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Development and Characterization of Particulate Filled Glass Fiber Reinforced Hybrid Composites

Harshvardhan Sahu
School of Mechanical Engineering, KIIT University, Bhubaneswar, 751024, Odisha, India, harshvardhan.sahu@gmail.com

Arun Rout
School of Mechanical Engineering, KIIT University, Bhubaneswar, 751024, Odisha, India, ArunRout@gmail.com

Alok Kumar
School of Mechanical Engineering, KIIT University, Bhubaneswar, 751024, Odisha, India, AlokKumar@gmail.com

Development and Characterization of Particulate Filled Glass Fiber Reinforced Hybrid Composites

Harshvardhan Sahu, Arun Rout & Alok Kumar

School of Mechanical Engineering, KIIT University, Bhubaneswar, 751024, Odisha, India
E-mail : harshvardhan.sahu@gmail.com

Abstract - This article depicts the processing and mechanical characterization of a new class of multi-phase composites consisting of polyester resin reinforced with glass fiber and filled with alumina particulates. Four different composite samples are prepared with 0, 5, 10 and 15wt.% of Al_2O_3(alumina). The mechanical properties of these composites are evaluated. It is found that Al_2O_3 modifies the tensile, flexural and the inter-laminar shear strength of the glass-polyester composites. The hardness and density of the composites are also greatly influenced by the content of these fillers.

Keywords - *E-glass fiber, Alumina powder, Polyester resin, Mechanical characterization.*

I. INTRODUCTION

Fiber reinforced polymer composites (FRPCs) have generated wide interest in various engineering fields because of high specific strength, high modulus, low density and better wear resistance [1]. Hard particulate fillers, consisting of ceramic or metal particles are being used these days to improve the mechanical and tribological properties of the polymer matrix [2]. The filler materials include organic, inorganic, and metallic particulate materials in both micro and nano sizes. Various kinds of polymers and polymer-matrix composites reinforced with metal particles have a wide range of industrial applications [3]. These composites are desired due to their low density, high corrosion resistance, ease of fabrication, and low cost [4-6]. The inclusion of inorganic fillers like alumina into polymers is primarily aimed at the cost reduction and stiffness improvement [7, 8]. In recent years much research has been devoted to explore the potential advantages of thermoplastic polymers in composite materials. Some of the commonly used thermoplastics are polyetheretherketone (PEEK),polyetherketone(PEK), polyether ketoneketone (PEKK), polyester, polypropylene (PP), etc. Several investigations on mechanical strength and wear properties of PEEK and its composites filled with fibers, organic, and inorganic fillers have been carried out [9,10] Patnaik et al.[11] have studied the erosion resistant of glass-fiber reinforced polyester composites filled with alumina powder. Bahadur and Gong [12] have investigated the action of various copper compounds as fillers on the tribological behavior of PEEK. Wang et al. [13] have investigated friction and wear properties of nanometric ZrO_2 and SiC filled PEEK composites with different filler proportions.

Aluminum oxide (Al_2O_3), commonly referred to as alumina, can exist in several crystalline phases, all of which revert to the most stable hexagonal alpha phase at elevated temperatures. This is the phase of particular interest for structural applications. Alumina is the most cost effective and widely used material in the family of engineering ceramics. It is hard, wear resistant, has excellent dielectric properties, resistance to strong acid and alkali attack at elevated temperatures, high strength, and stiffness. Hence, in the present work alumina is used as filler material to investigate the physical and mechanical strength of the composite.

II. EXPERIMENTAL DETAILS

2.1 Composite preparation

Bi-directional E-glass fiber mats are reinforced in polyester resin and four different weight proportions of alumina powder (0 wt%, 5 wt %, 10wt% and 15wt%) with average size of 80-90 micron are added as the filler material to prepare the composites C_1, C_2, C_3, and C_4 respectively. The composition and designation of the composites prepared for this study are listed in Table 1. The fabrication of the composite slabs is done by conventional hand-lay-up technique followed by light compression molding technique as shown in Figure 1. 2% cobalt nephthalate (as accelerator) is mixed thoroughly in isophthalic polyester resin followed by 2% methyl-etheyl-ketone-peroxide (MEKP) as hardener prior to fiber reinforcement. The polyester resin and the hardener are supplied by Ciba Geigy India Ltd. The bi-directional E-glass fiber and polyester resin possess Young's modulus of 72.5GPa and 3.25GPa respectively and a density of 2600kg/m^3 and 1350kg/m^3 respectively. Each ply of fiber is of dimension 200×200 mm^2. A wooden mould of 210×210×40 mm^3 dimension is used. A releasing agent (Silicon spray) is used to facilitate easy removal of composites from the mold after curing. The castings are put under load of about 50 kg for about 24 hours for proper curing at room temperature. Specimens of suitable dimensions are cut using a diamond cutter for physical/mechanical characterization as shown in Figure 2. Utmost care has been taken to maintain uniformity and homogeneity of the composites.

Table 1 : Designations and detailed compositions of the composites

Design-ation	Composition
C_1	Polyester (60wt.%) + glass fiber (40 wt.%)
C_2	Polyester (55 wt.%) + glass fiber (40 wt.%) + alumina (5 wt.%)
C_3	Polyester (50 wt.%) + glass fiber (40 wt.%) + alumina (10 wt.%)
C_4	Polyester (45 wt.%) + glass fiber (40 wt.%) + alumina (15 wt.%)

Fig. 1 : Fabricated samples

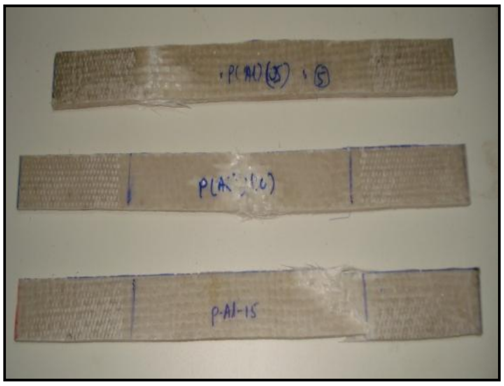

Fig. 2 : Specimens prepared for mechanical characterization

2.2 Mechanical Test details

2.2.1 Density

The theoretical density of a composite material can be obtained by using the following equation given by Agarwal and Broutman[2].

Each composite sample under this investigation consists of three components namely fiber, matrix and particulate filler. The theoretical density of the composite specimen in terms of weight fraction can be obtained as per the following equation

$$\rho_{ct} = \frac{1}{(W_f/\rho_f) + (W_m/\rho_m) + (W_p/\rho_p)} \qquad (1)$$

Where, ρ and W represent the density and weight fraction respectively. The suffix *m, f* and *ct* stand for the matrix, fiber and the composite specimen respectively. The suffix '*p*' indicates the particulate filler material. However, the actual density (ρ_{ce}) of the composite specimen can be determined experimentally by Archimedes principle. The volume fraction of voids (V_v) in the composite samples is calculated by using the following equation:

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \qquad (2)$$

2.2.2 Surface hardness

Hardness is measured using Rockwell-hardness tester (Figure 3) equipped with a steel ball indenter $(1/16'')$ by applying a load of 50 kgf.

Fig. 3 : Rockwell hardness tester

2.2.3 Tensile strength

The tensile strength is generally performed on the flat specimens. The dog-bone type specimen with end tabs is commonly used for tensile test. ASTM-D3039-76 standard test method is employed for tensile test of composite specimens. The dimension of the samples for the test is 150mm×10mm×4.5mm. 4.5mm thickness is maintained for all the specimens. The test is performed in the universal testing machine Instron 3369 (Figure 4) at across head speed of 10mm per minute. Six numbers of specimens with same composition are used to get the mean value of the tensile strength.

Fig. 4 : Instron 3369

2.2.4 Flexural and inter laminar shear strength

The short beam shear (SBS) test is performed on the composite samples for calculating the inter laminar shear strength (ILSS). The test is conducted as per the ASTM-D2344-84 standard for the prepared samples. The dimension of the samples for the test is 60mm×10mm×4.5mm. Universal testing machine Instron 2230 is used for the test. The cross head speed for the test is maintained 10mm/min and the test is repeated six times for the mean value of inter laminar shear strength. The ILSS is calculated as per following equation:

$$ILSS = \frac{3P}{4bt} \quad (3)$$

Here, P is the maximum load applied, b is the width of specimen and t is the thickness of the specimen. The same maximum value of load P is used to calculate the flexural strength (FS) also. A span of 40mm is used for obtaining both ILSS and FS. By using the following equation FS is calculated.

$$FS = \frac{3PL}{2bt^2} \quad (4)$$

Equation 3 and 4 are generally used to obtain the ILSS and FS respectively for composite materials.

III. RESULTS AND DISCUSSION

3.1 Mechanical properties

In the present investigation, the theoretical and measured densities of glass-polyester composites with alumina filler along with corresponding values of volume fraction of voids are presented in Table 3. It is observed that the theoretical values of density are not equal with the experimental values. The densities decrease with increase in filler content. The volume fraction of voids is also increases with increase in alumina content. The percentage of void content in the composite specimen increases with increase in alumina content. A maximum reduction of 1.7 gm/cc density is found with glass-polyester composites filled with 15 wt. % alumina with a maximum void percentage of 5.55.

Table 3 : Measured and theoretical densities

Comp o-sites	Measured density (gm/cc)	Theoretical density (gm/cc)	Vol. fraction of voids (%)
C_1	1.93	1.95	1.025
C_2	1.88	1.92	2.08
C_3	1.78	1.84	3.26
C_4	1.70	1.80	5.55

Surface hardness is considered to be one of the important factors in composites for determination of wear rate. The test result shows that there is a increase in hardness with increase in filler content. With the increase in alumina content from 0 wt.% to 15 wt.% the hardness is found to increase from 62 HRF to 75 HRF. This implies an increment of 21 % in hardness of the alumina filled composites. The hardness values of the composites along with different weight fraction of alumina are shown in Figure 5.

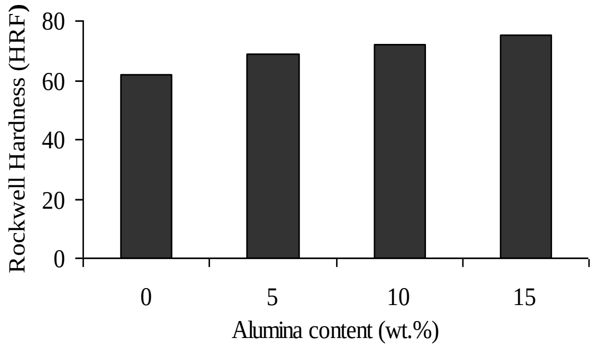

Fig. 5 : Variation of hardness of the composites with filler content.

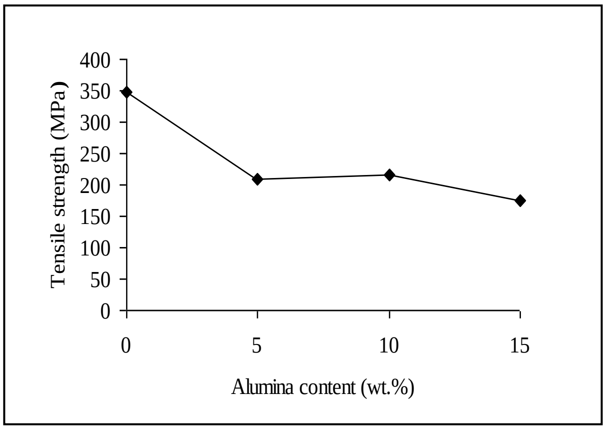

Fig. 6 : Variation of tensile strength of composites with filler content

The tensile properties of glass-polyester composites filled with alumina are shown in Figure 6. There is a gradual drop in tensile strength from a maximum of 348 MPa to a minimum of 174 MPa of glass-polyester composites filled with 15 wt.% of alumina. It clearly indicates that inclusion of alumina reduces the load carrying capacity of the composite specimen. This may be due to the poor interfacial bond strength between alumina particulate and polyester and may also be due to the stress concentration at the sharp corners of irregular alumina particles. The flexural properties of glass-polyester composites are studied and it is found that the flexural strength of the composite reduces with increase in filler content. It is observed that a gradual decrease in flexural strength from a maximum of 360 MPa to a minimum of 276 MPa as shown in Figure 7. Short beam shear test is conducted in composite laminates for determination of inter laminar shear strength (ILSS). It causes relative sliding between two consecutive laminae and failure occurs along the mid-plane of the adjacent layers. The variation of ILSS values of the specimens with alumina content is shown in Figure 8.

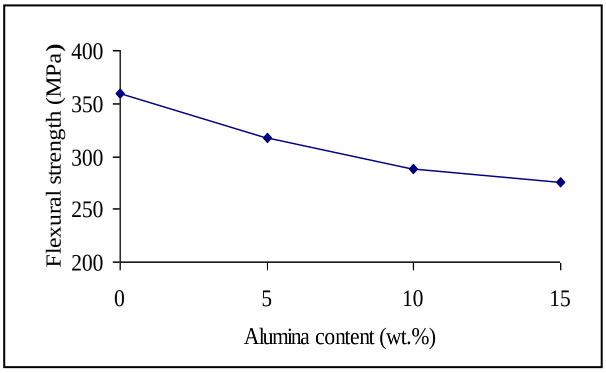

Fig. 7 : Variation of flexural strength with filler content

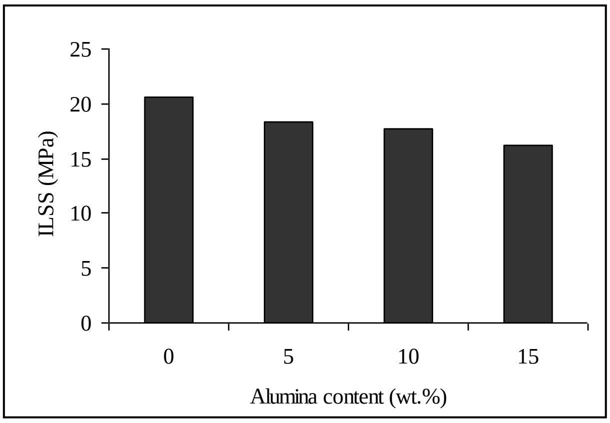

Fig. 8 : Variation of inter-laminar shear strength with filler content

IV. CONCLUSIONS

Based on the present investigation, the following conclusions can be drawn as:

(i) Successful fabrication of glass-polyester composites filled with alumina powder is possible by hand-lay-up technique.

(ii) A steady decline of tensile, flexural and inter-laminar shear strength is observed. However, the hardness of the composite samples improves with increase in filler content. (iii) The density of the composites is also greatly influenced by the filler content. Thus, while designing such composite systems for a specific requirement, there is a need for optimizing the alumina content.

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