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Article

Damage Behavior of Glass Fiber Composite Laminates for Different Stacking Sequences under Impact Drop Weight

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Abstract

Glass fiber composite laminates have attracted the interest of researchers all over the world due to their have outstanding applications in a lot of industrial fields. Toughness is a very important property in various applications. The current study gives a brief account of the effect of fiber orientation on the toughness of glass fiber composite laminates. Four different layups of stacking sequences [0] 4s, [0,90 ± 45] s, [0,90] 2s, and woven fabric are used. These laminates are manufactured using hand lay-up process technique. It is consisting of glass fiber as reinforcement material and epoxy as resin. Impact damage tolerance in composite laminates structures is a very active research topic. Drop weight impact test is applied to measure the depth of penetration through specimens' surface, therefore, the effect of fallen load on the topography of the specimen and damage will be noticed. The impact strength is nearly given the same behavior for the four stacking sequences at lower drop velocities, but the woven fabric sample shows a lower penetration depth when the drop velocity increases.

Keywords
Composite material, Laminates, Fiber glass, Toughness

1. Introduction

The composite material consists of two materials or more than and have two components: reinforced (particulates, fiber) and the matrix (ceramic, polymer, or metal). The properties of composites depend on the matrix, the fibers, and their interfacial compatibility. Composite laminate plays an attractive role in many industrial applications in the marine, aviation, and automotive industries (Cole, 1999). A comprehensive understanding of mechanical properties is of great intensity and importance, so it has been conducting a lot of research to investigate the mechanical properties of Fiber-reinforced plastics. The mechanical properties of glass fiber-reinforced polymer (glass fiber composite laminates) were presented in (Abdellah et al., 2015; Alharthi et al., 2020; Azzi & Tsai, 1965; Hassan, Abdellah, Azabi, et al., 2015; Mohamed K. Hassan, Abu El-Ainin H, 2013; Mohammed et al., 2014, 2015).

It is commonly known that an epoxy material shows brittle fracture behavior. Agrawal et al (Agrawal et al., 2014) acknowledged that brittle materials have a low energy absorption capability, which indicates a low impact resistance. Shah et al (Shah et al., 2019) noticed that woven fabrics show an increased impact resistance, as well as increased CAI damage tolerance. Andrew et al (Jefferson Andrew, Sivakumar M. Srinivasan, A. Arokiarajan, 2019) mentioned that Uni-Directional composite laminates show no effect of impactor mass at constant impact energy. Composites are classified as viscoelastic materials affected by fatigue as well as creep (Mohammed et al., 2014).

The fracture toughness of reinforced composite polymer was investigated in many works (Alharthi et al., 2020; Fouad et al., 2020; Hassan, Abdellah, & Marzouk, 2015; Mohammed Y. Abdellah, Mohamed K. Hassan, 2014). Fouad et al. (Fouad et al., 2020) mentioned the fracture toughness of epoxy resin reinforced with carbon fibers, Kevlar, and glass fibers for biomedical applications. The mechanical behavior under impact loading was studied by Abdellah et al. (Mohammed Y. Abdellah, Sulaiman S. Al Swailem, Ahmed Fathi Mohamed, Moataz Gomma, 2019). Delamination was considered as a damage type noticed in composite laminates (Tian Ouyang, Wei Sun, Rui Bao, 2021) Hassan et al (Hassan, Abdellah, Azabi, et al., 2015) presented the tensile and flexural strength of fiber metal laminate composite material based on aluminum under the static status of loading. Abdellah et al. (Mohammed Y. Abdellah, Sulaiman S. Al Swailem, Ahmed Fathi Mohamed, Moataz Gomma, 2019) performed the impact and relaxation loading of glass fiber-reinforced with epoxy. Stress relaxation is affected by the elastic and shear moduli of the matrix (Obaid et al., 2017). Ling et al (Liu et al., 2006) measured various curing cycles on the static three-point flexure and tensile strength of cross-ply laminates of stacking sequences [0,90] 3s. The vibration behavior of such a composite plate was investigated [20]. Giovanni and Roberto (Giovanni Belingardi, 2002) investigated the impact and dynamic behavior of glass fiber reinforced epoxy unidirectional and woven laminates. They used the drop weight fallen impact test. it was recorded the absorption energy and stored energy. It concluded that the considered materials, under the considered loading conditions, show no sensitivity to the strain rate effect. Abdellah et al. (Mohammed et al., 2015) investigated the mechanical properties of composite laminates with open holes under the tension of static stress. The effect of the geometry of the specimen with holes in the nominal tensile strength was studied. They extracted an analytical and numerical model to predict nominal resistance using the cohesive region model. Tien-Wei and Yu-Hao (Tien-WeiShyr, 2003) mentioned the impact behaviors of E-glass reinforced composite material. The test was applied using a drop weight fallen test. the results were based on fractography and recording the load history with time to measure the absorption of energy. Baucom et al. (2005) presented experimentally the damage performance of composite laminates using a repeating drop weight test. the test was performed on 2-D plain-woven laminates and 3-D orthogonally monolith ones. The results showed that the 3D composites had the greatest resistance to penetration and wasted more total energy than the other systems. Hoorn et al. (van Hoorn et al., 2022) elucidated the role of the thickness on the failure mechanisms under impact. Glass fibers give better impact behavior than carbon fibers at impact energies of 1.9 J to 2.7 J, while the impact behavior was more similar at impact energies of 2.7 J to 3.4 J (Abdellah et al., 2021).

Despite the valuable observations and conclusions of the previously mentioned experimental studies, there are still some fundamental issues that require attention in view of further development of glass fiber composite laminate structures. For instance, most studies focus on composites with a unidirectional reinforcement, while fabric reinforcements with toughened resin systems are being more extensively used nowadays for their increased impact damage tolerance. Therefore, the current study gives a brief account of the effect of fiber orientation on the toughness of fiber composite laminates by Measuring the depth of penetration through specimens' body and stored energy due to impact drop test for four different layups of stacking sequences [0]4s, [0,90 ± 45] s, [0,90] 2s, and woven fabric.

2. Materials and Methods

2.1. Hand Layup

The composite layer consists of epoxy as resin and glass fibers as reinforcement, reinforcer has stiffness, bending and strength properties, composite laminate is an assembly of several layers of fibrous composite materials as shown in Figure 1. There are several studies about the manufacturing techniques of laminate composite structures. The hand lay-up method (Hassan et al., 2015; Mohammed et al., 2014, 2015) was proved to be the most economical and the cheapest. In this manufacturing method, two glass plates are used in such a way that one of them is put like a base and is waxed with a release agent to prevent sticking. After that, this layer is coated by a layer of epoxy. Then, a layer of glass fiber is laid over and is impregnated with an epoxy resin. Then, glass fibers are placed on top of the epoxy resin layer to build up next layer, and the process is repeated until all laminate layers are formed and completed according to the build-up sequence shown in Figure 2, Figure 3 and Figure 4. (Table 1 show Mechanical and physical properties of glass fiber and epoxy resin). The specimens were manufactured out of eight square plates of approximately 800 mm length of the four tested materials of stacking sequence. The specimens were manufactured out of eight square plates of approximately 800 mm length of the four tested materials of stacking sequence. Later, the samples were cut automatically according to the dimensions required for the test. The laminates are manufactured in a stacking sequence [0]4s, [0,90 ± 45] s, [0,90] 2s, and woven of 8 layers. The laminates are manufactured in a stacking sequence [0]4s, [0,90 ± 45] s, [0,90] 2s, and woven of 8 layers. The volume fracture of the composite product is assessed using the ignition removal technique according to the ASTM D3171-99 standard (D3171, 2011). The average thickness of the produced plates was 5 mm for unidirectional [0] 4s, and quasi-brittle [0,90 ± 45] s, cross-ply [0,90] 2s and 3.6 mm for woven laminates.

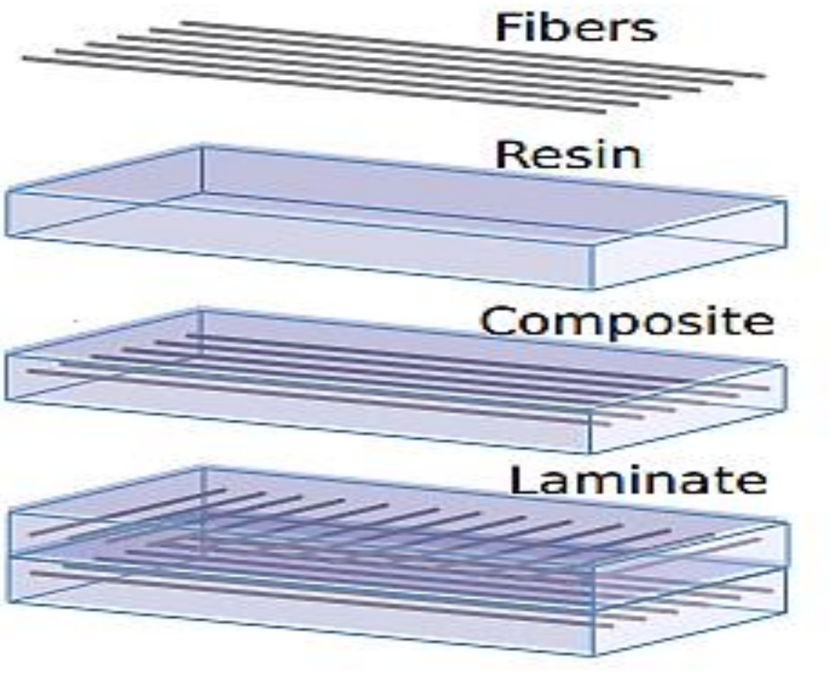

Figure 1. Schematic picture of a composite laminate (Jareteg et al., 2016)

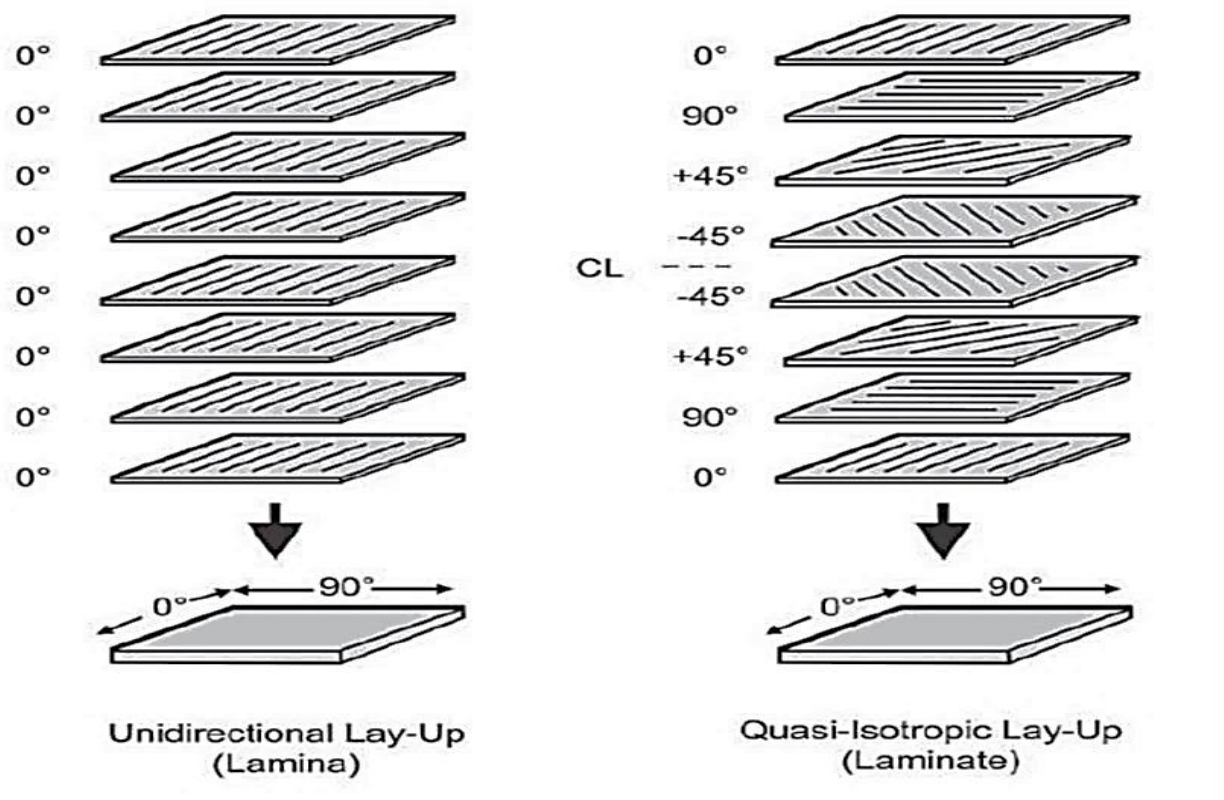

Figure 2. A Schematic sketch for different plies used in sample manufacture [0] 4s and [0,90 ± 45] s (W.J. Cantwell, 1991)

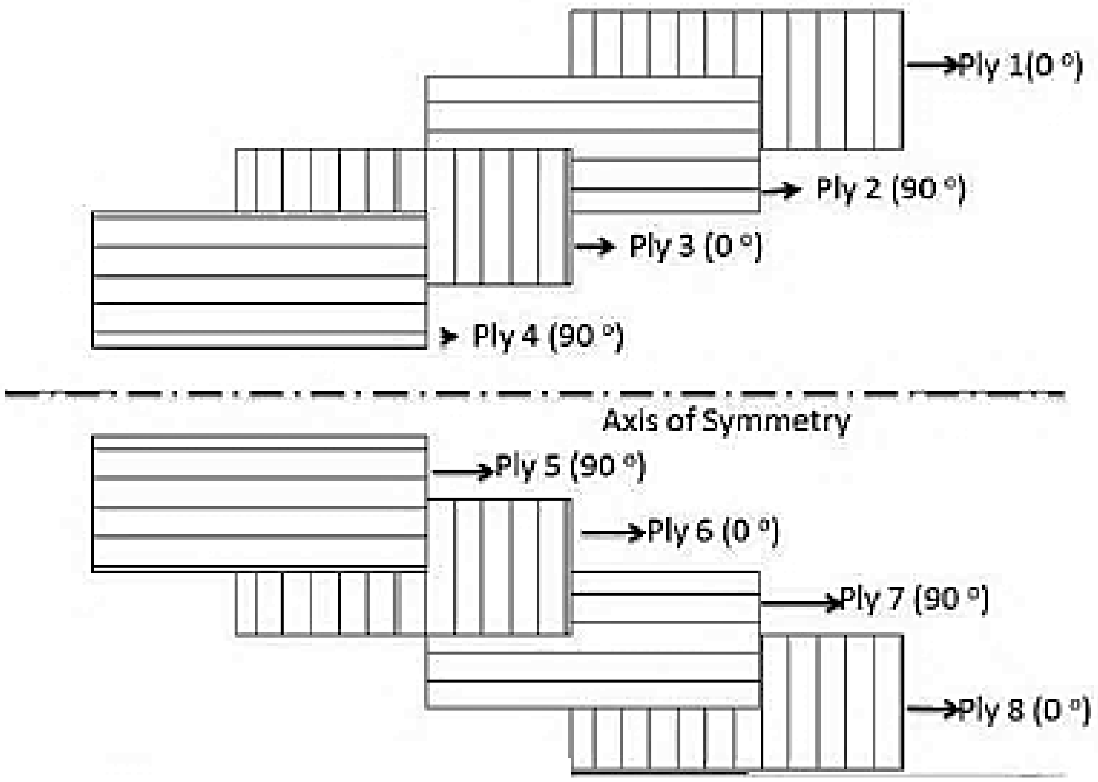

Figure 3. A Schematic sketch for different plies used in sample manufacture [0, 90] 2s (Mohammed et al., 2014)

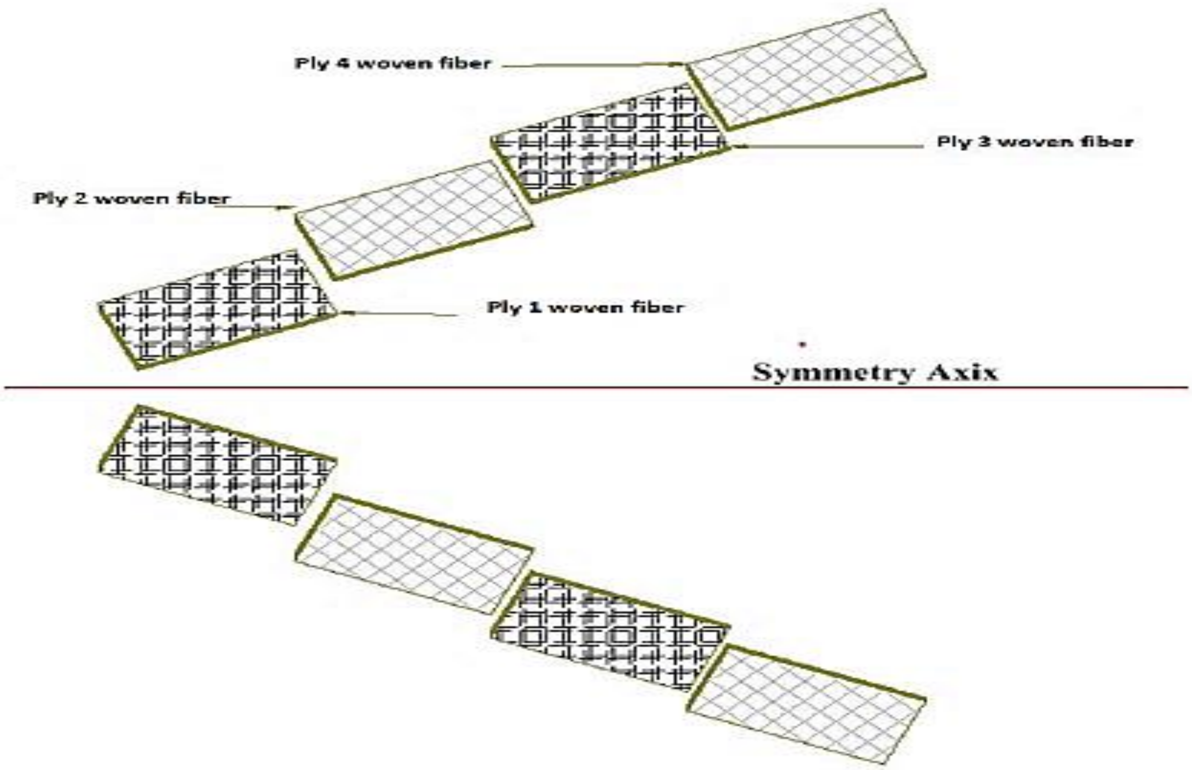

Figure 4. A schematic of the different woven plies used in sample manufacture (Abdellah et al., 2021)

Table 1. Mechanical and physical properties of E-glass fiber and epoxy resin (Mohammed et al., 2014)

Properties	E-glass	Kem poxy (150RGL)
Density, kg/m^3	2620	107±2
Tensile strength, MPa	3400	50-100
Tensile modulus, GPa	73	1.2-4.5
Passion ratio	0.21	0.35
In-plane shear modulus	30.8	1.24

2.1 Drop Weight Impact Test

Glass fiber composite laminates have outstanding applications in a lot of industrial fields such as aerospace, transportation and building structures due to their low specific density high specific strength and modulus, and corrosion resistance. To achieve the best design of such material, it is necessary to perform standard tests and find out their mechanical properties. Toughness testing, such as impact testing, is an important test of fiber-reinforced plastics that are usually used to determine the material's ability to absorb energy. Although Charpy and Izod are the most common ways of impact test, they have several restrictions including the necessity of using the notch in the specimen and limitation on the magnitude of the applied load. Another method called drop weight impact testing (DWIT) (Lu et al., 2012) can be used in the impact test. This method is based on an energy absorption capacity of materials is measured by dropping a weight onto the specimen. Under impact load, the composite material demonstrates different responses in comparison with metals. While metals under impact loads show a rapid elastic response followed by protracted plastic deformation, in composite materials, the elastic response is followed by different modes of failure that occurs in specimens such as delamination, matrix cracking, and breaking in fiber. This could be attributed to that impact energy in metals is absorbed by plastic deformation, while the energy in composite materials is absorbed by different modes of failure (Fathollah Taheri-Behrooz, & Mahmood Shokrieh. 2013).

Simple drop weight impact tester. It contains two long steel rods bolted over a rigid steel plate; the upper end of the rods restricted by a flat steel beam. A cross steel head connects the impactor to the two steel bars, this cross-steel head was made so that allow release and slides vertically over the two rods with the impactor pin to free fallen into the sample's surfaces. The depth of the indentation through the specimen surface due to pin penetration is measured. Impact time and distance of the fall are used to calculate the velocity of the falling, kinetic energy is calculated from the velocity of the falling and mass. The law of conservation of energy is applied to get the value of the energy absorbed in the samples The material absorption of energy is measured using the depth of penetration. The indentation depth is a measure of the energy absorption through the composite material. The specimens were cut with square sections of 40 mm length of the four tested materials of stacking sequences. Three different heights are used 0.5, 1, and 1.5 meters for each 1 and 2 Kg load.

3. Results and Discussion

Show in (Figure 5 A-D) impact velocity of different fallen loads (1 kg and 2 kg) at different fallen distant (0.5 m,1 m and 1.5 m) over the surface different layups of stacking sequences A) [0]4s, B) [0,90,±45]s, C) [0,90]2s, D) woven fabric of glass fiber composite laminates reinforced epoxy. From this figure we can notice that the depth of the penetration into the thickness of specimens increases with increasing velocity of the falling, this is due to increase of impact movement energy ($K.E=1/2\ m\ v^2$) which some of this energy is stored through the specimens in form of crack depth, and others energy went as noise and temperature. The penetration depth for all specimens is shown in Figure 6-8 for different layups of stacking sequences 1) [0]4s, 2) [0,90,±45]s, 3) [0,90]2s, 4) woven. As shown from the figures, the penetration depth increases directly with an increasing load than, Also the velocity increases with increasing load. The depth of indentation may be taken as a measurement of the stored energy through a material. Therefore, laminates for the four stacking sequences nearly give the same behavior. When using a load of 1 kg and a fall distance of 0.5 m, the samples with the lowest penetration depth were [0]4s (unidirectional), with the increase in height of fall and thus the increase in the fall velocity the less penetration was in the samples [0,90,±45]s and woven samples. But when the load is doubled to 2 kg and the fall distance was 0.5 m, the penetration was less in the samples [0]4s as well, but with the increase in the fall distance, the woven samples had less penetration depth. from the previously mentioned, we can note that composite laminates for the four stacking sequences nearly give the same behavior at the low velocity, but with an increase in falling velocity woven samples show a smaller penetration depth.

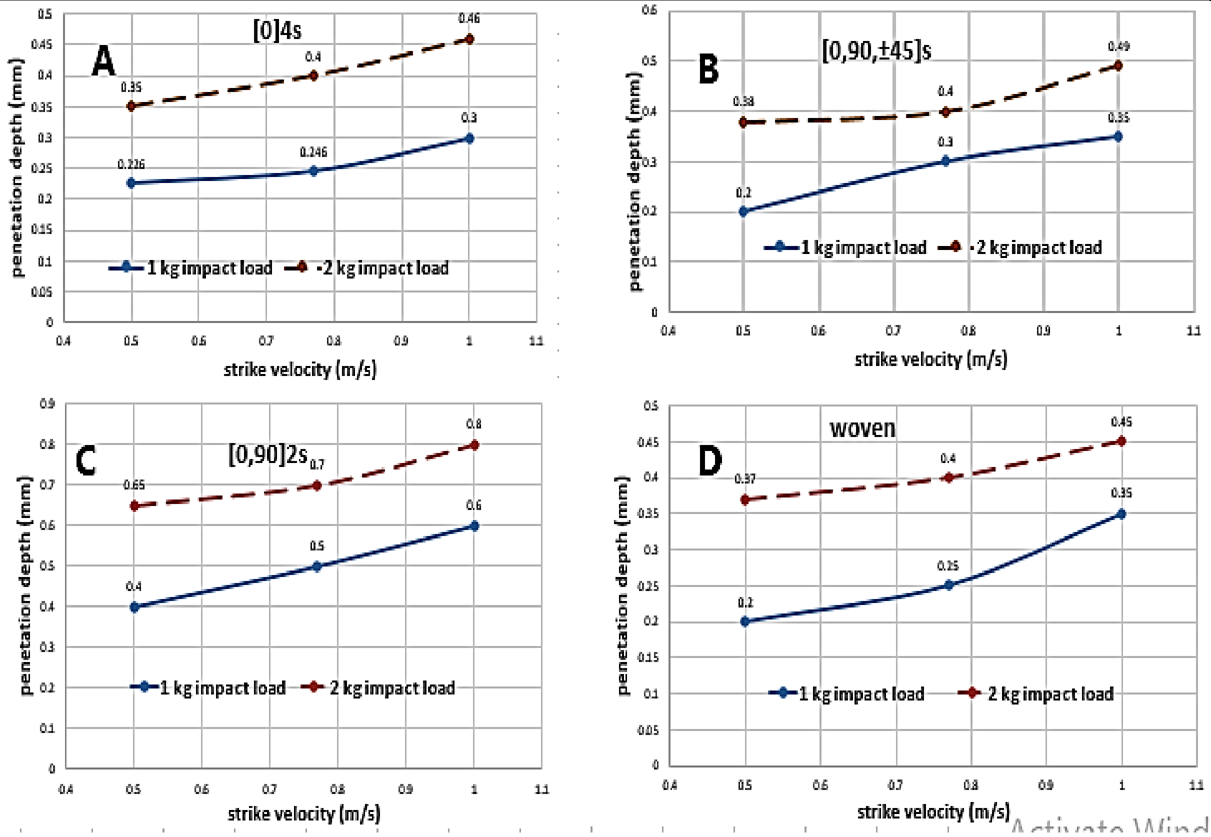

Figure 5. penetration of damage variation with impact strike velocity for A) [0]4s, B) [0,90 ± 45] s, C) [0,90]2s, D) woven

Figure 6. Damage surface depth through surface for: (1) [0]4s, (2) [0,90 ± 45] s, (3) [0,90] 2s, (4) Woven a) when h=0.5 m and m=1 kg, b) when h=0.5 m and m=2 kg

Figure 7. Damage surface depth through surface for: (1) [0]4s, (2) [0,90, ±45] s, (3) [0,90]2s, (4) Woven a) when h=0.1 m, m=1 kg, b) when h= 1 m, m=2 kg

Figure 8. Damage surface depth through surface for: (1) [0]4s, (2) [0,90 ± 45] s, (3) [0,90] 2s, (4) Woven a) when h=1.5 m, m=1 kg, b) when h =1.5 m, m=2 kg

4. Conclusions

Glass fiber composite laminates have many excellent and competitive properties. Impact tests are used to study failure modes of composite laminates. In this study, the impact test was performed by using two different loads and three levels of drop for four different layups of stacking sequences. It was found that the velocity of the fall increases with the increase in height, also the velocity increases with increasing load. depth of the penetration into specimens increases with the increasing velocity of the falling. The penetration depth increases directly with increasing load. The depth of indentation may be taken as a measurement of the stored energy through a material. Composite laminates for the four stacking sequences nearly give the same behavior at the low velocity, but with an increase in falling velocity, a woven samples show a smaller penetration depth although its thickness is less, which gives lighter weight. In all samples, the failure did not reach the bottom side.

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الملخص العربي

سلوك الضرر لرقائق الألياف الزجاجية المركبة لتسلسلات التراص المختلفة تحت تأثير سقوط الوزن

احمد سلامة [1]، محمد عبد اللاه[2]، أبو الحجاج سليم[3]، محمود سالم[1]، جمال عبدا لجابر[2]

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اجتذبت رقائق الألياف الزجاجية المركبة اهتمام الباحثين في جميع أنحاء العالم نظرًا لتطبيقاتها المتميزة في الكثير من المجالات الصناعية. المتانة هي خاصية مهمة جدا في مختلف التطبيقات. تقدم الدراسة الحالية سرداً موجزاً لتأثير اتجاه الألياف على صلابة رقائق الألياف الزجاجية المركبة. يتم استخدام أربع مجموعات مختلفة من متواليات التراص [0] 4 متواليات، [0.90، ± 45] متوالية، [0،90] متواليتين، والقماش المنسوج. يتم تصنيع هذه الشرائح باستخدام تقنية التصنيع اليدوي. وتتكون من الألياف الزجاجية كمادة تقوية والأيبوكسي كراتنج. يعتبر تحمل الضرر الناتج عن الصدم في هياكل الرقائق المركبة موضوع بحث نشط للغاية. يتم تطبيق اختبار تأثير سقوط الوزن لقياس عمق الاختراق من خلال سطح العينات، وبالتالي، سيتم ملاحظة تأثير الحمل الساقط على تضاريس العينة والضرر. تُعطى قوة التأثير تقريبًا نفس السلوك لتسلسلات التراص الأربعة عند سرعات السقوط المنخفضة، ولكن عينة القماش المنسوج تُظهر عمق اختراق أقل عندما تزداد سرعة السقوط.

الكلمات المفتاحية
المادة المؤلفة، الشرائح، الألياف الزجاجية، الصلابة