Low Velocity Impact Behaviour Analysis of Different Fibre Stacking Sequences of Glass Fibre Reinforcement Composite.

Jing Wen Wong¹, Chye Lih Tan¹*, Azaman, M D¹, Azmi, A I¹, Irina Wong Ming²

¹Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis, Kampus Tetap Pauh Putra, 026000 Arau, Perlis, Malaysia
²School of Engineering And Technology, University College of Technology Sarawak, No.1, Jalan Universiti, 96000, Sibu, Sarawak, Malaysia.

Abstract. Furthering understanding the damage deformation behaviour involved in the impact test of Fibre-reinforced composite material is important in designing for the structural components. Thus, this study presents the damage effect of different stacking sequence of glass fibre reinforce polymer (FRP) composite on low-velocity impact test (LVI). The glass FRP composites were fabricated using vacuum-assisted resin transfer moulding process, which is capable of producing constant thickness with high volume fractions of composite laminates as compared to the traditional wet hand lay-up method. The physical and impact properties were determined according to the ASTM D7137 standards. It was found that, bi-axial glass FRP composite can afford the energy until 90J and without the post perforation occurred, which mean that from the LVI test, the architecture weave of bi-axial glass FRP composite was showed high performance as compared to the unidirectional glass FRP composite. Lastly, component failures such as resin cracking, fibre breakage, fractured knit, fibre buckling, and delamination were also highlighted in this paper.

Keywords: Glass FRP composites, Low Velocity Impact, Stacking Sequences, Architecture

1. Introduction

Nowadays, glass fibre reinforced polymer (FRP) composite materials are considered as one of the cutting-edge material mostly implemented on the components of boats, aerospace structure and automotive parts which require waterproof, lightweight, high specific strength, and corrosion-resistant materials to prevent environmental attack [1]. Nevertheless, the susceptibility to damage from low-velocity impact is one of the top concerns in the application. When the low-velocity impact weighting is subjected, impact energy is absorbed with various failure mechanisms such as matrix cracking, fibre breakage/pullout, and delamination. Those failure mechanisms are caused by various incidences which comprising low energy impact loading, environmental factors, and damage during service life. Even though the damage is not visible on the part surface, they still showed the result in a reduction in the residual strength of a structure [2].

Impact velocities can be group into four types which are drop testing and pendulum testing for low velocity impact (LVI), ballistic testing for high velocity impact, intermediate velocity impact and hyper velocity impact. Normally, low velocity impact occurs at velocities below 10m/s and likely to trigger some dents and visible damage on the surface, such as matrix cracking, fibre breaking and also
delamination of the composite materials. Andrew et.al [3] have stated the important feature that affects the impact properties in composite materials which is the fracture toughness of the resin system. Brittle resin systems characterise low resistance to fracture onset and propagation. The fracture propagation resistance increased due to an improvement in the fracture toughness of the matrix. Under impact loading, a composite material having the absorb characteristic and dissipate a high quantity of impact energy in between a broad range of damage modes. When the damage level until up to the initial stage, most of the impact energy applied by the impactor are absorbed by the elastic behaviour of the structure. This absorbed impact energy capability is depending on numerous factors such as toughening of fibre, toughening of the matrix, toughening of the interface, the thickness reinforcements, selective interlayers and hybrids [4]. The chemical and mechanical behaviours of the fibres, matrices and interface affect the route in the deformation and fractures of the FRP composites. With the purpose to know well the effect of glass fibre stacking sequence on low-velocity impact behaviour, this paper aims to present the failure performance and effect of the architecture of fibre to the low-velocity impact test of biaxial and unidirectional glass FRP composites.

2. Material and experiment methods

2.1. Materials selection
The testing was conducted on glass fibres for biaxial and unidirectional glass FRP composite. The E-glass fibre with a mass of 200g/m², a density of 2.56g/m³ and low hardness were employed in this study. The epoxy EpoxAmite resin was selected as the matrix for this composite laminate which is suitable for the resin infusion process. All the fabrication materials were supplied by MechaSolve Engineering Sdn. Bhd.

2.2. Preparation of FRP composites
In this study, Vacuum Assisted Resin Transfer Moulding (VARTM) was used as the fabrication method to produce the bi-axial and unidirectional glass FRP composite owing to its high performance composite products and lower tooling and equipment cost [5]. Initially, the bi-axial and unidirectional glass fibre with a size of 300 mm x 300 mm were laid on a flat glass mould with vacuum bagging. Meanwhile, the combination of epoxy (EpoxAmite 100) and hardener (103 slow hardener) was prepared at a ratio of 4:1 and infused into the dry fabrics under a vacuum pressure of approximately 15 mbar. The wet panels were left cured for a minimum of 24 hours at room temperature. The glass FRP composite laminates were then cut into the required specimen size which is 100mm×100mm using a ‘water-cooled’ diamond saw for subsequent low velocity impact testing (LVI).

2.3. Low Velocity Impact Testing of Glass FRP Composite
The tests were performed using the IMATEK IM10R impact test machine based on ASTM D7137. This impact test machine has maximum impact energy which is control by the falling height (up to 1000mm) and fixed weight, 200N of the impactor. The impact test machine provides up to 94J of energy with an impact velocity of 4.34 m/s fully given by gravitational field. The function of the piezoelectric accelerometer is to determine the acceleration value of the impactor. For each impact, the total energy impact is determined by a balance translational kinetic energy of the impactor as

\[ E = \frac{1}{2} m (V_i^2 - V_r^2), \]  

Where E is the energy dissipated by the target; m is mass of impactor; Vi is incident velocity, and Vr is the residual velocity after rebound or perforation. In a case as specimen perforation, the friction between the target and penetrator would trigger a decrease in residual velocity, and this type of velocity is hard to measure accurately from the position signal. So that, the change in velocity, \( \Delta V \) is the yield from the integrated acceleration. Then the impact energy can be expressed in terms of the change in velocity and the initial velocity:

\[ E = -mV_i (\Delta V) - \frac{1}{2} m(\Delta V)^2, \]  

(2)
Where $v_i$ is the height from the position sensor and target and $\Delta V$ is calculated from the accelerometer signal. This solution can use for checking the accuracy of the accelerometer signal and good agreement is defined which less than 3% of the difference. A control panel was used to monitor the value of acceleration and falling height of the impactor automatically to produce the energy value during the impact test. Impact energy was measured from the displacement and acceleration signals. Therefore, incident energy can be derived based on the study of acceleration and height of the impactor by using Eq. (2) as assuming rigid body motion.

3. Results and discussion

Table 1 shows the value of peak impact force of biaxial and unidirectional glass FRP composite. The highest peak force for biaxial laminate is 17.7kN at 90J of energy impact which is higher than unidirectional laminate highest peak force, 13.4kN at 70J. Relationship between the impact force and contact impactor displacement for all specimens are showed in Figure 1 (a-d). Firstly, the impact force is showed in zigzag fluctuations pattern initially until up to the peak force. Then the impact force decreasing while the impactor hit the specimens and either the delamination or debonding matrix of composite laminates was formed. Secondly, after the peak force, two types of curve patterns are appeared in term of impactor displacement, resulted by the impactor either non-penetrated (post-penetrated, unidirectional laminate) or penetrated (biaxial laminate) which shows in Figure 1(d).

Figure 1: Impact force-displacement for biaxial and unidirectional laminate at (a) 40J (b) 70J (c) 80J (d) 90J
Table 1: The value of peak force of biaxial and unidirectional laminate.

| Energy Impact (J) | 40  | 50  | 60  | 70  | 80  | 90  |
|-------------------|-----|-----|-----|-----|-----|-----|
| Biaxial           | 13.3| 12.6| 16.4| 17.3| 16.3| 17.7|
| Unidirectional    | 9.5 | 11.3| 12.5| 13.4| 12.9| 11.4|

On top of that, it is noticed from Figure 1 (a-d) that unidirectional laminate displayed a stable progressive failure process while biaxial laminate displayed a progressive failure process with small fluctuation after the peak force. This might be due to the initial fibre fracture at the top surface area of those specimens and damage lightly after the impact test as shown in Figure 2. It is important to emphasize, only the biaxial laminate in Figure 1 (a) is showed a closed curve (showed in red circle) compared to the others. In the earlier studies [6-8,11], it has been revealed that the closed curve indicates the impactor did not penetrate the specimen and rebounded after hitting during the LVI test. While an open curved is presented the impactor has penetrated the specimens. Thus, the phenomena of closed curve indicated that the biaxial laminate is more susceptible to absorb more impact energy as compared to unidirectional laminate.

![Figure 2](image_url)  

Figure 2: The front and back surface for (a) Unidirectional (b) Biaxial laminate at 40J, 50J, 60J, 70J, 80J, and 90J.

With regards to displacement results, maximum displacement occurred due to the unidirectional laminate may not be sufficient to withstand the higher impact force from the testing and induced the penetrated phenomenon damage at the hitting zone. The most serious fractured knits have happened at 90J of unidirectional laminate which is shown in Figure 2 (a). Normally, serious delamination damages were observed at the surface and back of the unidirectional laminate. In Figure
3, it can be noticed that the component failures such as resin cracking, cross-shaped crack, fibre breakage, splitting of roving, and fractured knits on the hitting zone. In short, after the LVI test, the fewer component failures having at hitting specimen, the high performance of the specimen. Based on the result shown in Figure 3, much adversely damage have found on the unidirectional laminate as compared with biaxial laminate. It has been well documented that the unidirectional laminate, in which all fibres are arranged in one direction parallel to each other. Unidirectional laminate is highly heterogeneous because it can withstand the strength in the longitudinal direction of the fibre but being weak in the transverse direction. Hence, the unidirectional laminate is limited for multiple directional loading application. The biaxial laminate contains fibres overlapped with each other in +45° and -45° axes. This structure can improve the damage tolerance of the laminate on multiple axes. Therefore, the biaxial laminates tend to undergo different loading condition during their service life. Owing to the advantages of both laminates, unidirectional glass FRP composite suitable installed in a structure that needs to absorb load in the direction such as horizontal stabilizer and elevator at the tail of the aeroplane. While biaxial glass FRP composite is more suitable for the structure which is needed to withstand a very high impact load [7-11].

| Unidirectional | Biaxial |
|----------------|---------|
| 40J            | ![40J Unidirectional](image) ![40J Biaxial](image) |
| 50J            | ![50J Unidirectional](image) ![50J Biaxial](image) |
| 60J            | ![60J Unidirectional](image) ![60J Biaxial](image) |
| 70J            | ![70J Unidirectional](image) ![70J Biaxial](image) |
| 80J            | ![80J Unidirectional](image) ![80J Biaxial](image) |
| 90J            | ![90J Unidirectional](image) ![90J Biaxial](image) |

**Figure 3**: The cross section area of unidirectional and biaxial laminate after LVI test.
4. Conclusion
Low velocity impact (LVI) experimental test on glass FRP composites with different weave was carried out to understand the failure mechanisms within the structure composite material. The main conclusion draw from this study was the following: The architecture weave of biaxial glass FRP composite is presented a high performance in impact test as compared with the unidirectional glass FRP composites owing to biaxial glass FRP can withstand the maximum force of 90J and without post, perforation occurred. Obviously, component failures that can be inspected visually such as delamination, fibre buckling, fibre splitting and fibre breakage would have appeared on the biaxial and unidirectional specimen's surface after completed the LVI test.

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