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Hybridization influence on the mechanical properties of hybrid composite laminates: A review

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Abstract Due to the continuous change in environment, a researchers struggle to explorer their potential of natural and synthetic fibres along the wide diversity of industrial applications, through developing of the advanced fibre supported by fibre plastic composite to displace conventional metals and alloys. The current study aims to develop the on going researches through exploring the use of fibres as an alternative substance entered strongly in the production lines, and to investigate the hybridization on the mechanical properties of composite parts. This leads to describe the proposed structure in composite parts engaged with carbon, kevlar, glass and basalt fibres. The modeling and analysis of the components are carried out using finite element method. This analysis is permit to allow for examining and studying the effect of vibration and stress induced in the composite and allow to focus deeply into mechanical response.

Keywords:. composite materials; fibers; matrix; hybrid.

1 Introduction

Composites are materials composed of two components: reinforcing fibres and a matrix. High strength and stiffness are displayed by the resulting composite when the fibres bear the majority of the load.

In order to obtain best quality for the harnessing of composite components, a combination of reinforcing fibres and matrix are carried out through minimizing their drawbacks. Which the resistance to deformation for the binding components are identified from ensuring the connecting between matrix and fibres together, also the connection outsides has significant influences due to binding the shields with fibres, as the last improve strength and stiffness [1].

In aircraft sector, high advantage can be obtained from the composites ratio of high strength to weight, which helps to assist for creating composite structures that attributed to have light weight, good strength as well as longevity. Minimising weight may result to keep fuel efficiency within acceptable level, reducing the cost of operation and also enhanced the overall performance. Further, good resistance to environment with low corrosion and fatigue can be specified by performing composites. That's leading to increase reliability of manufacturing structures and components [2].

The composite parts of aerospace industry are manufactured in a special condition to have proper factors that is already required to increase the efficiency of the designed aircraft systems. Hyper design of composite parts are preformed for multiple types of fibres such as glass, basalt, aramid as well as carbon to improve strength and allow for providing good mechanical characteristics [3].

A "hybrid composite" is a term that is frequently used to describe a composite that contains two or more different types of fibers." Hybrid composites can offer enhanced properties by leveraging the unique characteristics of each fiber type. By combining different fibres, it is possible to tailor the composite's performance to meet specific requirements.

Hybrid composites can be divided into a number of categories. There are three typical categories::

1. Fiber-reinforced composites: These composites consist of a matrix material reinforced with different types of fibres. The fibres carry the majority of the load, while the matrix provides support and protection.

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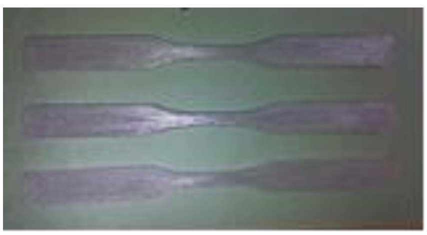
2. Particle composites: In these composites, particles of different materials are dispersed within a matrix. The particles contribute to the composite's properties, such as enhanced strength or improved thermal conductivity.
3. Structural composites: This category encompasses composites used in structural applications. It includes a wide range of composite configurations, such as sandwich composites, laminate composites, and hybrid laminates.[4]. The figures 1 below shown the three types of composite materials.

(a)



(b)

(c)

Fig. 1 Types of composites materials: a-fibre-reinforced composite ,b-particle composites, c- Structural composites

The efficacy of polymer composites is heavily reliant on the interface between the fiber and matrix, as indicated by several research studies [5, 6], wherein poor bonding among the matrix and fiber leads to a low inter laminar shear of strength [7]. Besides, the presence of voids or moisture in composites . For instance, in carbon with epoxy composites, an ILSS reduction of approximately 25% is observed when the void content is approximately 10% of the volume [8]. Moreover, the inter laminar shear strength is significantly influenced by the type of fiber and its orientation . Thus, hybridization is a viable approach for enhancing the inter laminar shear strength[9].

It has been discovered that the mechanical behaviors of fiber-reinforced in polymer composites exhibit varying degrees of rate-dependency, ranging from positive to negative, as well as rate-insensitive behavior. This may refer to such several factors such as composite system, type of fibers, matrix, type of load, the range of test and the direction of loading. These factors are confirmed by many studies [10-15]

Using a combination of different fibers may result to address the limitation of individual composites through motivating of hybrid composites. Increase the strength of the fibers and reducing its weakness for such a new materials is consider to be the main goal. This in fact have several advantages such as low cost of materials and improving of mechanical properties. Therefore, this study aims to investigate the effect of hybridization for the properties of fiber composite laminate. The research provide good model for testing the structure, has capability of understanding how to perform different treatments of fibers that directly affect the properties of hybrid fiber composite laminate.

2 Literature survey

The article written by N. Rachchh and D. Trivedi concentrated on examining the vibration analysis of hybrid composites that are comprised of glass and bagasse fibers. Its main objective was to scrutinize the mechanical properties of composite plates that are produced by combining glass witn bagasse fibers, bound by polyester resin. Both practical experimentation and analytical analysis were employed to conduct the research. The hand-lay-up approach was utilized to construct composite plates with varying bagasse fiber weights. Mechanical and vibration characteristics of these plates were analyzed in the study. The authors' main conclusions are:

1. The mechanical properties of hybrid composites improve with an increase in bagasse fiber weight percentage, indicating enhanced overall performance and strength of composite plates.
2. Among the tested weight percentages, 9% bagasse fiber content yields the optimal mechanical characteristics for composite plates as shown in figure 2. Therefore, the composite composition with 9% bagasse fiber content achieves a favorable balance of properties, resulting in improved performance.

3. The highest natural frequency vibration occurs in composite plates with 9% weight of bagasse fiber, indicating better stiffness and rigidity.

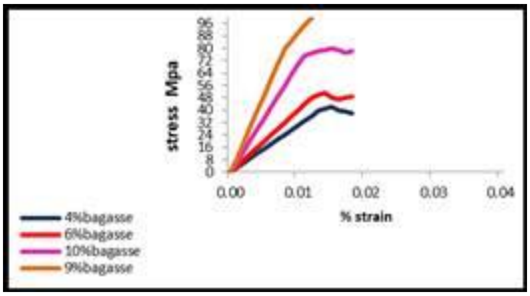


Fig. 2 Results of tensile test for composite materials reinforcement with different fibers.

Overall, the findings of the study suggest that the incorporation of bagasse fibres in hybrid composites alongside glass fibres can enhance the mechanical properties and vibration behaviour of the composite plates. The specific weight percentage of bagasse fibres (9%) is identified as the optimal composition for achieving improved mechanical characteristics and higher natural frequency vibrations.[16]

T. Sebaey and Ahmed Wagih conducted a study comparing two hybridization methods: sandwich laminate (SL) and inttraply laminate (IL). The research aimed to examine the impact of hybridization on the bending strength of laminates composed of carbon and Kevlar fibers.

The hybrid carbon/Kevlar laminate was fabricated using the resin transfer molding technique. The researchers examined three lay-up methods, including Kevlar laminate (AL) and interplay laminate (IL). The findings of the study are as follows:

1. The technique used for hybridization had an effect on the bending strength of laminates, leading to varied flexural behaviors. This indicates that the selected hybridization method can alter the properties and performance of laminates.
2. Sandwiched and intraply laminates have different failure modes and damage patterns, depending on the hybridization technique used. The laminates have a gradual failure mode, while the intraply laminates have severe damage.
3. The hybrid laminates showed a 1.3 times increases in specific strength compared to non-hybrid laminates. This indicates that the combination of carbon and Kevlar fibers improved the strength-to-weight ratio.[17]

Another study contributed by Ary Subagia et al, confirms the examination of bending for carbon and basalt fibres based on a difference stacking configurations. The study declared its objectives through investigate on the performance of carbon composite bonded with basalt fibres in individual manner, this will results to minimize reliance and allow for promoting use of carbon composite in hybrid laminates.

The productivity of fibres are carried out on using vacuum assisted resin transfer modeling (VARTM) technique, and the surfaces were examined using (SEM). This leads to following observations such as:

1. Effect of Stacking order: stacking process of fibres carries many benefits that is significantly enhanced bending strength and laminated. The overall mechanical behaviour of such hybrid lamination can be obtained through identified from the proper arrangement of carbon with basalt fibres together.
2. Flexural resistance: the flexural resistance of carbon fibres shows increase due to the influence of hybrid composite laminates on the compressive side. It is suggested that this arrangement may leads to enhance the resistance of the composites relative to the bending forces.
3. Influence of stacking: The study demonstrated that the appropriate stacking of the hybrid laminates resulted in improved mechanical characteristics, including enhanced bending strength.

In summary, both studies highlight the impact of hybridization techniques on the me properties and performance of composite materials. The choice of hybridization method and the arrangement of fibres within the laminates can lead to variations in bending strength, failure modes, and overall mechanical characteristics. Proper hybridization and stacking configurations can result in improved properties for hybrid composites [18].

The low speed of the resistance to impact in fiber composites comprised of fiber' types was examined by Dingdong et al. in their publication. It was discovered that: Due to their brittle nature, carbon layers were shown to exhibit significantly lower impact resistance than basalt and glass layers. On the other hand when put through the same impact test, the latter two displayed nearly identical performance. It was discovered that the three layers' placement within the laminate affected how impact-resistant they were. Also, when the carbon fibers were at the center of the object, the most energy was measured. and Weave fabrics showed lower deformation to unidirectional fabrics [19].

Somen K. Bhudolia et al. used a variety of experiments, including impact testing and vibration analysis, to explore the performance of hybrid composites. Kevlar in weave, and E-glass fibers are combined to form hybrid laminates. The composite with a higher percentage of Kevlar performed best in flexural and bend strength testing. The glass layer with the most layers demonstrated superior impact resistance. Peak load was higher in the material with more Kevlar.

The findings included:

1. It was discovered that the introduction of Kevlar fibers improved the hybrid composite structure's damping characteristics and natural frequency.
2. It was discovered that the amount of Kevlar fibers utilized directly increased the bend strength.
3. The fabric count affected the impact resistance.[20]

At various temperatures, the mechanical properties of glass with carbon hybrid composites was examined by Srinivasu Dasari et al.. The behaviour of glass with epoxy, carbon with epoxy, and glass with carbon were examined to gain a better knowledge of the behaviour of composites. This behaviour was investigated because it was discovered that the tensile performance deteriorated with respect to temperature rise. Tests were done on the samples at three distinct temperatures: 300, 700, and 1100°C. It was discovered that the increase in temperature had an impact on the tensile properties of the composites. Following are the conclusions from the study;

1. It was discovered that replacing the glass fibres by two carbon layers of fibres at the top of the glass with epoxy increased the elasticity at 300 and 700.
2. When carbon fibers were used in place of the glass fibers, pseudo ductility was discovered.
3. The glass fiber with epoxy composite displayed superior hybrid characteristics at 1100°C when a glass fiber was replaced with a fibers carbon [21].

Vibration analysis was done on a hybrid composite made of glass, carbon, kevlar, and epoxy by Pruthwiraj Sahu et al. . The specimen was transformed into a panel with a curvature. The hybrid composites were constructed by hand layup. On the vibrational behavior of the hybrid fibers composites, the effects of several design parameters, including thickness ratio, variable geometry, variable supports, and curvature ratio, were investigated. Five different sorts of specimens were created. They are (2 glass and 2 carbon), (3 glass with 1 carbon), (2 glass, 1 carbon, and 1 kevlar), and (4 kevlar layers), in that order. From the research, the following conclusions were made:

1. For all hybrid composites, it was discovered that frequency decreased with increasing aspect ratio. With an increase in aspect ratio, this overall stiffness decreased.
2. It was discovered that the natural frequency decreased as the thickness ratio increased. This is because the laminate becomes less stiff as its thickness decreases.
3. The curvature in both the longitudinal with transverse directions of the spherical geometry caused it to exhibit the maximum frequency. It became stiffer due to its curvature.
4. The support condition with the gretest natural frequency was the CCCC (cylindrical). The quantity of DOFs limited has an impact on the laminates' stiffness because the strength of the laminates reduced as the curvature ratio increased, it was discovered that the natural frequency fell as well. [22]

By adjusting the fiber orientation and stacking order, Srivathhsan A. investigated the mechanical characteristics of hybrid composite (glass with Kevlar). The specimens were made using kevlar 49 and E glass weave textiles. Fabrication took place using the most popular hand layup technique. Each of the three separate specimens, each made up of eight layers of fibers, had a different configuration.. ($G_2/K_2/G_2/K_2$), ($G_2/K_2/G_2/G_2$), and ($G_2/G_2/K_2/K_2$) were the stacking order. All of the specimens were oriented as (-45, 45/0, 90). The specimens were then subjected to static tests for tensile, flexural, and shear behavior. Additionally, a SEM microscope was used to examine the damage's degree. The findings were as follows:

1. The stacking order had no appreciable impact on the composites' tensile behavior, which can be attributed to the equal distribution of progressive loads across all layers.
2. It was discovered that the orientation of the fibers

had an impact on the composites' tensile behavior. However, under this circumstance, all of the laminates' flexural and shear strengths were nearly comparable.

3. For basic symmetry, the orientation angle of (-45, 45/0 , 90) demonstrated greater shear and flexural of strength.[23]

Erkliğ et al. studied the consequence of cutouts of the fixed-free condition with respect to the hybridization of woven composite beams in terms of their natural frequency values. To produce hybrid composites; Kevlar, S-glass fibers with epoxy and woven were utilized. For [(0/90) 3] S configuration hybrid composite beams, its natural frequencies of the were experimentally evaluated. On the other hand, numerical analyses were carried out to examine the impact of each; circular and rectangular cutouts and their length ratios and positions as well as the fiber orientation angles on natural frequency. With a slightly difference between the numerical and experimental results, the authors concluded that the natural frequency is strongly affected by the fiber type employed in the layers, beam' cutout position and size values.[24]

Quanjin et al. examined, using ABAQUS software, the free vibration analysis of kevlar/glass/epoxy resin hybrid composite laminates at various fiber hybridization. Using the 3D shell element and quasi-isotropic laminated composite; various models were evaluated in terms of mode shape and natural frequency. Furthermore, ANSYS software was also employed to increase the accuracy of the numerical results when the latest were compared with those from ABAQUS software. The results showed that element size i.e. mesh accuracy has a significant influence on the obtained results. On the other hand, the satisfactory agreement between numerical results, obtained from ANSYS software and the experimental ones can enhanced free vibration of composite laminates analysis [25].

In their study, I. Ary Subagia et al conducted survey to explore the flexural strength of the carbo with basalt fiber composites. The manufacturing process employed for these hybrid composites was the vacuum-assisted resin transfer molding (VARTM) process. The research revealed that the flexural strength was dependent on the amount of basalt fiber used and the positioning of carbon with basalt fibers within the composites. The results from the bend test on hybrid fiber composite laminates sho findings:

1. The bend strength was solely affected by the configration of the fibers.
2. Higher flexural strength was observed when carbon fibers formed the outer layer.
3. Consequently, the strength of bend is dependent on the property of the fracture at outer layers [26].

Masoud Khazaie and colleagues conducted a study on basalt with Kevlar hybrid composites to assess their impact resistance. The research involved subjecting the composites to a high velocity impact test using different velocities. To gain better insights, three distinct laminate specimens were fabricated: Kevlar with epoxy, basalt with epoxy, and a kevlar laminate. The study examined the effects of the three varying projectile velocities on composites with different thicknesses . The laminate fabrication process utilized the hand lay method.

The study's findings revealed two key conclusions:

1. Among the three specimens tested, the basalt with epoxy resin composite demonstrated the highest impact resistance.
2. In the case of the basalt-epoxy composite, failure consistently occurred along a straight line, with the length of this line increasing after each impact event.[27]

J. Tirillio et al. explored the resistance of the impact in a basalt with carbon composite by fabricating six different specimens using the hand lay-up method. The specimens included four hybrid composites: sandwich type and intercalated type. The study's findings included:

1. The composite laminates containing basalt fibers demonstrated a good ability to withstand high-velocity impacts.
2. Failure in the laminates was primarily due to debonding, whereas failure in the carbon composites was attributed to fracture, likely due to the brittle of carbon fibers.[28]

In another study by Christian N. and Dongwei Shu , the focus was on the vibration in delaminated multilayer beams. Delamination, a defect found in composites with many layers, is caused by inadequate adhesion between the layers of the composite structure. This defect can result from various sources, such as material discontinuities, or mechanical loads, and can lead to a reduction in the valuable properties that make these composites strong and stiff. The reduction in stiffness causes a decrease in the natural frequency, which can lead to resonance.

During the free vibration analysis of the specimens containing delamination, the following observations were made:

1. The stiffness in the delaminated area significantly influenced the frequency in the 'constrained mode'.
2. The 'free mode' frequency was primarily influenced by the weakest delaminated layer [29].

Çallioğlu et al., examined, numerically and analytically, using the Timoshenko beam theory, the effects of orientation angle as well as the delamination length on the symmetric composite beams’ natural frequency. Using contact element with finite element analysis in ANSYS software, a 2D model of the delaminated beams was carried out. With an almost negligible a difference between the numerical and analytical results, it was concluded that the change of orientation angle has an effect on the natural frequencies. Moreover, the beam delamination length decreases at higher natural frequency values.[30]

Another researcher Gha.I and S.A. study the mechanical properties of the epoxy foundation reinforced with carbon fibres (20 wt.%, 15 wt.%) and palm fibres in weight ratios of (5 wt.%), (10 wt.%). After conducting mechanical tests on the composite materials, tensile, creep and shock tests, the results were compared between the two types of composite materials. The results showed that the maximum stress, Young's modulus, and shock resistance of the composite materials reinforced with carbon fibre were greater than the composite materials reinforced with palm fibres, and that there was a convergence in the creep behaviour of the composite materials reinforced with palm fibre at the weight ratios (20wt.%) and the percentage (10wt. %) of palm fibres, while there is no such convergence for the rest of the weight percentages of the two material.[31].

S.A and Gha.I.The study includes an experimental of the production in polymeric compound material. The polymer strengthened with different sizes of glass powder and fibers. with various weight proportions of glass powder (10wt.%, 20wt.%, 30wt.%). After studying the mechanical properties of the manufactured models, which included compressive and tensile resistance. The findings demonstrated that 10% increases in the tensile strength of glass-strengthened powder led to the composite material becoming strong. The bonding strength between the base and the reinforcing material weakens, which causes the tensile and compressive strength to strength to decrease. As a result, the unsaturated polyester hardness values rise. Of the 20wt.% decrease in tensile and compressive strength, 30% is attributable to the insufficient amount of polyester used in gluing glass powder. however when the proportion of weight increases the 10wt.% glass addition results in a less solid rise [32].

3 Conclusion

Based on the findings of this comprehensive analysis, it is evident that fibers, whether natural or synthetic, have gained popularity as a viable substitute to other materials commonly utilized in industries such as metals and plastics. This is mainly due to their exceptional strength to weight ratio, which makes them highly applicable in sectors such as aerospace and automobile. Consequently, it can be inferred that the appealing characteristics that render fibers desirable include...

1. In comparison to metals, which are prevalent in nearly all industrial applications, they exhibit a superior strength.
2. In contrast to materials such as wood, metals, and plastics, they possess a lightweight quality.
3. The hybridization effect shows that the highest values of interlaminar shear strength (ILSS) are achieved for composites that incorporate carbon and glass fibers.
4. The damping properties of laminated hybrid composites are significantly influenced by boundary conditions, fiber configuration, and orientation angle.
5. The natural frequency of laminated composites is significantly impacted by hybridization.
6. The specific method of hybridization employed can have a profound impact on the mechanical properties and overall performance of laminates.
7. Optimal hybridization and stacking configurations can lead to improved properties in hybrid composites.
8. Delamination has a marked effect on the mechanical properties of hybrid composites.

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