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Influence of Varied Layer Counts and Fiber Dispersion on Composite Laminate Performance

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Abstract

Fiber-reinforced composites are widely used in a variety of global industries, including transportation vehicles, sports equipment, and spacecraft. The purpose of this research is to determine the effect of fiber distribution and layer count on the mechanical properties of woven fiber-reinforced composites by altering the layer count or fabrication process . The composite plates are manufactured by hand lay-up and infusion procedures. All composite plates undergo three mechanical tests: ultimate tensile strength (UTS), interlaminar shear stress (ILSS), ultimate flexural strength (UFS). Additionally, the microstructure of the laminates is analyzed to determine the fractal dimension (FD). It is revealed that the partition of fibers as determined by FD contributed significantly to the improvement of mechanical properties. Additionally, the usage of vacuum molds aided in the improvement of mechanical qualities. One could infer that all mechanical qualities are proportional to FD.

Keywords: *Fiber-reinforced, Fractal dimension, Infusion, Polymers Matrix Composite,*

NOMENCLATURE	
Vf	volume fraction
$ILSS$	Interlaminar shear strength (MPa)
UFS	Ultimate flexural strength (MPa)
UTS	Ultimate tensile strength (MPa)
FD	Fractal dimension

1. INTRODUCTION

Humans previously used straw with clay to make bricks. The use of clay alone has weak mechanical properties. However, mixing clay with straw gave better mechanical properties. Some said that straw prevented cracks from mud after a drought. For example, clay with straw was used to build houses in the thirties of the twentieth century. Using fiberglass and resins improved the mechanical qualities even further. As a result, it was used in the construction of boats and planes. Because of their superior properties, glass fibers have found employment in a broader range of applications. Other observed composite materials can take the place of conventional metal alloys. Even though composite materials are more expensive, the difference in low weight is noticeable. Every pound of weight saved by commercial jets is like saving a dollar a year. Total operating costs are hampered by high fuel costs. Less expensive operations increase the profitability of a commercial airline. Due to their low price, composite materials have played a limited role in aviation industry research because of their limited properties. Production engineers have the responsibility of ensuring that standards are followed, which is a vital factor in eliminating faults. Silica and oxides make up the glass fibers. This process, which involves melting the glass and passing it through a small aperture, is the most dispersed and has the second-highest concentration of glass fiber. Compounds comprised of graphite/epoxy fibers, for example, are frequently utilized in space structures as advanced fibers.

The impacts of several processing parameters on mechanical characteristics in fatigue and static tests have been explored, according to the literature [1]. For example, using nylon [4] and or natural fibers [5] carbon fiber [2] has been shown to increase the mechanical properties of the other forms of fibre. The woven fabric is one of the composite materials with numerous characteristics, including high specific strength and excellent formability. As a result, it's being considered for use in a variety of industries, including aviation, automobiles, and energy. Polymeric materials are mimicked in the form of woven ply linked with more than one layer of woven fabric. In the direction of accumulation, they are utilized in directions inside the plane, where pressure is applied during injection of the polymer with the weaving on each other [6]. The reinforced fiber composites' high mechanical qualities and low weight make them extremely versatile. Space structures, the automobile sector, and energy and marine domains are only a few examples of these application fields. High-performance materials with high strength-to-weight ratios, high stiffness, and improved fatigue performance are increasingly in demand. Fiber-reinforced cars have advanced rapidly as a result of this increase in mechanical property performance. Due to the broad use of the composite materials system, this quantity is employed in a wide range of applications, including private air transportation. It is a two-material composite made of a matrix resin (epoxy or other polymers) with fibers such as aramid (glass) and carbon (carbon fibers). Each material's size is determined by the criteria on which it is based as well as its manufacturing and distribution methods, as well as engineering guidance. The autoclave stage is not required for the infusion procedure. It is possible to accelerate the production rate of composite materials by skipping the autoclave stage during the manufacturing process. Also, in order to increase mechanical characteristics while also decreasing energy consumption, high-performance compounds need to standardize their autoclave. The size of fiber breakage is reduced when autoclaves are used. Due to the increased pressure created by employing autoclaves, it may also contribute to an increase in fiber volume fraction (Vf). Although the traditional autoclave plays an important role in enhancing autoclave treatment, the pressure at which it is used varies [7,8]. Recent years have seen an increase in the porosity of materials, as well as new features including high compressibility and extreme elasticity. As a result, the interior microstructure has undergone some changes [9]. Most people rely on simple fiber models, which take maximal stresses as their norm. There is a focus on friction-cohesive surfaces, which means that further tests are conducted to determine the compound's damage tolerance. Research teams have used image microstructure analysis in a variety of ways [11, 12]. This study focuses on the structure of the fibers in order to analyze the fiber structure and understand the influence of fiber distribution on mechanical characteristics. This approach may be superior to figuring out the fiber volume ratios manually. By being more precise, microstructure analysis differs from the common way of computing the fiber size ratio. Clarity, lower costs, and faster outcomes are all advantages.

2. EXPERIMENTAL WORK

A mold made of glass with a dimension of 400 x 400 mm was used in this study to produce composite plates. The cleaning liquid is applied initially to remove the mold. It was covered with a special wax to help prevent the mold from developing. Polyester and hardener are both included in the matrix, and the ratio is set at 100:1. The glass fibers are inserted in the glass mold, forming the glass structure. A specific form of cloth (peel ply) was applied to the glass fibers directly, as a cover. After the sample has hardened, the peel ply is removed. Polyester was mixed with toughened for three minutes with continuous stirring, after which the mixture was centrifuged for a couple of minutes. Vacuum pressure is used to fill the mold with resin, which hardens after a 24-hour wait. In order to meet the standard requirements, samples are chopped into pieces in a rectangular shape. Alternatively, composite sheets are made in a 399x399 mm glass mold. The cleaning solution was used to clean the mold for the first time. The mold was covered with a special wax to protect it from becoming scratched. The amount of fiberglass layers in each plate was based on the requirement. As the number of glass fiber layers in each plate increases, the thickness of the sample increases. The plate is made consistent in thickness by moving the matrix in all directions. A 24-hour period is required for every sample to entirely harden. The completed plate is prepared for testing according to the criteria. Figure 1 shows the intravenous infusion methods [1].

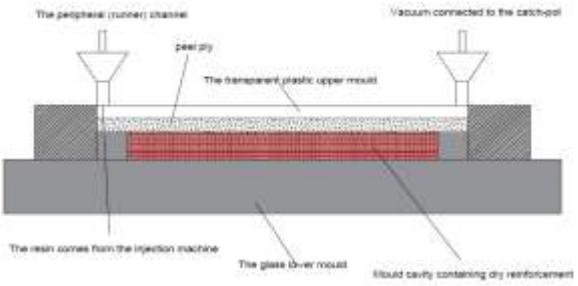

Figure 1: Intravenous infusion methods

3. MECHANICAL TESTS AND IMAGE ANALYSIS OF THE MICROSTRUCTURE

Eight panels of glass composite are created, with 3 layers, 4 layers, to the six layers for each production technique, hand lay-up and infusion this design has five layers for each production method, infusion, and hand lay-up. To investigate the Interlaminar shear strength (ILSS), ultimate flexural strength (UFS), ultimate tensile strength (UTS), and fractal dimension (FD), five test samples were cut from each of the four panels. The process demonstrated in Figure 2 involves utilizing image analysis tools to analyses over 100 photographs. Figure 3. depict the laboratory of testing and have been represent the high and low fiberglass respectively in figure 4 and figure 5

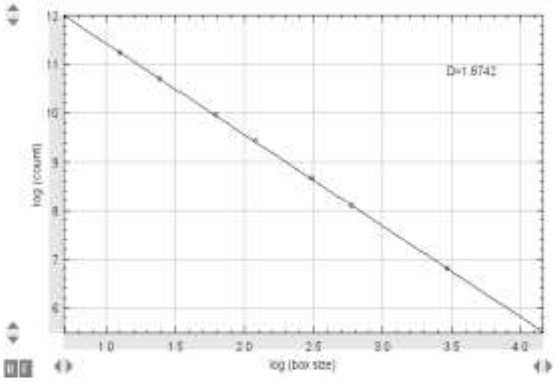

Figure 2: Fractal dimension determined by Image J

Figure 3: Processes of Polishing and Grinding

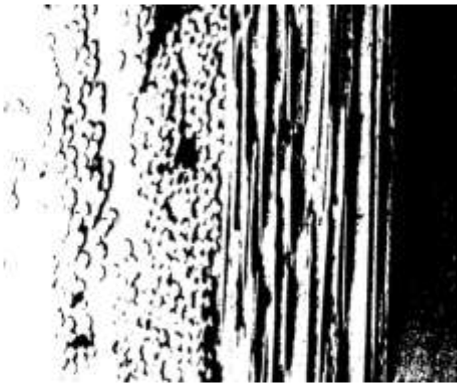

Figure 4: Fiberglass binary images of poor quality

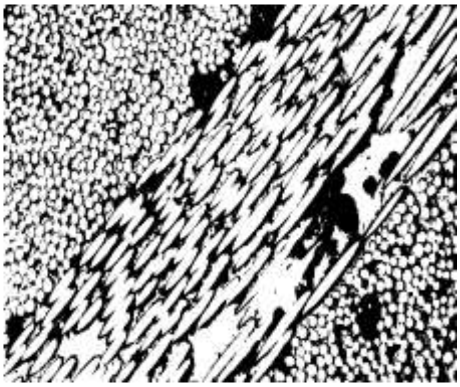

Figure 5: Fiberglass photos in high resolution binary

The test samples have been cutting from the composite plates in accordance with British requirements. The traditional method of cutting tensile samples from composite plates is prescribed by British standard (BS) EN ISO 527-5. It is done at a constant pace of one millimeter per minute. Each sort of plate that was found to be able to measure mechanical qualities was subjected to at least five tests. To verify that the sample is vertically fixed, the vertically measure is utilized. According to British standard BS EN ISO 14125:1998, the flexural strength of the composite plates is done. Dimensions (14 x 59) mm are used to cut composite samples. A total of five samples from each plate type were selected. The (ILSS) test is carried out in accordance with the British standard BS

EN ISO 14130:1998. To calculate the area of a composite plate sample, cut off a piece and divide it by the equation. Length is 10 times the thickness; breadth is 5 times the thickness.

In order to examine whether the properties observed (static) correlate with the microstructure that has been measured as a fractal dimension (FD), a correlation between the measured properties and the fractal dimension (FD) is sought. For each sort of plate that was made, more than five images are prepared. After being studied by the image analysis program, the fractal dimension is acquired from these photos. Higher performance is achieved as a result of greater uniformity in the dispersion of the fibers, and this is tied to enhanced mechanical properties for the composite films. Using the fractal dimension (R2) to describe the microstructure of the scale, where R2 equals one real number, and therefore it is possible to express the scale's dimension. Depending particular microscopic form can forecast the mechanical characteristics of woven fabrics in a shorter period and at a lower cost.

4. RESULTS AND DISCUSSION

Figure 6.a shows the number of layers against the ultimate tensile strength for hand lay-up. Tensile strength was the highest with the four plate layers. Due to the most even distribution of fiber throughout the layers, the layered plates are given a high UTS score, the UTS is shown to be proportional to the fractal dimension, and its relationship to fractal dimension is outlined by equation 1.

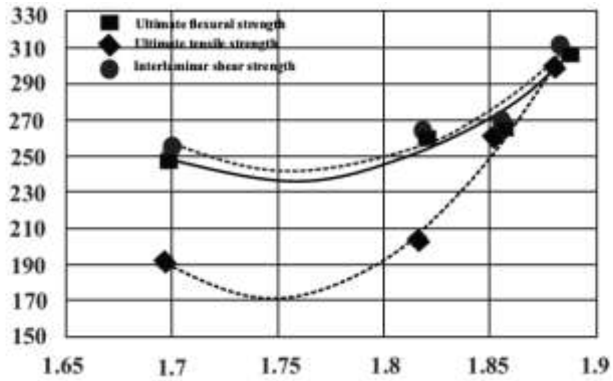

Figure 6.: Ultimate tensile strength and ultimate flexural and interlaminar shear against FD

$$UTS = 5010.3 + 1564.6FD^2 - 5512.6F \qquad (1)$$

Figure 6. showed how the ultimate flexural strength differed according to the number of layers when hand lay-up was employed. Flexural strength was provided by the plates in the four layers configuration. Higher UTS is measured by FD.

$$UFS = 12432 + 3945.1\,FD^2 - 13872.1FD \qquad (2)$$

The findings of the Interlinear Shear Strength have been verified and shown to be in agreement with the results of UFS and UTS, as shown above. Figure 6. shows the Interlinear Shear Strength and the number of layers used for hand lay-up are compared and illustrated. By studying the 4-layer plates, have been seen that they produced the highest value of Interlaminar Shear Strength, since the best distribution of fibers was used in making the 4-layer plates, as seen above in Figure6.illustrates the relationship between the ILSS and fractal dimension, while equation 3 depicts it graphically.

$$ILSS = 105.63 + 35.051FD^2 - 113.84FD \qquad (3)$$

Fiber distribution measured by FD results in the mechanical properties being proportional to it (percentage). Figure 7 demonstrates the ultimate tensile strength or tensile strength versus the number of layers. The ten-plate design with its tensile strength reveals that the five-layer plate structure produced the strongest outcome. The five-layer plates have a high UTS as illustrated in Figure 7 because of the ideal fiber dispersionuses a log-log scale to display the UTS, and in addition, the fractal dimension is shown alongside. It is proven that equation 4 is correct, as seen in the figure.

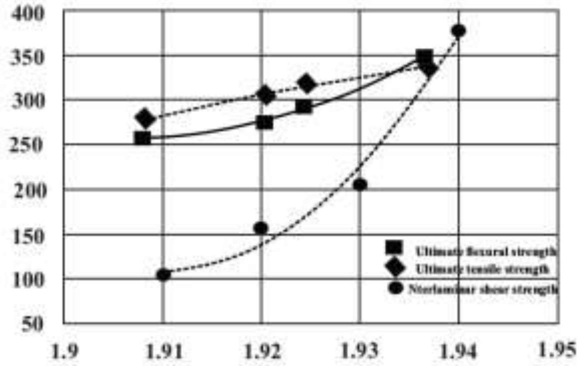

Figure 7. Ultimate tensile strengthand , Ultimate flexural strength and : Interlaminar shear strength against fractal dimension

$$UTS = 78122 - 19982FD^2 + 79162FD \qquad (4)$$

In Figure 7. have seen that four-layers plates resulted in the best flexural strength. As demonstrated in mentoined figures , the four layers' plates have a high UTS, with help to the optimal fiber dispersion. This chart highlighted just how proportional the UFS is and the relationship between it and fractal dimension is made clear

$$UFS = 626701 + 170870FD^2 - 654345FD \qquad (5)$$

The outcomes from the infusion process mirror those of hand lay-up. The results of UFS and UTS support the existence of interlinear shear strength. Figure7. showed the ILSS of the five-layer plates versus the number of layers and displayed the FD of the same sample, where it's proven that the five-layer plates yield a high value of ILSS because of the best fiber distribution of it, which is measured by FD. The relationship between the ILSS and fractal dimension is depicted by in Figure7.c.

$$ILSS = 10982 + 3017.5FD^2 - 11491FD \qquad (6)$$

In the infusion plates, such as ILSS , UFS and UTS , the mechanical qualities are greater than hand lay-up plate mechanical properties. A large factor in why the average distribution of the fiber is better when hand lay-up plates are used than in infusion plats is due to the fact that hand lay-up plates distribute the fiber better. Another way in which the Infusion process could aid to eliminate voids is by reducing them. Reduced mechanical qualities are possible.

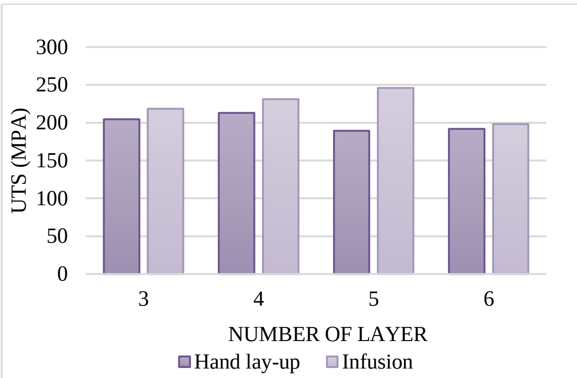

Figure 8: The number of layers against ultimate tensile strength

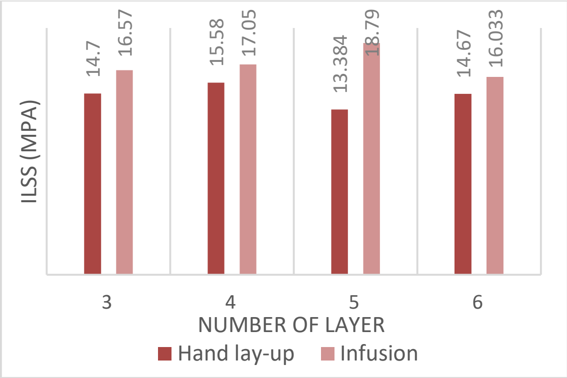

Figure 9: Interlaminar shear strength against the number of layers

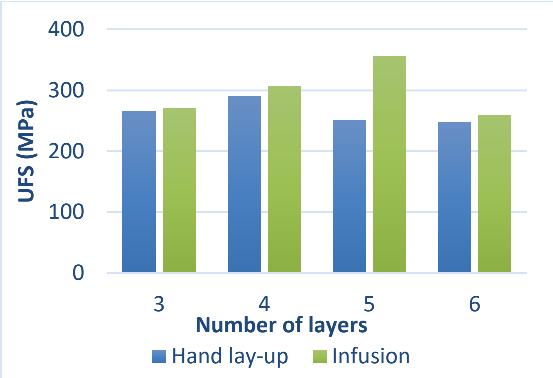

Figure 10: The number of layers against ultimate flexural strength

5. CONCLUSION

The mechanical properties are explored in this study where the impact of the fiber distribution and the quantity of different layers of fiberglass are taken into consideration. Hand lay-up uses three to six layers, depending on the project. In the infusion procedure, a similar number of layers are used. For all composite plates, three mechanical tests are run, including ultimate tensile strength(UTS) and Interlaminar shear stress. Furthermore, to further investigate fractal dimension (FD) microstructure analysis is performed on the laminates. It may be concluded that the FD-measured fiber distribution had a positive effect on mechanical parameters. The use of vacuum moulds also had a further role to play in increasing mechanical qualities. There are proportionate relationships between all the mechanical properties, FD included.

6. REFERENCES

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