The Impact Energy of a Composite Material under Thermal Conditions

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Abstract:
The most recent cars exhibit design and construction defects in their body, specifically in the bumper and fender. The bumper becomes damaged under conditions of elevated air pressure. Dangerous accidents can occur as a result of the body experiencing low levels of impact energy. This work focuses on studying this problem. The Toyota bumper is replicated using a composite material composed of chopped glass fibers and reinforced polyester. The mechanical properties, specifically tensile and impact properties, are determined through experimental methods. The study compares the results obtained from testing the bumper material of Toyota at various temperatures (0, 20, 40, 60, and 80°C) within the working range in the Kingdom of Saudi Arabia. The findings indicate that the reproduced bumper demonstrates higher levels of stress. Specifically, the greatest stress observed in the Toyota bumper is 40 MPa, whereas the GFRP bumper exhibits a maximum stress of 92 MPa. The thermal impact resistance of Glass Fiber Reinforced Polymer (GFRP) was found to be approximately 200 times superior to that of a Toyota bumper when measured at the same temperature. The utilization of chopped glass fiber-reinforced polyester in car body manufacturing as an alternative to sheet metal can offer a viable means of safeguarding against corrosion.

Key words: composite materials, tensile properties, glass fibers, impact energy
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1. INTRODUCTION

A composite material refers to a complex system that comprises at least two constituents. Such constituents may include, but are not limited to, matrix, reinforcement, and interphase, with distinct forms and material compositions that are essentially insoluble in each other (Formela, Kurańska et al. 2022, Sharma, Sudhakara et al. 2023). The reason why composite materials are so popular is because they provide advantageous qualities that none of the constituent materials can achieve on their own.
The use of advanced composite materials has experienced a substantial increase in recent decades for the construction of structural elements. Advanced composite materials are being used more frequently as substitutes for traditional materials such as steel, aluminum, and wood because of their superior specific properties. Polymeric matrix composites, particularly those reinforced with glass or carbon fibers, exhibit stiffness-to-weight and strength-to-weight percentages that are advantageous. Therefore, these manufacturing sectors consider them to be highly appealing.(Mouritz, Gellert et al. 2001, Carlsson, Adams et al. 2014, Faruk, Bledzki et al. 2014).

The design of a new composite element requires consideration of both geometry and material design. In the past, the lack of comprehensive knowledge about composite material behavior necessitated the reliance on empirical methods for their utilization. This methodology is limited in its ability to accurately characterize specific materials and stacking sequences due to the vast number of possible material combinations. The experimental characterization of materials is expensive and poses challenges when applied to various material configurations.(Carruthers, Kettle et al. 1998, Senthil, Arockiarajan et al. 2013, Asyraf, Ilyas et al. 2022)

The Mercedes A Class utilizes glass reinforced polypropylene GMT extensively. The BMW Mini utilizes thermoplastic composites for semi-structural applications.(Wilson 2003) The front-facing carrier component of this vehicle is produced with StaMax.(Ciliberti and Schijve 2003, Seeba, Srikari et al. 2010).

The bumper beam structure of the Peugeot 806/Evasion van is constructed using Twintex, a type of long glass fiber reinforced polypropylene. The material has been proven to perform well in both low and high speed collisions. It remains intact during testing and effectively addresses concerns related to catastrophic collapse and failure. (Kulkarni and Schijve 2011, Soubaneh 2017).

The BMW M3 employs Tow Flex, a glass-reinforced Nylon 6 composite with extended fibers, in its various applications. The bumper beams are produced through the thermoforming process, which involves using preconsolidated sheets of thermoplastics powder that are infused with glass fibers. The bumper crush tubes are produced using a continuous molding compression technique, utilizing the same material. The tested bumper system exhibited improved crash performance and a 60% reduction in weight compared to a similar metallic bumper system(Thomason 2009).

Experimental techniques were employed to evaluate the mechanical properties of a composite material composed of reinforced polyester and chopped glass fibers, with the intention of replicating the Toyota bumper. The tensile properties, including Young's modulus, strength, force, energy, and elongation, were measured and documented(DorMohammadi, Repupilli et al. 2018) . This study examined the impact toughness performance of a composite material reinforced with Musa acuminata stem fibers (MASF) (Darmo 2020, Darmo and Sutanto 2023). The study found that the inclusion of MASF improved the impact toughness of the composite material. The mechanical properties of composites incorporating woven roving (W) and chopped strand mat glass fiber (C) exhibited variations. The study determined that W/UP composites had higher impact strength, while C/UP composites demonstrated superior flexural behavior(Erden, Sever et al. 2010). WC/UP hybrid composites exhibited superior mechanical properties in general. The experimental methods employed in these studies offer valuable insights into the mechanical properties of a composite material similar to the Toyota bumper, encompassing tensile and impact properties.(Kiss, Stadlbauer et al. 2020).

Most polymer composites use carbon and glass fibers. The Boeing 787 has 32 tons of composites. Aircraft structures are believed to comprise above 50% composite materials, principally CFRP and GFRP(Sreejith and Rajeev 2021). Aeronautical firms include Airbus A350 and Bombardier composites. Composite materials like FML contain CFRP, GFRP, and thin metal alloy sheets.(Thamizh Selvan, Vishakh Raja et al. 2021).

Fiber strength and modulus, chemical stability, matrix strength, and fiber/matrix interface bonding for stress transfer determine a fiber-reinforced composite's mechanical performance. With adequate fiber compositions and orientations, GFRP composites have equivalent quality and functional features to steel, better rigidity than aluminum, and a fifth of the specific gravity. Composites feature long longitudinal, woven mat, chopped fiber (distinct), and chopped mat GF reinforcements for mechanical and tribological qualities. Fibers deposited or laminated in the matrix during composite preparation determine characteristics. Polymeric composites were employed in aircraft rudders, elevators, fuselages, and landing gear doors due to their light weight, lower fastener fatigue resistance, and quantity of components.(Sethi and Ray 2015).

Marine applications use polyester matrix-based composites, which break down due to water absorption. Epoxy resins are ideal for the aforementioned applications due to their chemical and corrosion resistance and low curing shrinkage. Epoxy resin networks' crosslinking and processing flexibility caused brittleness. Composites needed energy dissipation in vibration settings.(Chen 2021)

FRP composite energy dissipation was modified by fiber volume, orientation, matrix material, temperature, moisture, lamina thickness, and composite thickness. Temperature impacts all polymeric composite mechanical properties. Analysis of polymer matrix composites' dynamic stability, including storage modulus and damping effects, at low and high temperatures was crucial. Damping was calculated using four time- and frequency-domain approaches. Time-domain Hilbert transform with logarithmic decrement analysis Moving block analysis and half-power bandwidth were used in the frequency method. Slide, rub, and roll composites against other materials or themselves in tribology. GFRP matrix with fillers optimized wear and friction. In bearings, gears, wheels, and bushes, composite materials are used.(Rajak, Wagh et al. 2021)

Figure 1 illustrates various applications of fiber composites from 1985 to 2005. It is evident that the utilization of fiber composites is expanding across numerous applications.In contemporary times, composites have emerged as the preferred material option in cases where a combination of qualities is required, surpassing the capabilities of any individual material. The demand for a combination of rigidity, strength, and low density has prompted structural designers to opt for composite materials in many technological components within industries such as automotive, marine, and aeronautics. Fiber-reinforced polymer (FRP) composites are a notable instance of such a material. Hence, in recent decades, there has been a substantial endeavor(Christensen 2017).

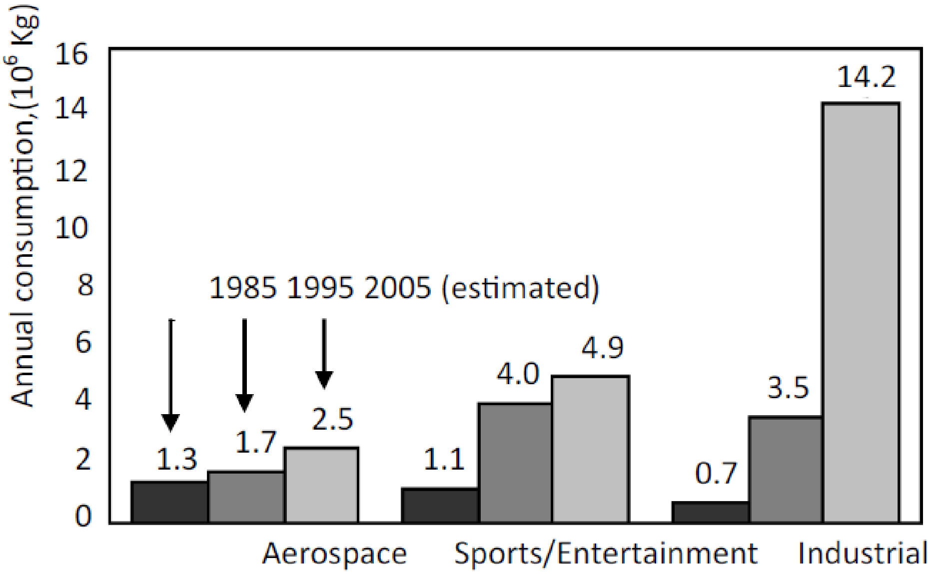


Figure 1. Application of fiber composites during the period 1985-2005(Christensen 2017)

These composites are used in aircraft wings, wind turbines, rotor blades, and car bumpers due to their high strength-to-weight ratio, corrosion resistance, and fatigue resistance. (Gamdani, Boukhili et al. 2015, Christensen 2017, DorMohammadi, Repupilli et al. 2018, Darmo 2020, Miah, Yu et al. 2022), . Most polymer composites use carbon and glass fibers. The Boeing 787 has 32 tons of composites. Aircraft structures are believed to comprise above 50% composite materials, principally CFRP and GFRP. Aeronautical firms including Airbus A350, Bombardier, and EMBRAER utilise FML composites (Sathishkumar, Satheeshkumar et al. 2014, Atmakuri, Palevicius et al. 2020). Composite materials like FML contain CFRP, GFRP, and thin metal alloy sheets (Gou, Xie et al. 2023). Besides synthetic fibers and metals, a lot of thermoset matrix, mainly epoxy resin, is used. The thermoset polymers are highly resistant to humidity, temperature, and microbes. The end of all these components creates more plastic trash, forcing researchers to address waste management difficulties [(Khalid, Arif et al. 2022, Miah, Yu et al. 2022).

This study addresses design and construction defects in modern car bodies, focusing on the bumper and fender. By replicating the Toyota bumper using a composite material of chopped glass fibers and reinforced polyester, the researchers determine its mechanical properties. Testing at different temperatures reveals that the replicated bumper exhibits higher stress levels compared to the original Toyota bumper. Additionally, the Glass Fiber Reinforced Polymer (GFRP) bumper demonstrates significantly superior thermal impact resistance, making it a promising alternative to sheet metal for corrosion protection in car body manufacturing.

2. Objectives of the present work:

This study investigates the influence of thermal conditions on the energy absorption capacity of Chopped-GFRP material. The temperatures considered in this study are 0, 20, 40, 60, and 80°C. The impact energy of Chopped-GFRP material is being compared to the impact energy of Toyota's bumper material. The study is conducted within the temperature range commonly experienced in the Kingdom of Saudi Arabia (KSA). The study involves altering temperatures to examine the thermal impact at various levels, specifically focusing on the average temperature of the real atmosphere, which typically falls within the range of 30 to 40 degrees. This variation in temperatures enables a comprehensive analysis of the temperature's influence on thermal effects. The choice of utilizing chopped glass fiber in this research was motivated by its remarkable strength and effectiveness, making it highly suitable for a wide range of applications in defense, energy, and economic sectors. Additionally, the inclusion of glass fibers significantly improved the tensile and flexural characteristics of the composites. Glass fiber reinforcement plays a vital role in enhancing the flexural properties and ductility of glass fiber-reinforced polymer (GFRP) materials. In particular, chopped glass fiber was employed in the manufacturing process of bumper composites for automotive components.

3 . Experimental work:

3.1 The manufacturing process of Chopped-GFRP

Glass Fiber Reinforced Polymer) composites and the preparation of samples for Toyota. The manual lay-up process was utilized to fabricate composite laminates that were subsequently cut into pieces as shown in Figure 2. Six layers, each measuring 500×500 mm^2, were made from the chopped glass fiber mats. A layer of resin was applied to a 700×700 mm^2 glass plate that had been treated with a release agent, specifically wax

a) b) c)

Figure 2. Procdures steps of sample preparation a) manual lay-up b) layers of resin applied c) glass plate treated with release

The process of fabricating a composite structure typically involves the application of multiple layers, each consisting of glass fiber matting and resin. The first layer of glass fiber is applied onto the resin and then compressed using specialized laminating rollers which eliminate any visible air bubbles and ensure that the mat is entirely saturated with the resin. This process is repeated several times, alternating between layers of resin and glass fiber matting, until the desired level of accumulation is achieved.(Masuelli 2013)

After saturating all the layers with resin to ensure that no air voids were present, the final layer was covered with cellophane paper. This paper was then rolled over using a round aluminum pipe to get rid of any visible air bubbles and excess resin, thus creating a smooth surface. To ensure the composite laminate had a consistent thickness of approximately 2 ± 0.1 mm, a 25 Kg weight was placed on a glass plate, which was positioned on cellophane paper, and a metal tap measuring 2 mm in thickness was inserted between the two glass plates at each corner as shown in figure 3.

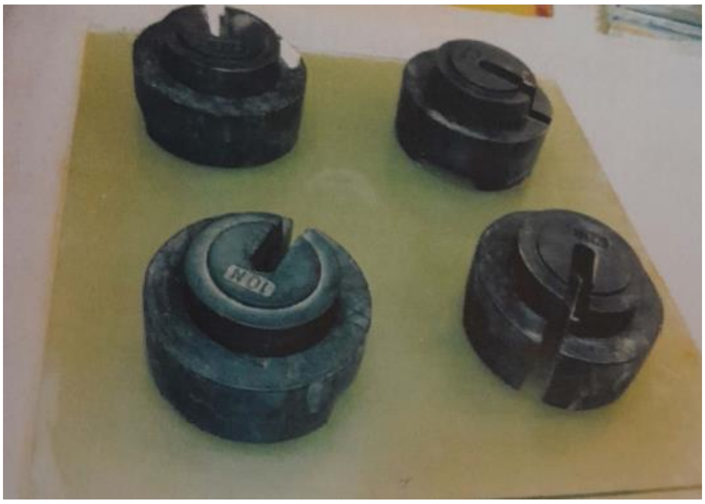


Figure 3. Final layer of GFRP under weght 25 Kg.

After 24 hours, the plate of glass and cellophane paper were removed, and the laminate was left to cure for 21 days at room temperature. Once cured, the laminate was cut to the necessary dimensions using sawing, milling, and drilling machines. These processes ensured that the composite laminate was of high quality and fit for its intended application. The use of cellophane paper, a metal tap, and a glass plate were all essential in the creation of a uniform and high-quality composite laminate. Overall, the process of creating composite laminates requires precision and attention to detail to produce a consistent and desirable end product. To create test specimens, the laminate margins were trimmed, leaving a minimum distance of 20 mm from the edge. The working components of the samples were then extracted, ensuring a separation of approximately 30 mm from the edge. Five Toyota Camry bumper samples were cut and prepared using identical dimensions. The samples are uniformly cooled as well as heated to the desired temperatures using a consistent method.

3.2 Determination of Fiber Volume Fraction of Composites:

The primary objective of this study is to determine the fiber volume fraction of composites. To achieve this objective, an extensive experimental analysis was conducted using the ignition technique (Pan 1993, El Messiry 2013). The study's findings will contribute to the understanding of composites' mechanical properties, thereby facilitating their application in diverse industrial contexts. Four specimens measuring 10×10×2 mm^3 were extracted from each of the corners of each laminated materials. Each specimen was stored in desiccated containers. The mass of each dried container was measured using a digital balance with a resolution of 10^{-4} g, denoted as Mo, before the specimen was placed inside. The test samples were placed in an open muffled furnace at a temperature of 575±25 ºC for a duration of five minutes. The door remained closed for an additional 30 minutes. The weight of each container, along with the specimen, was measured to the nearest 10^{-4} g, denoted as M1. The fiber's fractions of volume have been determined using the following equation (El Messiry 2013).

$$Vf = \frac{\frac{M1 - Mo}{\rho_f}}{Vc} x100 \quad (1)$$

Where; ρ_f is the density of glass fiber ($2.56x10^6 g/m^3$), V_C is the volume of the composite specimen (length width× thickness). The mean fiber volume fraction was 30%. These values of fiber volume fraction are the maximum values that can be achieved by hand lay-up technique.

3. 4 Tensile Tests:

Tension tests were conducted on laminated composites using a universal testing instrument (Testometric 200kN) in accordance with ASTM D3039 as shown in Figure 4. The loading member's cross-head speed was 2 mm/min. A total of five specimens underwent testing. The size and shape of the test the sample were shown in Figure 2. Strength levels are determined using the mean value. The load-displacement graph is generated by the testing device's PC for all samples analyzed. Digital strain gauges are affixed to a surface. The strain Meter Tc-21K model 232 was used to measure strain on a single specimen for each type of composite. The measurements were conducted to ensure the accuracy and consistency of the test results.

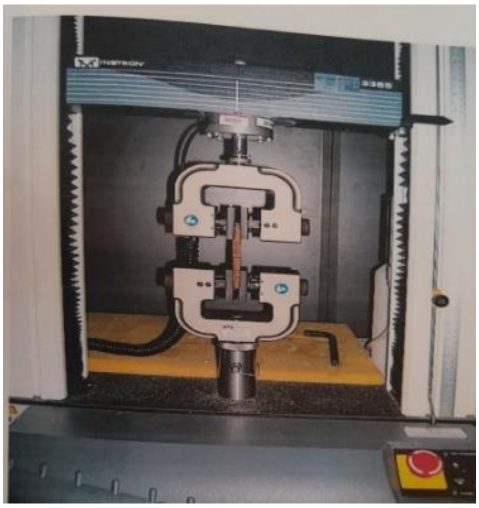
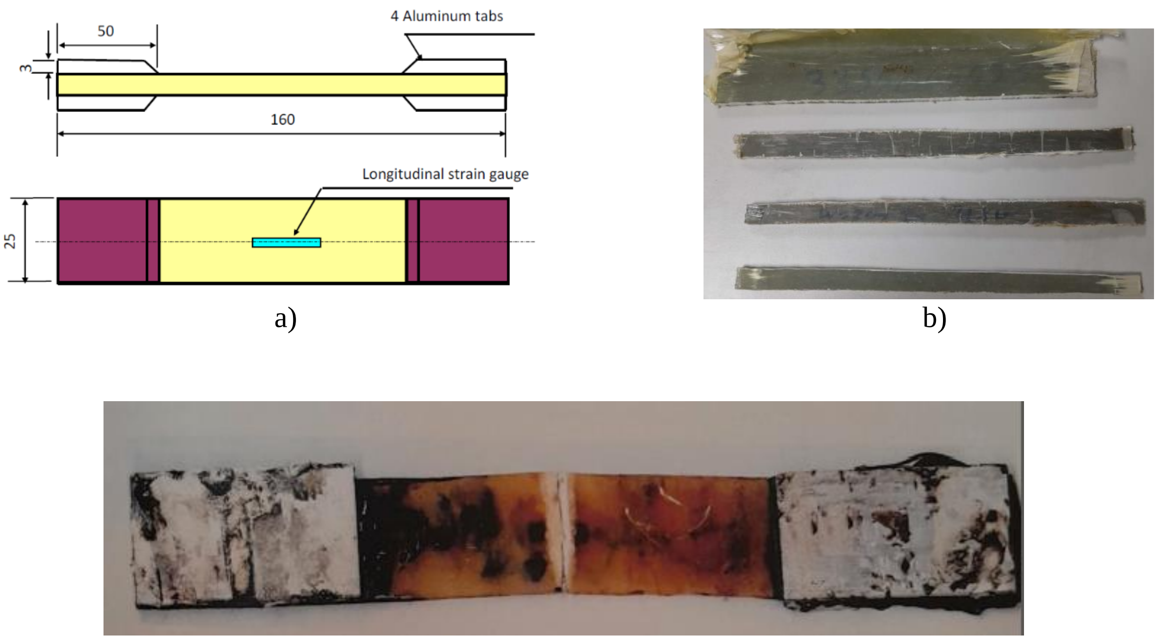


Figure 4. universal testing instrument

Epoxy resin was utilized to adhere four rectangular aluminum end pieces, commonly referred to as tabs, to the gripping length of each test specimen, which measured 50mm. Prior to the bonding process, the surface of the aluminum tabs underwent roughening using a fine grade of abrasive paper. This process was necessary to ensure a sturdy bond between the tabs and the test specimen. The assembly underwent overnight pressure and was assessed after the resin had fully cured. The end tabs have the dual purpose of reducing stress concentration from the serrated grips and preventing the test specimen from slipping. The use of end tabs is an efficient way to transfer the lateral compressive load from the testing machine's grips to the specimen. In addition, they provide protection against the test specimens being crushed between the grips. The implementation of end tabs in the testing process is a crucial step in ensuring accurate and reliable results. The use of epoxy resin, coupled with the roughening of the aluminum tabs, significantly improves the bonding strength and overall durability of the test specimen. It is a cost-effective and practical method that can be utilized in various testing procedures.

The figure5 illustrates the measurements of the tension test sample, as specified by ASTM D3039, in addition to the grips utilized for said test(Moreno-Núñez, Abarca-Vidal et al. 2023). The dimensions of the specimen are of paramount importance in ensuring the accuracy and validity of the results obtained from the tension test. The ASTM D3039 standard serves as a critical guideline for obtaining reliable and repeatable data during tensile testing(Sola, Chong et al. 2022).



a) b)

c)

Figure 5 a) schemitaic dimensions of the tension test specimen as specified by ASTM D3039. b) sample after cutted to diminsition test c) sample after tensile test

3.5 Impact test:

The maximum values of the fiber volume fractions were attained through the utilization of the hand lay-up technique. To begin, four rectangular aluminum end pieces, also known as tabs, were bonded to the gripping length of every test specimen, which measured 50mm. Epoxy resin was utilized to bond the tabs. Prior to the bonding process, a fine-grade abrasive paper was used to create a rough texture on the surface of the aluminum tabs. After the resin had fully cured, the assembly was subjected to overnight pressure and subsequently tested. The end tabs serve two crucial purposes: they reduce stress concentration caused by the serrated grips and also prevent the test specimen from slipping out of the grip. Moreover, they facilitate the transfer of lateral compressive load from the testing machine grips to the specimen, preventing the crushing of the test specimens. These end tabs played a significant role in the experiment, which ultimately resulted in the maximum values of fiber volume fractions being achieved through the hand lay-up technique(Gamdani, Boukhili et al. 2015).

3.5 Sample Preparation:

According to the American Society for Testing and Materials (ASTM) standard D 256, the determination of the average impact resistance of a specific sample material requires a minimum of five individual tests, with ten or more being preferable. In order to achieve accurate results, the samples are first immersed in cooled water and then subjected to varying temperatures between 0 and 80 degrees Celsius. This methodology ensures reliable and comprehensive data, which is essential for the evaluation of material performance and overall quality.

3.6 Charpy Impact Test:

The test principle of this test varies from the Izod test as it involves supporting the test piece as a beam at both ends, with the striker directly impacting the center of the face. Charpy testing has the capability to simulate the impact of typical car accidents on the human body, making it a valuable tool for assessing the effects of such accidents. To achieve this, an anatomical model such as a dummy can be employed, which incorporates spring rib members designed to mimic the structure and behavior of human ribs. This allows for a more accurate representation of the forces and stresses experienced by the human body during car accidents when conducting Charpy testing. The JBW-500 type of the Computer Screen Monitor Pendulum Impact Tester from the JBW Series is utilized in Figure 6. Its primary specifications are listed in the table.1

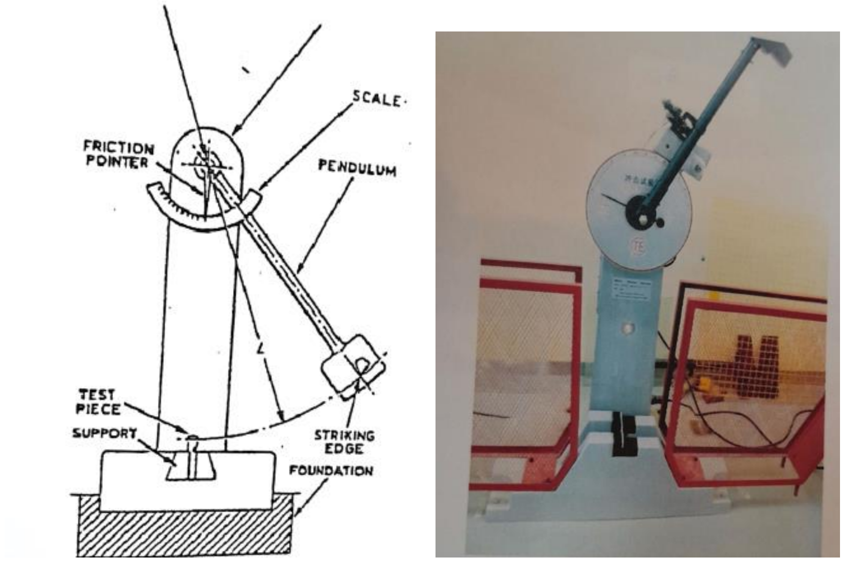


Figure 6. The JBW-500 type of the Computer Screen Monitor Pendulum Impact Tester

Table.1 Specifications of the JBW Series (JBW-500 type)

Specifications	JBW-500
Impact Energy (J)	500
Impact Velocity (m/s)	5.40
Raised angle	150°
Standard Span (mm)	40
Size of Specimen (mm)	180 x 24 x 2

4. Results and discussions:

The stress-strain characteristics illustrated and the moment-curvature analyses were conducted with meticulous care, taking into account the previously established behavior of confined concrete. The exploration of the mechanical response of reinforcement materials, which includes the analysis of strain behavior and the occurrence of strain hardening, carries substantial significance within the domain of materials science and engineering(Gonabadi, Oila et al. 2021). The findings derived from the tensile tests, as depicted in Figure 7, demonstrate a notable correlation between the moment capacity of the section and the ductility of the curvature. This analysis provides an in-depth examination of the mechanical properties exhibited by the bumper material utilized by Toyota, in combination with the integration of chopped glass fiber-reinforced polymer (GFRP)(Mazzuca, Firmo et al. 2022). The aforementioned Figure 3 depicts the stress-strain characteristics of both materials, revealing the presence of nonlinearity in their behavior, even at strains that are below the yield point. The findings regarding stress characteristics indicate that Glass Fiber Reinforced Polymer (GFRP) demonstrates a more advantageous performance when compared to Toyota plumbers, as supported by the data presented in Table 2.

Table 2 The Young's moudulus and Ultimate tensile stress properties for both materials.

Material	Young's modulus (E) (GPa)	Ultimate stress (Mpa)
Chopped GFRP	62.5	92
Toyota's bumper material	40	40

The study findings demonstrate that the mechanical properties of glass fiber reinforced polymer (GFRP), including ultimate stress and Young's modulus, exceed those of the Toyota bumper. This conclusion is supported by the data presented in Table 2 and Figure 7. The maximum stress of glass fiber reinforced polymer (GFRP) is 90 MPa, whereas in the Tyotya bumper it is 40 MPa. This implies that GFRP may offer greater strength and stiffness compared to the Toyota bumper. The investigation's findings have important implications for the development of stronger and more durable materials across various applications.The comprehensive analysis of all findings (El-Wazery, El-Elamy et al. 2017, Gonabadi, Oila et al. 2021).

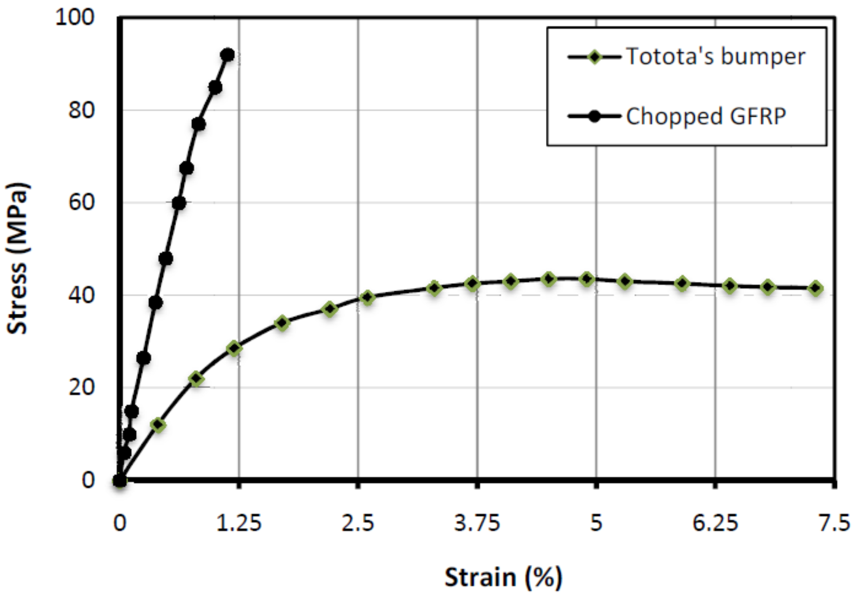


Figure 7. Stress-strain diagram of chopped GFRP and Toyota bumper.

Figure 8 illustrates a notable decrease in impact energy as temperature increases. Which studies exhibit strong agreement with the research conducted by Amin Salehi-Khojin and colleagues (El-Wazery, El-Elamy et al. 2017). The impact energy of chopped-GFRP is roughly twice that of Toyota's bumper material, and both decrease with increasing temperature. Temperature was observed to significantly influence the impact behavior of fiberglass composite material and Toyota's bumper material. The relationship between impact energy and temperature for GFRP follows a linear trend(Kosmann, Riecken et al. 2014), while the same relationship for Toyota's bumper material is inverse.

The findings derived from the impact assessment conducted at various operational temperatures (0, 20, 40, 60, and 80°C) have revealed that the Glass Fiber Reinforced Polymer (GFRP) substance demonstrates a heightened level of efficacy in contrast to Toyota bumpers. The aforementioned phenomenon is graphically depicted in Figure 8. The observed maximum impact energy of the glass fiber-reinforced polymer (GFRP) material, when subjected to a temperature of 0 degrees Celsius, has been quantified as 11.5 Joules. Nevertheless, upon elevating the temperature to 80 degrees Celsius, it is observed that the impact energy experiences a discernible reduction, dwindling to a magnitude of 8 Joules. In contrast, it has been determined that the Toyota bumpers exhibit a maximum impact energy of 6 joules when subjected to a temperature of 0 degrees Celsius. Upon subjecting the system to an elevated temperature of 80 degrees Celsius, it is observed that the impact energy experiences a further reduction, reaching a value of 4 joules. The thermal influence of glass fiber reinforced polymer (GFRP) at a temperature of 0°C was ascertained to be 11.5 joules, whereas the lowest recorded value at a temperature of 80°C was 10 Joules. In contrast, it was observed that the Toyota bumper demonstrated a thermal impact of 6 J at 0°C. However, as the temperature increases, the impact energy decreases to 4 J at 80°C. This implies that the efficiency of Glass Fiber Reinforced Polymer (GFRP) surpasses that of the Toyota bumper in terms of resistance to elevated temperatures. (Polyzois, Raftoyiannis et al. 2007, Miah, Yu et al. 2022).

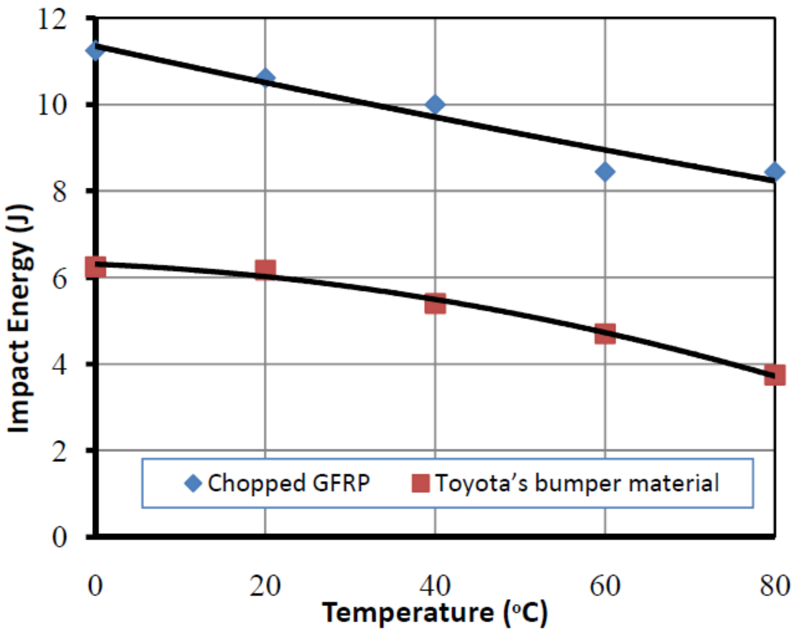


Figure 8. Comparison between impact energy for Chopped GFRP and Toyota' bumper materials

The primary failure mode resulting from impact on chopped glass fiber reinforced polymer (GFRP) materials (Salehi-Khojin, Bashirzadeh et al. 2006, Gupta, Gupta et al. 2016, Jogur, Nawaz Khan et al. 2018, Mazzuca, Firmo et al. 2022). The impact failure mode of chopped glass fiber reinforced polymer (GFRP) shows was broken due to its brittle as shown in figure 9.

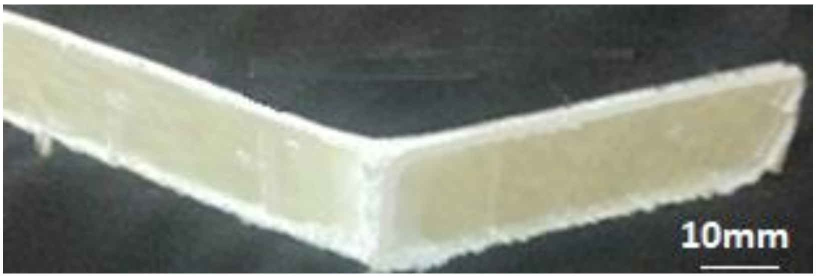


Figure 9. The mode of failure by impact of chopped-GFRP

The impact-induced failure mode of Toyota's bumper material is primarily attributed to its superior resistance to impact, which can be attributed to the ductile nature of the material, allowing it to better withstand the energy of an impact as shown in figure 10.

Figure 10. The mode of failure by impact of Toyota's bumper material

5.Conclusion:

The proposed process leads to the development of a bumper design that offers improved durability and effectiveness, enabling it to withstand various impact forces and environmental conditions.The study findings indicate that the chopped Glass Fiber Reinforced Polymer (GFRP) bumper exhibits higher levels of impact energy and increased brittleness compared to the Toyota bumper under different temperature conditions. Specifically, the GFRP bumper demonstrates a maximum stress threshold of 92 MPa, while the Toyota bumper reaches a maximum stress capacity of 42 MPa. The comparative analysis reveals a significant advantage in thermal impact resistance for the Glass Fiber Reinforced Polymer (GFRP) material, with approximately 200 times greater resistance compared to the Toyota bumper under identical temperature conditions. Furthermore, the GFRP exhibits a higher resistance efficiency of 87% across temperatures ranging from 0°C to 80°C, while the Toyota bumper shows a slightly lower efficiency of 75%. The use of chopped glass fiber-reinforced polyester as an alternative to traditional sheet metal in automotive body manufacturing offers a promising solution to address the challenges posed by corrosion. This approach can potentially provide numerous advantages in terms of durability and protection against corrosion-related issues. It is recommended that future research endeavors be expanded to encompass the examination of properties fortified with nanoparticulate reinforcements, such as carbon nanofibers, as well as natural fibers.

Nomenclature	
GFRP	Glass Fiber Reinforced Polymer
ASTM	American Society for Testing and Materials
V_f	Volume friction
ρ_f	Density of glass fiber
MASF	Musa acuminata stem fibers
E	Young's modulus
Mo	The mass of each dried container
M1	The weight of each container with the specimen

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