International Journal of
Engineering Research and Science & Technology

IJERST

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Research Paper

EFFECT OF LAMINATE THICKNESS AND QUANTITY OF CATALYST ON FLEXURAL STRENGTH PROPERTIES OF GLASS REINFORCED POLYESTER COMPOSITE

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In the manufacturing process of composite materials that involve the hardening of a thermosetting resin, the material is usually thermally treated to accelerate exothermic chemical reactions that change the matrix from liquid to solid state. The properties of the resin alter as the cross linking density of its polymer molecules increases and temperature varies. This study aimed at investigating the effect of laminate thickness and quantity of catalyst on the flexural properties of glass reinforced polyester composite used in manufacture of furniture. This research utilized pre-accelerated unsaturated polyester resin, Methyl Ethyl Ketone Peroxide (MEKP) catalyst and E-glass chopped strand mat reinforcement for sample preparation. Different amounts of catalyst ranging from 0.5% to 5% were dispensed on the polyester resin to make test samples of thicknesses ranging from 1 mm to 3 mm. Hand lay-up processing technique was used and curing was done at room temperature. Flexural strength properties of the samples were determined according to ASTM D790-05 standards. Data was analyzed using Statistical Analysis Software (SAS). Flexural strength was observed to increase with laminate thickness from 116.93 Mpa at 1 mm to 177.03 Mpa at 2 mm then it gradually reduced for the remaining thickness range, whereas increase in quantity of catalyst caused a decrease in flexural strength. Statistical analysis showed that the laminate thickness, quantity of catalyst and interaction of the two had a significant effect on the flexural properties of glass reinforced polyester composites but the quantity of catalyst had the highest influence than the rest.

Keywords: Polyester resin, E- glass Fiber, Catalyst, Hand lay-up, Flexural Strength, Laminate thickness

INTRODUCTION

Currently, composite materials are considered as a new and important class of engineering materials. Composite is defined as a material that

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consists of one or more discontinuous phases which are usually hard and strong embedded in a continuous phase. The continuous phase is called the matrix while the discontinuous phase is termed as the reinforcement material (Kokta *et al.*, 2005). Reinforcement provides strength and rigidity, helping to support structural loads whereas the matrix or binder (organic or inorganic) maintains the position and orientations of the reinforcement. Significantly, constituents of composites retain their individual chemical, physical and mechanical properties, yet together, they produce a combination of the properties which individual constituents would not be capable of producing alone (Bledzki and Gassan, 2008). Composites tend to have characteristics such as high strength, high modulus, low density and excellent resistance to fatigue, creep, creep rupture, corrosion and wear (Mokhtar *et al.*, 2007; Monk, 1997).

Glass-reinforced plastic is a type of composite material made up of a plastic matrix reinforced by fine fibers made of glass. These engineering materials have found applications in automobiles, boats, aircrafts, furniture and as construction materials. This is because unlike the conventional materials such as steel, wood, aluminum and concrete, fiber reinforced composites have excellent specific mechanical properties (high strength to weight ratio), corrosion resistance and are low cost (Garkhail *et al.*, 2000; Sheikh and Channiwalla, 2010; and Gaylord, 1974).

Several studies that have been done showed that, generally, the properties of fiber reinforced composites are governed by the factors such as the type, amount and composition of the resin and reinforcement materials, processing conditions, laminate thickness and additives used. If the proper curing conditions of resins in particular are provided and the right quantities of additives are used then, the anticipated properties dictated by the resin and fiber type selected would be attained (Simitzis *et al.,* 1997; Visco *et al.,* 2007; and De Garmo *et al.*, 1997). This indicates that the selection of the material type and quantities and the processing conditions should be carefully selected for quality and economically feasible product to be produced.

A satisfactory cure of the resins is influenced by the overall thickness of the layer to be cured, the gel time required, and the working temperatures. Laminate thickness and quantity of catalyst as an additive, plays a significant role in the cure time of the laminate since it affects the exothermic temperature and hence properties of the composite (Ling *et al.*, 2004). However there is limited information on how these factors relate to the properties of the particular composite product. The focus of this research was to study the effect of laminate thickness and the quantity of catalyst on the flexural properties of glass reinforced polyester composite laminates that could be used in the manufacture of furniture.

MATERIALS AND METHODS

Production of Laminate Samples

The samples were made from pre-accelerated unsaturated polyester resin impregnated on E-glass fiber. Various samples sizes thicknesses were produced by combining different fiberglass mat sizes using hand lay-up processing technique. Dimension of the mould used to prepare the samples was 0.45 m long by 0.15 m wide by 0.004 m thick and was made from flat glass plates. Quantity of catalyst was varied from 0.5% to 5% by volume of the resin for each selected laminate thickness which ranged from 0.5 mm to 3 mm. The selection of thickness range

was based on the thickness to which most of the furniture manufactured from fiber reinforced plastic fall under. The following procedure was followed in production the samples:

i. The mould was cleaned with warm soapy water then wiped to dry.

ii. Mirror wax polish was applied and then wiped with cotton waste to remove any impurities on the mould.

iii. To facilitate the removal of the sample from the mould, releasing agent was applied on the polished mould surface.

iv. The gel coat was then applied on the mould and left to dry.

v. Glass-fiber mat was spread over the gel coat and a layer of catalyzed resin brushed on the mat surface before rolling using a squeegee to remove the air bubbles.

vi. The sample was then left to cure and the curing time was taken once the laminate is hardened.

Determination of Flexural

Flexural strength is the ability of the samples to withstand bending forces applied perpendicular to its longitudinal axis. The test was carried out in accordance to ASTM standard D790-05 using a three point bending fixture on a Hydraulic Universal Material Tester, 50 kN (WP 310).

A rectangular beam cross-section sample of 127 mm by 12.7 mm and varying thickness was placed on the two supports with a span of 100 mm. Displacement load was then applied at its center until strain in the outer surface of the specimen had reached the maximum strain (5%) or rupture occurred on the sample. The resulting flexural strength was recorded. For each test set, five replications were done. The three point fixture was attached to the Universal Testing machine as shown in Figure 1.

Figure 1: Three Point Bending Fixture

The flexural strength (σ_b) of the given sample was calculated using Equation (1) below;

$$\sigma_b = \frac{M_{b\max}}{W_b} \quad \text{...(1)}$$

where $M_{b\max} = \frac{F_{\max}L}{4}$ ...(2)

$$W_b = \frac{bd^3}{12} \quad \text{...(3)}$$

M_{bmax} Bending moments in Nm

F_{max} Maximum bending force in N

L Span length in m

W_b Second moment of area in m⁴

b Width of the sample in m

d Thickness of the sample in m

Data Analysis

The Statistical Analysis Software (SAS) was used in data analysis. Analysis of variance (ANOVA) was performed on the treatment means for each parameter. But to examine whether there was significance difference in the means, Least Significance Difference (LSD) was performed at 5% level of significance.

RESULTS AND DISCUSSION

The results of the flexural strength are shown in Table 1 and their graphical representations are given in Figure 2.

Table 1: Flexural Strength (MPa) at Different Thickness and Catalyst Level							
Thickness (mm)	**Catalyst (%)**						**Mean (Lsd=3.023)**
	00.50%	**1%**	**2%**	**3%**	**4%**	**5%**	
1	178.05	160	123.88	89.71	75.51	74.44	**116.93ᶜ**
1.5	286.92	228.76	180.49	134.6	110.95	110.49	**175.37ᵃ**
2	260.76	231.29	169.47	150	130	120.67	**177.03ᵃ**
2.5	192.31	172.11	156.39	146.6	132.1	131.27	**155.11ᵇ**
3	140.78	126.33	109.74	97.75	95.36	92.41	**110.40ᵈ**
Mean (Lsd=3.31)	211.76ᵘ	183.68ᵛ	147.99ʷ	123.73ˣ	108.78ʸ	105.86ʸ	

Note: Means followed by the same letter(s) a,b,c,d in same column; (u,v,w,x,y,z) in same row are not significantly different at 5% level of significance using LSD.

Figure 2: Flexural Strength Versus Catalyst for Varying Thickness Levels
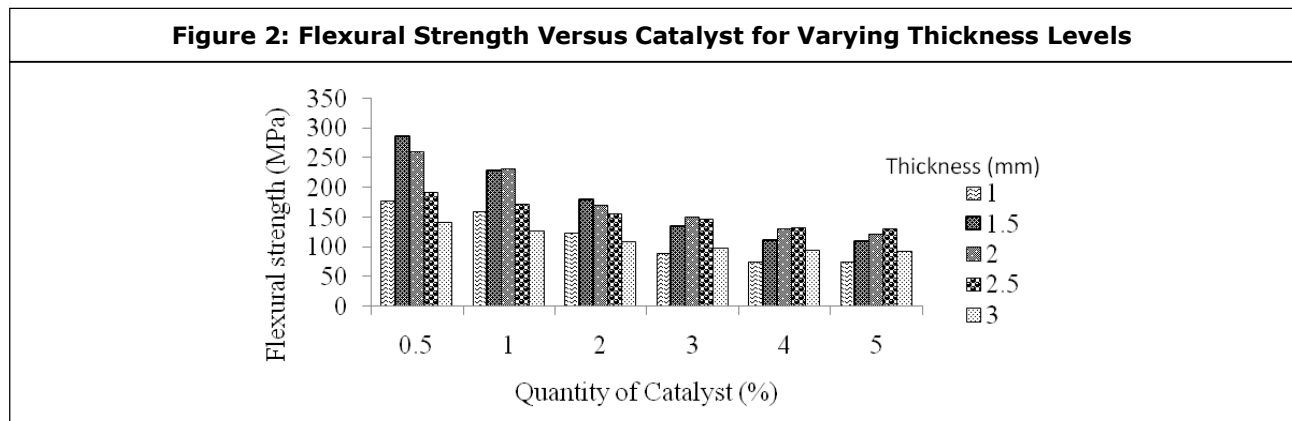
The flexural strength of the composite samples increased with the laminate thickness up to 2.0 mm but gradually reduced for higher laminate thicknesses. The mean flexural strength obtained was 116.93, 175.37 and 177.03 MPa at 1.0, 1.5 and 2.0 mm laminate thicknesses, respectively then reduced from 155.11 MPa at 2.5 mm to 110.40 MPa at 3.0 mm as shown in Table 1. These results agree with the findings of Mohamed and Chambers (2007) in their study of the effect of voids on the flexural performance of Unidirectional Carbon Fiber. The increase in strength for different laminate thickness could be attributed to increase in fiber content which raise the stiffness of the composites and hence the flexural strength. The gradual decrease in flexural strength for thicker laminates, however, could have been caused by residual stresses resulting from the heat generated during polymerization and retained as the laminate cooled to room temperature. It could also be due to the increase in the rate of reaction caused by exothermic heat retained by thick parts leading to development of internal flaws like void and micro cracks which resulted in reduced strength of the laminate as the thickness is increased.

Another observation was a reduction in the mean flexural strength with increase in quantity of catalyst. At 0.5% catalyst level, the mean flexural strength was 211.76 MPa, 140.99 at 2% and 105.86 MPa at 3% catalyst, respectively. Statistical analysis showed there was a significant difference between each catalyst level up to 4% but no significant difference between 4% and 5% at 5% level of confidence. These results gave an indication that high catalyst concentrations beyond 4% have no significant effect on flexural strength. This could have been because as the quantity of catalyst is increased the rate of polymerization reaction also increases leading to

increase in the polymerization temperatures. The residual stresses are generated during cool-down, mainly due to the mismatch between the Coefficients of Thermal Expansion (CTE) of the fiber and matrix.

Residual stresses affect the thermo-mechanical behavior of composite materials and, moreover, the resulting stresses are sufficient to initiate fracture within the matrix-fiber interface therefore lowering the flexural strength (Maligno *et al.*, 2008). Adnan and co-researchers (2007) in their study reported that the increase in the temperature within the laminate as a result of heat generated by the exothermic reaction of the resin and that due to reaction rate can cause damage to the part if not controlled.

Statistical analysis comparing the effect of laminate thickness and quantity of catalyst on flexural strength. It showed that the quantity of catalyst had more effect on the flexural strength compared to laminate thickness but the interaction between the two had minimal influence as indicated by their *F*-values at 5% level of significance.

CONCLUSION

Lower catalyst levels results in higher flexural strength properties of glass reinforced polyester composites but thin composites give low flexural strength. On the other hand, thicker laminates have poor flexural strength. This is because of increased curing defects as quantity of catalyst is increased but improved cross linking density at higher thicknesses.

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