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ANALYZING IMPACT BEHAVIOUR OF GLASS FIBER EPOXY COMPOSITES FOR HIGHER SAFETY SYSTEMS

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Abstract: *This study investigates the impact behaviour of glass fiber epoxy composites with a focus on achieving enhanced safety. A drop weight impact test machine was used to perform a series of impact tests on the composite samples. Two different impactors as dimensions and three velocities were used to investigate the impact behavior of glass fiber epoxy composites. The study's goal is to investigate the impact response of these composites and their potential for usage in impact protection applications. The study findings show that glass fiber epoxy composites have outstanding impact resistance properties, as well as high levels of the ability to absorb energy and withstand the initiation of damage. The findings suggest that both the impactor (as shape and dimensions) and the velocity of impact have a notable influence impact on the damage mechanisms and energy absorption capacity of the composite materials. The failure mechanisms detected in the composites were mostly delamination and fibre breakage.*

Keywords: multiaxial glass fiber epoxy composites, impact behaviour, drop weight impact test.

1. Introduction

Because of their superior mechanical qualities and promise for better safety, innovative composite materials have been essential in impact protection systems in recent years. Glass fiber epoxy composites have emerged as a viable choice for impact protection applications among these materials. However, there is still a need to better understand materials' impact behaviour in real-world applications, for improving their performance and their safe. The strength of composite materials can be significantly compromised by low-velocity impacts. Strength of composite structures may experience a reduction due to internal damage caused by low-velocity impacts, such as instances where tools are dropped during maintenance [1].

Effectively addressing damage in composite structures caused by impact events is a concern in the design and application of composite materials [2]. Impact events, on the other hand, may be categorised based on their impact velocity, impactor shape and dimensions and the answer of the hit structure. Low-velocity impact events take place when the contact duration of the impactor surpasses the time period of the lowest vibration mode, as stated by Naik and Shrirao [3]. The support conditions play a vital role as they allow the stress waves generated by the impact to propagate and reach the boundaries of the structural component, resulting in its complete vibration. Impact damage depends on many

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factors, such as the impactor material, shape, dimensions, the velocity of impact and the arrangement of layers in a polymeric composite material [4].

Researchers have explored alternative impactor shapes, including flat-ended and conical shapes, apart from the commonly used hemispherical shape [1]. Mitrevski and colleagues [5], [6] conducted an experimental study to examine the impact response of thin woven carbon/epoxy laminates. They investigated the influence of impactor shape by using 12 mm diameter impactors with hemispherical, ogival, and conical shapes.

The authors of the article [7] conducted an experimental investigation to assess the accumulation of damage in two-dimensional (2D) and three-dimensional (3D) architecture of woven fabrics composites subjected to repeated transverse drop-weight impact loading. 3D architecture offers inherent characteristics that allow for efficient energy dispersion over a wide radial area and greater resistance to perforation as compared to 2D fabric systems.

Delamination between layers of composite laminates due to low-velocity impact is a well-known process that may occur without any noticeable surface damage.

This delamination can deteriorate over time, in service. It will reduce stiffness and, as a result, it will damage the system structural integrity. The examination of composite laminates, subjected to low-energy projectile impacts, demonstrated a significant reduction of 50% in tensile and compression strength. This reduction led to a complex fracture process [8].

The objective of this research is to investigate the impact behaviour of multiaxial glass fiber epoxy composites for protective systems. We intend to examine the energy of these composites' energy absorption characteristics, and failure mechanisms under drop weight impact conditions. The outcomes of this research endeavour may serve as a guide to the design and development of innovative composite materials for increased safety, as well as providing vital insights into the viability of glass fiber epoxy composites for impact protection applications.

2. Materials and Methods

We give a complete explanation of the experimental technique and methodology employed in this investigation, as well as a thorough analysis of the impact behaviour data. In addition, we examine the significance of our findings for the usage of glass fiber epoxy composites in impact protection systems, as well as possible uses of these materials in different sectors. This research is an important addition to the field of impact protection materials and systems, and we expect that the findings will be of interest to a wide spectrum of researchers.

2.1. Description of Epoxy System and Unidirectional (Quadriaxial) Glass Fiber Fabric

The impact strength and load carrying capacity of a composite material are influenced by the properties of the matrix.

The production method employed for the composite plates involved the utilization of the laying-up and pressing technique. Two-layers of glass fiber fabric, 1200 gr/m^2 each layer. The fabric used in this study is composed of differently orientated layered (0°/+45°/90°/-45°), which implies that the fabric will have a quasi-isotropic behaviour. The trade name is 1200 g/m^2 Quatriaxial Glass Cloth (0°/+45°/90°/-45°) 127, having the code WTVQX1200-1 E-glass, Q1200E10Q and was purchased from Castro Composite SL. A bicomponent epoxy resin (Biresin CR82 with Biresin CH80-2 hardener) supplied by Sika AG were used based on fibers selection process, where specific components were carefully identified and included.

Table 1 shows the properties of resin and hardener used in study. The polymer properties are shown in Table 2. A specialized ageing heat treatment was employed to cure the composite plates.

After the ageing process, the composite plates were cut into specimens with dimensions measuring 60 mm x 60 mm.
Table 3 shows the used glass fiber architecture of the fabric. The role of the material in a composite structure holds great significance, as it effectively absorbs a considerable portion of the applied load. Currently, a wide range of materials are accessible, offering various options for selection: carbon, glass, aramid. Previous research [9] investigating the performance of various continuous fiber composites has indicated that glass and aramid fibers composites demonstrated Charpy impact test strengths that were higher than those of carbon fiber composites.

2.2. Experimental Setup

Two different spherical steel impactor diameters were used during low-velocity impacts. Impactor 1 has a size of 10 mm in diameter, while impactor 2 has a size of 20 mm in diameter. This is the difference between the two types of impactors. Impactor velocity varies between 2 m/s and 4 m/s, with three different values tested for each impactor size: v1= 2 m/s, v2= 3m/s, v3= 4m/s.
The impact tests were conducted at room temperature, using Instron CEAST 9300 Series Drop tower Impact Systems, as illustrated in Figure 1. It was used to subject the composite systems to repeated (3 times) transverse impact loading conditions. Extensive research has been conducted to investigate the impact mechanism of composite materials, exploring the influence of impact energy levels, impact velocity, and impactor diameter.

Table 1 Properties of resin and hardener used in study [10]

Properties		**Resin Biresin® CR82**	**Hardener Biresin® CH80-2**
Mixing ratio	weight	100	27
Mixing ratio	volume	-	31
Colour		transparent	colourless to yellow or blue
Viscosity, 25^0C	mPa.s	1600	-
Density, 25^0C	g/ml	1.11	0.99

Table 2 Polymer properties [10]

Properties		**Polymer**
Potlife, 100g/RT, approximate value	min	80
Mixed viscosity, 25°C, approximate value	mPa.s	600

Table 3 Glass fiber architecture of the fabric [10]

Quatriaxial glass fiber fabric architecture		
Fiber orientation	Fiber type	Surface weight, [g/m^2]
0^0	600 Tex	283
45^0	300+600 Tex	300
90^0	600 Tex	307
-45^0	300+600 Tex	300
Auxiliary yarn	76 DTex	10

Figure 1: Instrumented drop weight impact tester (CEAST 9300 Series -Instron) during tests

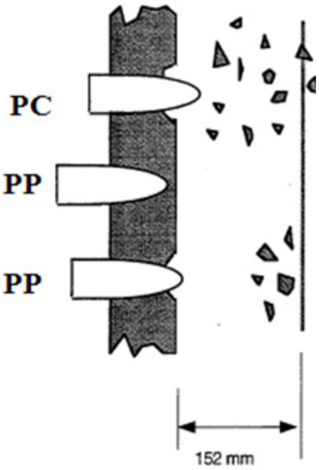

Figure 2: Ballistic limit of a material: PC- complete penetration, PP- partial penetration [15]

3. Results and Discussion

A ballistic limit of the composite plate usually exists. The concept of the ballistic limit, often represented by the velocity at which only perforation or full penetration of a plate occurs (as in Figure 2), is commonly employed. In some cases, particularly in military systems [11], [12], the ballistic limit is determined by establishing a velocity known as V_{50}. V_{50} represents the velocity at which there is an equal probability (50%) of penetration and perforation of a specific target. The assessment of V_{50} involves conducting experiments in a controlled range, where the projectile velocity can be measured and adjusted by modifying the gas pressure. The V_{50} velocity is determined by incrementally varying the projectile velocity until multiple projectiles both penetrate and fail to penetrate the target, at similar velocities.

The average projectile velocity is known as the V_{50} velocity [13], [14].

Our study deals with low velocity impacts on glass fiber epoxy composites where failure mechanisms and characteristics during impact are important factors in using the authors' composite materials for actual structure.

Making a comparison between figure 3 and figure 4, we can easily notice that the smaller impactor, i.e. the 10 mm impactor caused more damages to the composite plates. In this case, the entire plate is penetrated. While in the case of the composite plates tested with the second impactor, of 20 mm in diameter, the penetration is partial.

In the case of the 10 mm impactor, matrix cracking and matrix peeling occurs under all impactor velocities. At low speed impact (v1) and impactor of 20 mm the resulting damage may not be easily noticeable without magnification. However, under higher velocity impact conditions (v2 and v3, for both impactors), the damage inflicted on the composite plate is considerably more severe, resulting in significant structural impairment.

The load-time histories reveal important differences for the two impactors, particularly in terms of peak loads and zero load. The results demonstrate the influence of the effect of the size of the impactor and velocity on the dynamic response of the plate during impact.

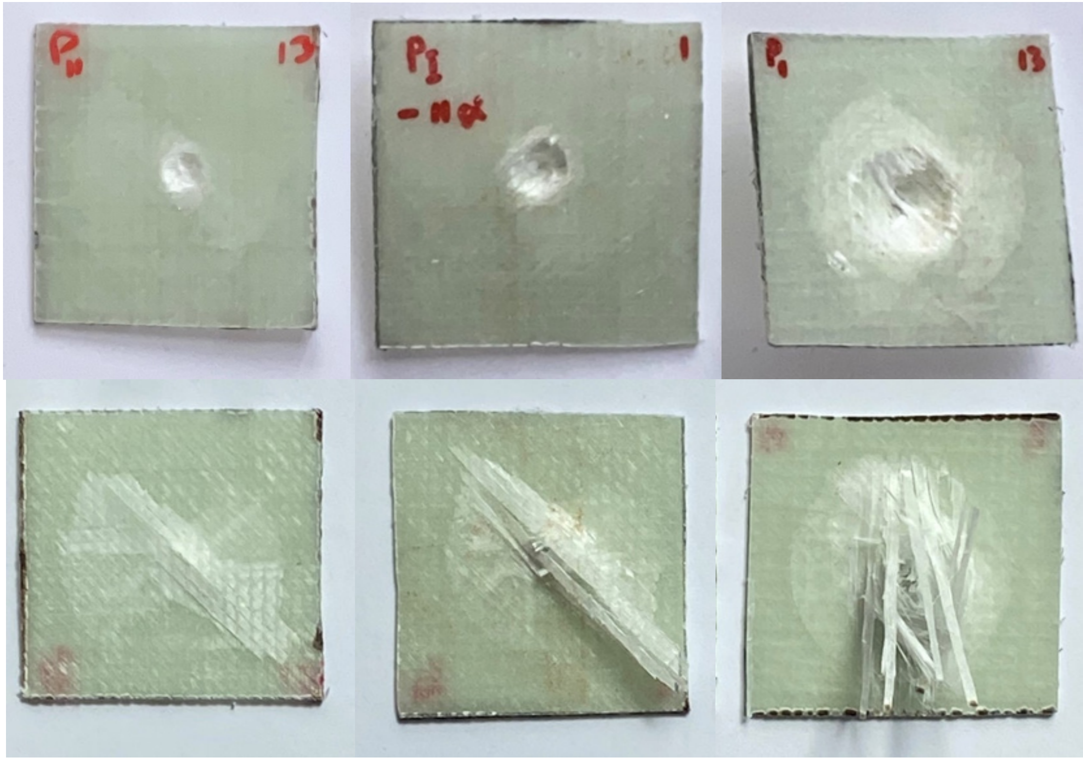

Figure 3: Photographs captured from both sides: face (up) and back (down) of the specimens that were subjected to impacts, at impact velocities v1, v2, and v3 (from left to right), using a 10 mm impactor.

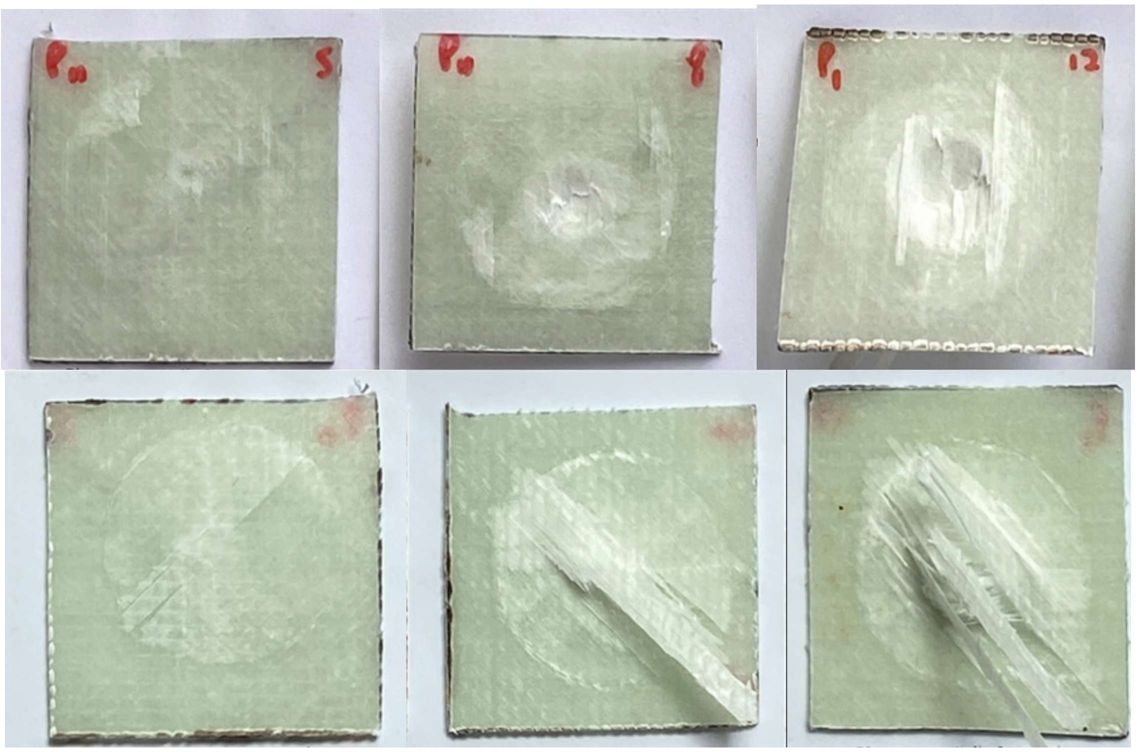

Figure 4: Photographs captured from both sides: face (up) and back (down) of the specimens that were subjected to impacts, at impact velocities v1, v2, and v3 (from left to right), using a 20 mm impactor.

Figure 5 shows the load-time impact history for the 10 mm impactor, at different velocities. At 2 m/s, the load increases gradually, reaching a peak load of approximately 3500 N, at 5 ms. When the velocity is increased to 3 m/s, the load rises more rapidly and attains its maximum value of 4500 N, at 3 ms. Finally, at 4 m/s, the load-time history exhibits a similar trend, with the peak load occurring at an earlier time as compared to the previous cases. The 20 mm impactor consistently experiences higher peak loads as compared to the 10 mm impactor, for all tested impact velocities. This outcome is expected since the 20 mm impactor has a larger contact area, resulting in a lower stress impacted area upon impact.

As the velocity increases for both impactors, there is a corresponding decrease in the time required to reach the peak load. This behavior indicates that higher velocities lead to faster force transfer and quicker attainment of maximum loads.

Figure 6 shows the energy–time history for booth impactors, for all tested velocities. The energy-time records provide information on the dynamic energy transfer during impact and show how impactor size and impact velocity affect energy absorption capacity. The results show that the two impactors absorb significantly different amounts of energy. Across all tested impact velocities, the 20 mm impactor has a much larger energy absorption capacity than the 10 mm impactor. This difference is to be expected, as the 20 mm impactor's larger contact surface allows for higher energy transmission during impact.

Figure 7 shows the displacement–time history for booth impactors for all tested impact velocities under all impact velocities, the 20 mm impactor consistently has larger peak values of displacement than those of 10 mm impactor. The increased contact area and mass of the 20 mm impactor contribute to a higher displacement during the impact event. It is crucial to highlight that displacement characteristics of both impactors changes with velocity.

4. Implications and Applications

Currently, there are no standard acceptable test procedures for conducting impact tests on composite materials. Consequently, a diverse range of test procedures, specimen geometries and data analysis techniques are presently employed. The study findings have important implications for designing and developing composite materials used in impact protective systems and significant implications for increasing protection in high-risk contexts.

4.1. Insights from Study Findings

The findings of the study can be utilized to improve the design of impact protection systems, made of glass fiber epoxy composites. It may be feasible to increase the impact resistance of composites against low velocity impacts by selecting adequate components of the composite. The findings of the study may also aid in the development of predictive models for the damage evolution and strength of composites subjected to low-velocity impacts, which may be useful in designing reliable and safe structures for applications that require exceptional performance such as protection systems, aerospace and marine industries, body armor, helmets and vehicle armor.

It is crucial to note, however, that when selecting a composite material for a specific impact protection system, the individual application requirements and environmental circumstances must be discussed.

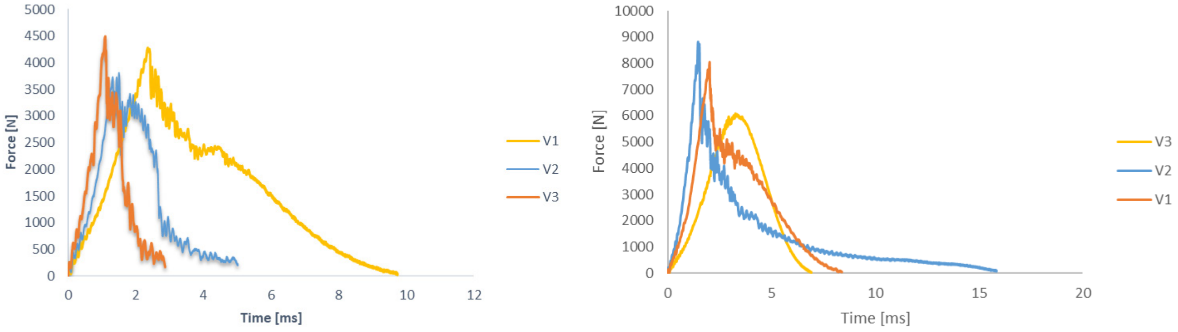

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Figure 5: Load–time history for both impactors, at all tested velocities: a- Spherical impactor of 10 mm diameter; b- Spherical impactor of 20 mm

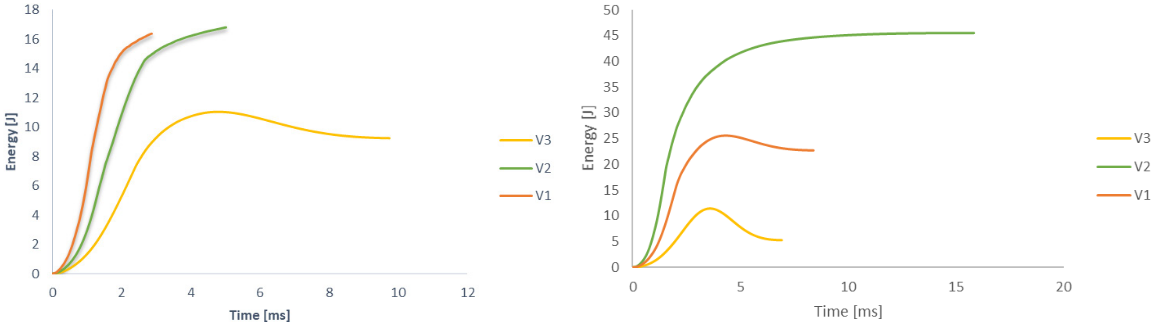

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Figure 6: Energy–time history for both impactors, at tested velocities: a- Spherical impactor of 10 mm diameter; b- Spherical impactor of 20 mm

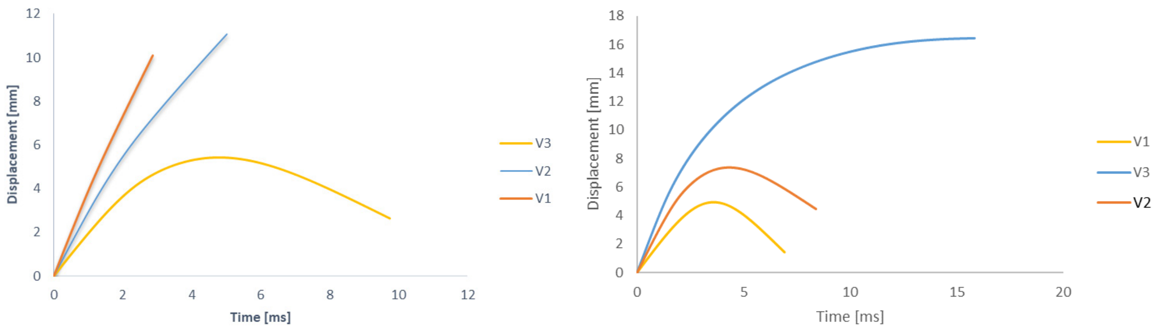

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Figure 7: Displacement–time history for both impactors, at all tested velocities: a- Spherical impactor of 10 mm diameter; b- Spherical impactor of 20 mm diameter

4.2. Potential Applications of these Materials

Composite systems with quadriaxial fibers offer enormous promise for usage in applications, including vehicle and armor systems, due to their ability to fulfill crucial design objectives, such as high strength, reduced weight and improved damage tolerance. These materials might also be employed in other impact protection applications, such as helmets, sports equipment, and blast-resistant constructions. Specifically, they can be used for mitigating the impact effects and improving their impact resistance of the structures.

These materials might be used for a variety of purposes, including:

- aircraft: due to their favorable characteristics, superior fatigue resistance and low moisture absorption, glass fiber epoxy composites are frequently employed in aircraft applications. They are found in airplane constructions, engine parts, and interior panels,
- automotive uses glass fiber epoxy composites for lightweight, high-strength components, including body panels, structural supports and suspension components,
- sporting equipment: due to its high strength, stiffness, and durability, glass fiber epoxy composites are extensively used in sporting equipment such as tennis rackets, bicycles, and golf clubs,
- nautical: because of its resistance to moisture, corrosion, and UV radiation, glass fiber epoxy composites are employed in maritime applications. They are utilized in the construction of boat hulls, decks and other structures,
- construction: bridge decks, reinforcing bars and structural components are some of the uses for glass fiber epoxy composites in construction. They are extremely strong, durable and resistant to weathering and chemical assault.

5. Conclusions

The article emphasizes the significance of understanding the impact behaviour of glass fiber epoxy composites in order to ensure the safety of various engineering systems. The study uses experimental methodology to offer an examination of the impact behaviour of designed composites.

Understanding impactor load-time histories is critical for assessing the forces generated during impacts. This information is useful in a variety of domains, including material science, vehicle safety and biomechanics. The load-time histories of 10 mm and 20 mm impactors subjected to different impact velocities are analysed in this work to obtain insights into the dynamic response and emphasize the influence of impactor size and velocity on the load-time curves.

The study findings indicate that this glass fiber epoxy composite has outstanding impact resistance, making it appropriate for use in high-stress situations, where safety is of the highest priority.

Engineers may develop safer systems that can endure high-stress circumstances by knowing the impact behaviour of these materials.

Overall, the work offers useful insights of glass fiber epoxy composites impact characteristics and underlines the significance of continuing research in this field to enhance the safety and disponibility of engineered systems.

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