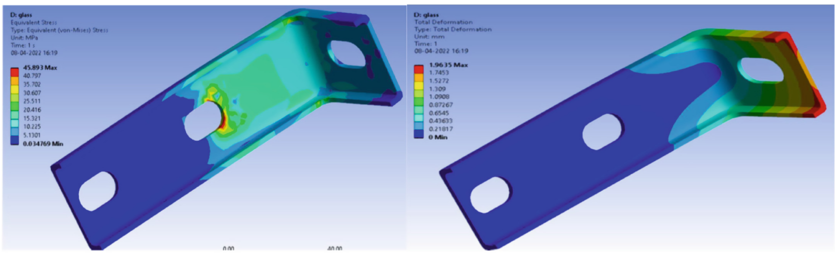
(a) (b)

Fig. 5. (a) Stress Plot for Steel Material, (b) Deformation Plot for Steel Material



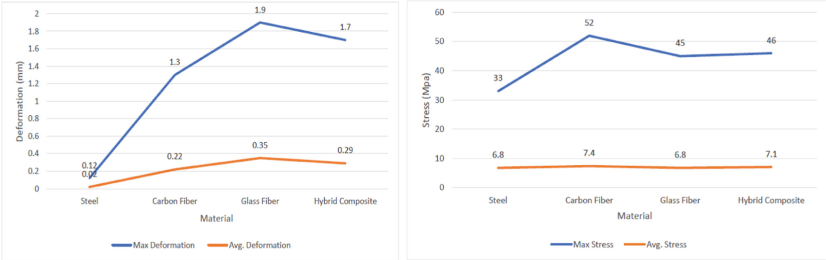
(a) (b)

Fig. 6. (a) Stress Plot for Carbon Fiber Material, (b) Deformation Plot for Carbon Fiber Material



(a) (b)

Fig. 7. (a) Stress Plot for Glass Fiber Material, (b) Deformation Plot for Glass Fiber Material



(a) (b)

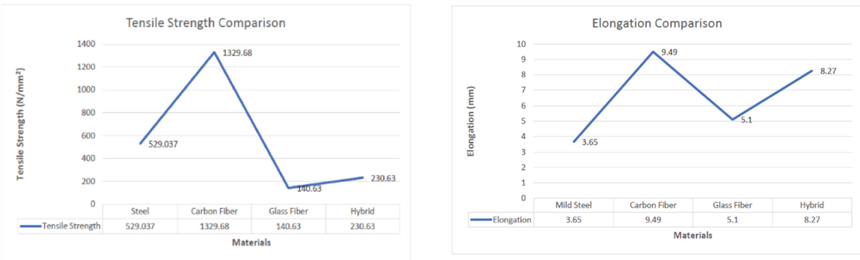
Fig. 8. (a) Deformation Analysis Chart, (b) Stress Analysis Chart

8 Results and Testing

8.1 Testing

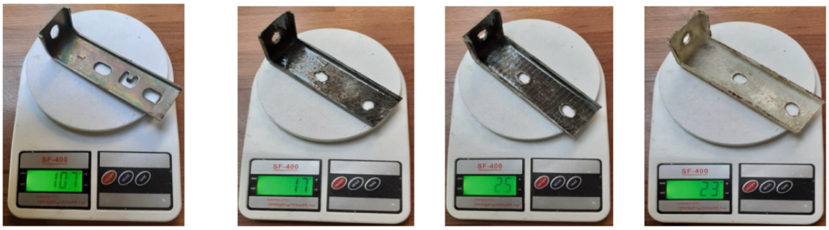
We have requested the tensile testing of all materials used for making the bracket. For this purpose, we prepared the standard specimen of size 20 mm x 170 mm x 5 mm of all materials i.e., Steel, Glass fiber composite, Carbon Fiber-Epoxy composite and Hybrid Carbon-Glass fiber composite. This testing is performed under observation of authorized person at "Delta Metallurgical Laboratory & Services, Sangli", which is approved Lab by National Accreditation board for Testing and Calibration Laboratories (NABL) (Figs. 9, 10 and 11).

8.2 Weight Comparison



(a) (b)

Fig. 9. (a) Stress Analysis Chart Tensile Strength Result Comparison, (b) Elongation Result Comparison



(a) (b) (c) (d)

Fig. 10. Weight of (a) Steel, (b) Carbon Fiber C, (c) Glass Fiber C, (d) Hybrid Composite

(a) (b)

Fig. 11. Images of Hybrid, Glass, Carbon Fiber, Steel Bracket from (a) Front side (b) Back side

Table 1. Results

Materials	Weight (gm)	Stress (MPa)	Deformation (mm)
Steel	107	33	0.12
Carbon Fiber Composite	17	52	1.3
Glass Fiber Composite	23	45	1.9
Hybrid Composite	25	46	1.7

9 Conclusion

In our paper, referring to BIS (Bureau of Indian Standard) we have done tensile testing and weight measurements of components. It was seen from Stress analysis results that Von- misses stresses for steel, carbon, glass fiber composite and hybrid fiber composite are 33 MPa, 52 MPa, 45 MPa, 46 Mpa respectively. Also, the weights are 107 g, 17 g, 23 g and 25 g respectively.

Referring to those results we can conclude as,

- The stress difference between the materials is very negligible whereas there is considerable difference between the weights of the brackets.
- Hence, from the results we can say that composite materials found good in strength and light in weight. Composite materials give better results and suitable for application but are relatively costlier than conventional materials.

References

1. William D. Callister, “Callister’s Materials Science and Engineering”, by Jr. Wiley India Pvt. Ltd., Reprint 2013.
2. Mr. Pramod Walunje, Prof. V.K. Kurume, Optimization of Engine Mounting Bracket Using FEA‖, PARIPEX - INDIAN JOURNAL OF RESEARCH, Volume : 2 | Issue : 12 | Dec 2013, ISSN - 2250–1991 page no 72 to 75.
3. R. Bunsell, B. Harris, “Hybrid carbon and glass fiber composites”, Volume 5, Issue 4, 1974, Pages 157–164.
4. Shama Rao N., Simha T. G. A., Rao K. P. and Ravi Kumar G. V. V, “Carbon Composites Are becoming Competitive and cost Effective”, Infosys White paper, 2018.
5. Marzbanrad, Javad; Alijanpour, Masoud; Kiasat, Mahdi Saeid, “Design and analysis of an automotive bumper beam in low-speed frontal crashes”, Thin-Walled Structures (2009) vol. 47(8-9) pp. 902-911.
6. Obradovic, Jovan; Boria, Simonetta; Belingardi, Giovanni, “Lightweight design and crash analysis of composite frontal impact energy absorbing structures” Composite Structures (2012) vol. 94(2) pp. 423–43
7. Karthikeyan, M., Jenarthanan, M.P., Giridharan, R. et al. “Investigation on Crash Analysis of a Frontal Car Bumper”. Trans Indian Inst Met 72, 2699–2709 (2019). https://doi.org/https://doi.org/10.1007/s12666-019-01741-w
8. Monali Deshmukh Prof. K R Sontakke, “Analysis and Optimization of Engine Mounting Bracket” International Journal of Scientific Engineering and Research (IJSER), ISSN (Online): 2347–3878, Impact Factor (2014): 3.05, Volume 3 Issue 5, May 2015, page no 131 to 136.