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Effect of Number of E-Glass Fiber Layers on the Hardness of Fiberglass/Polyester Reinforced Plastics

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Glass fiber-reinforced plastics are an important composite material in the marine, automotive, and military industries due to their excellent mechanical properties, such as high strength, corrosion resistance and lightweight. This study aims to determine the effect of the number of glass fiber layers on the hardness of glass fiber/polyester composite materials. Random chopped strand mat glass fibers with a mass per unit area of 450 g/m² were used to prepare samples using the hand layup technique. The number of layers varied between 3 to 6 layers. The thickness of all samples is 3 mm. The Vickers microhardness device is used to measure the hardness, with a load of 50 g applied for a dwell time of 15 s. The results indicated that when increasing the number of glass fiber layers decreases the hardness values. The sample of three-layer listed the highest hardness value of 14.34 HV, while the values for the four-layer sample decreased to 11.42 HV, the five-layer sample to 9.72 HV, and the six-layer sample had the lowest value of 7.7 HV. This decrease in hardness is attributed to the increased number of interfaces between layers, which may lead to the appearance of weak points or air voids that affect the mechanical properties of the composite material.

1. Introduction

Due to their ease of fabrication and lower density compared to all other materials, polymers are of great importance as matrix materials. Polymers, particularly high-temperature resins, find appreciable use in high-speed aircraft and rockets, where composite materials are indispensable in electronic and aerospace applications. In reinforcing resins with fibers, most of the load goes to the fibers, and more so for weaker matrix systems like glass/polyester composites. The fibers themselves mostly provide most of the mechanical functions demanded by the composite [1]. One of the advantages of fiber-reinforced composite materials is their high stiffness and strength, which can be compared to or even surpassed by engineering metals. Their lower specific weight, added to the higher weight-specific strength ratios, makes them outperform metals. Also, a few composite laminates have better fatigue durability and damage tolerance than some metals [2-3].

Chopra et al. [4] studied the mechanical and physical properties, for the hybrid composite's which consist of fiberglass and plain weave copper strip mesh. The hybrid composite showed significant improvements compared to the GFRP composite: 16.357% increase in tensile strength, 29.019% increase in flexural strength, 55.55% increase in impact energy, 57.208% increase in density, and 13.846% increase in hardness. EL-Wazery et al. [5] developed an E-glass fiber reinforced polymer composites with varying fiber volume fractions using the hand lay-up technique. Mechanical properties improved significantly with increasing glass fiber content, including higher tensile and flexural strength, increased impact energy, and hardness. The best properties were observed at 60 wt.% of glass fiber. Alagarraja et al. [6] investigated sisal-glass fiber-reinforced epoxy composites with varying fiber volume fractions to assess their viability as alternatives to traditional materials. Sisal-GFRP composites show lower tensile strength, higher flexural and compression strength, maximum impact strength, and increased hardness. Suhas Yeshwant Nayak et al. [7] investigated the effect of varying E-glass fiber weight fractions on the mechanical properties of CNSL-epoxy resin composites. Their results showed that increasing the volume fraction of E-glass fiber content in CNSL-epoxy resin composites significantly improves their mechanical properties. Specifically, higher fiber weight fractions (from 15% to 45%) enhanced the composites' micro-hardness, tensile strength, and flexural strength. Hind W. Abdullah et al. [8] studied the effect of fiber orientation and layering configuration s on the thermal conductivity and hardness in epoxy composites reinforced with glass fibers. They found that the thermal conductivity increased with more glass fiber layers, with random fiber composites showing lower values than other configurations. Additionally, hardness tests revealed that the epoxy composite's hardness increased as the number of glass fiber.

The present work study experimentally the effect of the layers count of random glass fiber on hardness properties. The specimens were manufactured with a varying number of layers from 3 to 6 layers of fiberglass with a mass per unit area of 450 g/m² and a constant thickness of 3 mm for all specimens using unsaturated polyester resin. The specimens were tested using the Vickers hardness test by applying a load of 50 grams for a dwell time of 15 seconds. In each specimen, 5 indentations were applied, then the average of the 5 readings was calculated, and the VHN value was determined.

2. Materials and method

2.1. Materials

2.1.1. Glass Fiber

Glass fiber is lightweight, exceptionally strong, and durable. Its bulk strength, rigidity, and weight characteristics are highly advantageous in comparison to metals. E-glass fiber in the form of random chopped strand mat was utilized as a reinforcing agent within the unsaturated polyester resin matrix. This type of glass integrates the properties of E-glass with excellent electrical insulation [1].

2.1.2. Unsaturated Polyester

Unsaturated polyester resin is a liquid that solidifies upon the addition of a hardener. It has been specifically designed to be effective at ambient temperature. The hardener MEKP (Methyl Ethyl Ketone Peroxide) is incorporated to catalyze the curing and solidification of the resin [1].

2.2. Preparation of Fiberglass Composite

The hand layup technique was utilized to fabricate the composite material. First, a mixture of polyester resin and catalyst was prepared in a clear bowl and stirred for one minute to ensure thorough mixing. The resin-to-catalyst ratio was maintained at 100 grams of resin to 1.5 grams of catalyst. The fiberglass laminate was cut into 25 x 25 cm. Molds were prepared from wood with the lower and upper molds shaped to the desired dimensions. Before casting, a smooth sheet of Prospan paper was placed on the surface of the lower mold and later the upper mold after casting, ensuring easy release of the composite. A thin layer of polyester was applied to the Prospan paper in the bottom mold, followed by a layer of fiberglass, which was then fully saturated with polyester resin. The mixture was spread evenly, and an iron roller with a spiral, screw-like design was used to remove air bubbles after the resin was applied to the fibers. Fiberglass layers were added one by one, each filled with resin, until the desired number of layers was reached. Once all layers were in place, a final polyester layer was applied. To ensure uniform thickness (3 mm), two rectangular plates were placed on the sides followed by the placement of the upper mold. The entire setup was subjected to a load of 70 kg for 15 to 24 hours to allow proper curing. Afterward, the composite was trimmed to the desired size, and the final laminate was obtained. Various composite types are listed in Table 1 .

Table 1: Laminate designation

Designation	Number of layers
Specimen 3	**3**
Specimen 4	**4**
Specimen 5	**5**
Specimen 6	**6**

2.3. Hardness test

This experiment utilizes the Vickers hardness test to measure the hardness of fiberglass reinforced plastic specimens according to ASTM E384 standard [9-10]. The test was conducted using a Wilson hardness device as shown in Figure 2. A load of 50 g force was applied for a duration of 15 seconds. Five different points on each specimen were tested, and at each point, the values of d_1 and d_2 were recorded through the microscope attached to the device. The average of the two values was then calculated and recorded as d_{avg}. Using the readings obtained from the test, the VHN value was calculated using the relevant equations, and this was repeated every five indentations for each specimen. After completing and calculating the VHN values for the five indentations, the average of the five readings was calculated and recorded.

The Vickers Hardness Number is calculated according to the following laws.

$$HV = \frac{1.8544 \times F}{(d_{avg})^2} \quad (1)$$

where F is the applied load (Kgf), d_{avg} is the mean of d_1 and d_2 of the indentation mark (mm).

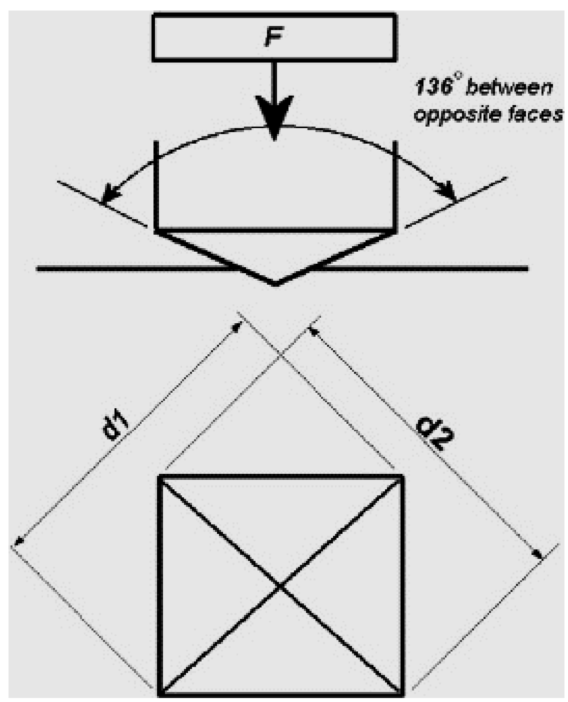

Figure 1: Schematic represents Vickers hardness test

Figure 2: Wilson hardness device

3. Results and discussion

Data from the test results with Vickers hardness test are tabulated in Table 2.

It was observed from Figure 3 that as the number of fiberglass layers increased, there was a noticeable decrease in hardness. This trend was particularly evident for fiberglass composites, where a drop in hardness was observed in composites with four or more layers of fiberglass. This may be attributable to the development of air voids on the composite's surface [11]. The hardness of the composite with four fiberglass mats is lower due to localized plastic deformation. This reduction in hardness may also occur in composites with five and six fiberglass mats, as voids in the material act as stress concentration centers. Voids may arise from inadequate wetting of the fiberglass by the polyester resin, resulting in air entrapment. Moreover, inadequate drying of the composite or entrapped air during mixing may also lead to the creation of voids [12-13]. It appears that there is a trend showing that an increase in fiberglass content results in a decrease in hardness. This is because the smooth surface of the fiberglass leads to weaker interphase bonding. As a result, composites with higher fiberglass content showed lower hardness values, as showed in Figure 3 [14].

Lobo et al. [15] reported a slight decrease in hardness in bamboo-fiberglass reinforced isophthalic resin composites as the number of fiberglass layers increased. Composites without fiberglass had a hardness of 84, while those with one, two, and three layers showed values of 82, 80, and 79, respectively. Similarly, Mubarak et al. [16] evaluated the hardness of composites reinforced with chopped E-glass fibers and epoxy resin at varying fiber content ratios. The results showed that the 10 wt% composite had the highest hardness, indicating that lower fiber content enhances surface resistance to indentation and deformation. Conversely, increasing the chopped E-glass proportion led to decreased hardness values. In another study, Arumugam et al. [17] demonstrated that the hybrid GF/SF/CTS composite sample A5 exhibited a maximum Vickers hardness of 59.6 HV, reflecting a significant enhancement compared to other combinations. This increased hardness is due to the composite's unique sandwich structure, which contributes to its mechanical stability and resistance to deformation. The relationship between fiber content and hardness indicates that lower fiber content enhances hardness, while excessive fiber content may reduce it due to increased porosity and altered bonding characteristics.

Table 2: The Vickers hardness of specimens

Specimen 3			
d_1	d_2	davg	VHN
86.89	82.5	84.695	12.9
80.07	80.62	80.345	14.4
78.52	72.5	75.51	16.3
81.75	83.09	82.42	13.6
80.57	79.61	80.09	14.5
Mean VHN		**14.34**	

Specimen 4			
d_1	d_2	davg	VHN
88.9	86.02	87.46	12.1
102.55	92.92	97.735	9.7
93.84	95.56	94.7	10.3
85.09	82.21	83.65	13.3
88.07	90.08	89.075	11.7
Mean VHN		**11.42**	

Specimen 5			
d_1	d_2	davg	VHN
102.68	100.75	101.715	9
80.91	84.43	82.67	13.6
99.87	111.34	105.605	8.3
104.31	99.75	102.03	8.9
101.25	103.6	102.425	8.8
Mean VHN		**9.72**	

Specimen 6			
d_1	d_2	davg	VHN
111.88	109.71	110.795	7.6
100.83	101.71	101.27	9
116.7	117.87	117.285	6.7
117.16	110.08	113.62	7.2
108.41	107.24	107.825	8
Mean VHN		**7.7**	

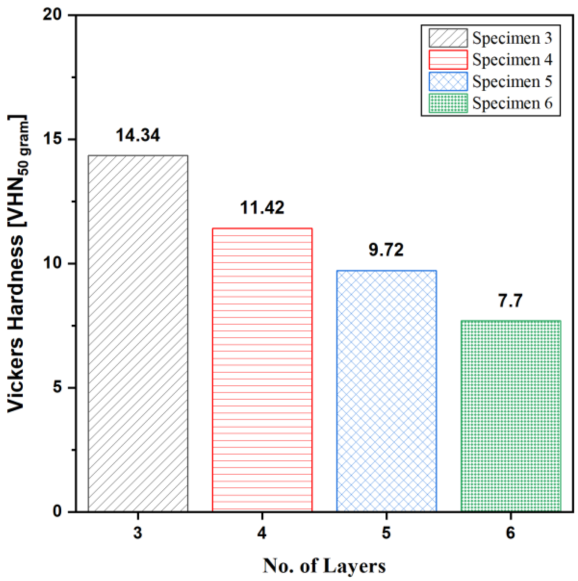

Figure 3: Vickers hardness of different composites at 50 gram force and 15 second dwell time

4. Conclusions

The results indicated that the hardness value diminished as the number of glass fiber layers increased. The hardness values of glass fiber composites with 3, 4, 5 and 6 layers are 14.34 HV, 11.42 HV, 9.72 HV, and 7.7 HV, respectively.

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