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Effect of $CaCO_3$ and Al_2O_3 Fillers on Mechanical Properties of Glass/Epoxy Composites

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ABSTRACT

Fibre reinforced plastic materials are widely used in various engineering applications because of their superior performance and tailor made properties. Nowadays specific fillers/additives are added to the composite materials to reduce material costs, enhance and modify the quality of composites to some extent, in some cases to improve processability and product performance. Some of the commonly used fillers are carbon black, calcium carbonate, clay, alumina, alumina tri-hydrate, magnesium hydroxide, bone powder, coconut powder, hematite powder, TiO_2, SiO_2, ZnS, graphite, etc. In the present work plain woven glass fabric reinforced epoxy composites filled with two different types of fillers, such as calcium carbonate($CaCO_3$) and Aluminium Oxide (Al_2O_3) at different weight fractions (0, 5 and 10 wt%) are studied. The composite specimens required for different tests are fabricated by hand lay-up technique as per ASTM standards. These composites are investigated for their mechanical properties such as ultimate tensile strength, flexural strength, impact strength as well as hardness. The obtained results are compared with pure glass fiber/epoxy composites. From the results it is found that there is a decrease in tensile and flexural strength with the addition of filler material. However significant improvement in mechanical properties such as impact strength and hardness is observed. The ranking for the composite materials is given by using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method with output parameters of their mechanical and water absorption attributes.

Keywords: *Glass Fibre Reinforced Composites, Epoxy resin, Fillers, Mechanical Properties, TOPSIS.*

I. INTRODUCTION

Over the past few decades, remarkable interest has been observed in production and development of new composite materials or modification of existing composite materials is the real challenge for most of the materials engineers for production of composite materials with low cost and improved mechanical behavior compare to conventional alloys. Even though epoxy based composites have tremendous potential to substitute the traditional metallic materials, researchers showing interest in filler materials to modify resins for further improvement in mechanical properties.

Many researchers have studied and examined the influence of various fillers on the mechanical properties of fibre reinforced composite materials. Sachin Kumar Chaturvedi et al. [1] studied effect of calcium carbonate filler on tensile strength of glass composite materials and from the results it is concluded that as the weight fraction increases the tensile strength of the composite increases rapidly. Increase in $CaCO_3$ filler content increases the hardness and impact strength. K. Devendra, T.

Rangaswamy et al. [2] investigated the mechanical properties of Al_2O_3, Mg $(OH)_2$ and SiC filled E-Glass/ Epoxy Composites. It can be observed that increase in addition of Al_2O_3 and $Mg(OH)_2$ enhances the flexural strength, hardness, impact strength and decrease in tensile strength. Ramesh K. Nayaket et al. [3] studied the effect of epoxy modifiers ($Al_2O_3/SiO_2/TiO_2$) on mechanical performance of epoxy/glass fiber hybrid composites. The improvement in mechanical properties is observed with decrease in ceramic particle size. Alumina modified epoxy composite increases the hardness and impact energy. S. Rajesh, B. VijayaRamnath, et al. [4] examined the mechanical behavior of Glass Fibre/ Al_2O_3 - SiC reinforced polymer composites. From the results it is observed that the GFRP composites with epoxy resin have very high tensile strength compared to metallic filler addition. Wasim Akram, Sachin Kumar Chaturvedi, et al. [5] performed comparative Study of mechanical properties of E-Glass/Epoxy composite materials with Al_2O_3, $CaCO_3$, SiO_2 and PbO Fillers. It has been noticed that the mechanical properties of the composites such as hardness, tensile strength torsion strength, impact strength etc. are influenced by filler content. Raffi Mohammad et al. [6] reported all the mechanical properties on the Glass Fiber reinforced particulate filled composites for mechanical characterization and TOPSIS is implemented to measure the proximity to the ideal solution. J.S. Suresh et al. [7] investigated on hybrid composites and the TOPSIS technique is implemented for the ranking of the matrix with respect to the mechanical properties.

The main objective of this work is to investigate the effect of $CaCO_3$ and Al_2O_3 fillers on the mechanical properties of glass fibre reinforced epoxy composites. The mechanical properties such as ultimate tensile strength, flexural strength, impact strength are determined at 0, 5 and 10 wt% of fillers and the results are compared with the results of glass epoxy composites without fillers. TOPSIS is implemented to measure the proximity to the ideal solution.

II. MATERIALS

A. Woven Glass Fabric (E-Glass)

Woven glass fabric is a light weight, strong and robust material. Even though its strength and stiffness properties are somewhat lower than carbon fiber, the material is typically far less brittle and the raw material is much less expensive. Woven glass fiber fabrics have the significant range in the market and the best command over all the properties of all forms of glass fiber materials. This offers the textiles engineer a great choice on controlled fabric properties which satisfies the design needs and its objectives.

B. Epoxy Resin

Epoxy resin (Araldite LY 556) is having excellent adhesion to different materials with great strength and toughness resistance to chemical attack and to moisture [8]. It possesses excellent mechanical and electrical properties. It is odorless, tasteless and completely nontoxic. In the present work Hardener (Araldite) HY 951 is used. This has a viscosity of 10-20 poise at 25^{o}C.

C. Calcium Carbonate and Aluminium oxide

Calcium carbonate, which is also referred to as Calcium trioxocarbonate ($CaCO_3$), is one of the most widely available chemical compounds on the earth. It occurs naturally in the earth crust, and is said to make up approximately 7 percent of the earth's crust. The $CaCO_3$ has different common names such as calcite, limestone, chalk, pearl, marble, aragonite, etc. Aluminium oxide is a chemical combination of aluminium and oxygen. Usually, among all the aluminium oxides that occurred it is specifically indicated as aluminium (III) oxide. The common name of Al_2O_3 is alumina and can be identified with different names depending upon the use and applications.

III. FABRICATION PROCEDURE

The fabrication of epoxy resin composites using calcium carbonate and aluminium oxide with different proportions of $CaCO_3$ and Al_2O_3 along with GFRP is done. Hand lay-up technique is used to fabricate the composite laminate. A mold of size 400 x 400 x 3 mm is prepared and the work side of the mold was coated with a releasing agent mansion white wax. Resin and hardener were mixed and stirred mechanically in a ratio of 10:1 by weight for both epoxy and polyester laminates with and without filler material. With the help of a brush the mixture of resin and hardener are applied inside the mold surface after the application of mansion wax. One layer of woven E-Glass fabric of size 400 x 400 mm is placed in the mold. E-glass sheet is coated with the resin and mild steel roller is used to remove the entrapped air bubbles and to get uniform distribution of resin and another layer of E-glass fiber is placed on it and the process is continued up to eighth layer and it is cured at room temperature for 24 hours. After that the laminate is removed from the mould and it is cut into different sizes as per ASTM standards for conducting different tests on the specimens. The designation and composition of Epoxy, Glass fiber & Fillers are shown in Table I.

I. Designation and composition of composite materials

S. No.	Designation	Composition
C1	Pure GFRP	55 wt% epoxy + 45 wt% glass fiber
C2	GFRP + 5% $CaCO_3$	50 wt% epoxy + 45 wt % glass fiber + 5 wt % $CaCO_3$
C3	GFRP+5% Al_2O_3	50 wt% epoxy + 45 wt % glass fiber + 5 wt % Al_2O_3
C4	GFRP+10% $CaCO_3$	45 wt% epoxy + 45 wt % glass fiber + 10 wt % $CaCO_3$
C5	GFRP+10% Al_2O_3	45 wt% epoxy + 45 wt % glass fiber + 10 wt % Al_2O_3

IV. TESTING OF COMPOSITES

A. Mechanical testing

Tensile tests were conducted on computerized Universal Testing Machine having 40 Tons capacity with a cross-head speed of 10 mm/min. The tensile test samples were prepared according to ASTM D638 standard and shapes of samples were like dog-bone. Three points flexural test specimens were performed on the same machine at cross-head speed of 10 mm/min according to ASTM: D790 M standard. The compression strength and ILSS can also be calculated on the same equipment with the same standards. Impact test specimens were cut according to ASTM D 256 M to measure the impact strength. The specimens were prepared with the dimension of 63.5 x 12.7 x 10 mm. A V-notch is arranged on the composite specimen with a sharp triangular file having an included angle of 45^0 at the centre and at 90^0 to the sample axis. The samples were fractured in Charpy impact testing machine and the energy (joule) absorbed while being broken was observed. Computerized Vickers Hardness Tester was used to measure the hardness of composite specimens under the ASTM D1339 standards. The Vickers hardness test is performed by indentating the diamond indenter on to the test specimen in the form of a square pyramid shape at an angle of 136^0 subjected to a load up to 100 kgf. A load of 1 kgf is applied on the specimen for dwell period of 10 seconds. Readings of the diagonals of indentation are taken and hardness is calculated.

B. Water absorption test

Moisture absorption studies were performed according to ASTM D 570-98 standard test method for moisture absorption of plastics. The weights of the samples were taken and then dipped them to normal water [9]. After 24 hours, the samples were taken out from the moist environment and all surface moisture was removed with the help of a clean dry cloth or tissue paper. Then the samples were reweighed to the nearest 0.001 mg within 1 min of removing them from the environment chamber. The samples were regularly weighed at 24, 48, 72, 96, 120 hrs respectively. The moisture absorbed by the specimens is calculated by weight difference. The percentage of water absorbed is obtained by the weight gain in percentage to the initial weight of the specimen [10].

V. RESULTS AND DISCUSSION

A. Mechanical properties

a. Tensile strength

The results of tensile test such as ultimate tensile strength are shown in Fig. I. with variation of weight percentage of fillers in GFRP composites.

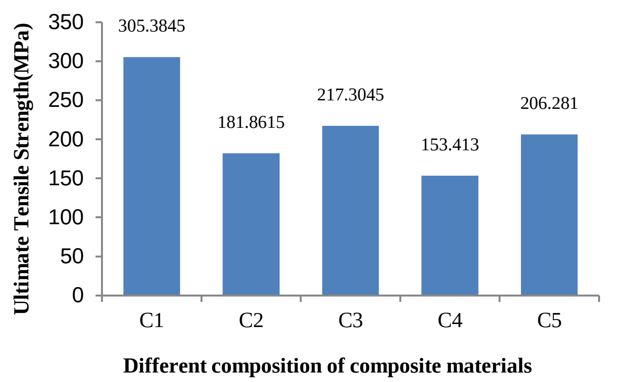

Fig. I. Ultimate Tensile strength of $CaCO_3$ and Al_2O_3 filled GFRP composites

From the results it is observed that, the unfilled glass epoxy composite has a strength of 305.485 MPa in tension and ultimate tensile strength decreases as the weight percentage of fillers increases (for both the cases of $CaCO_3$ and Al_2O_3). There can be two reasons for the decrease in ultimate tensile strength of these particulate filled composites compared to the unfilled ones:

- Due to the presence of pores at the interface between filler particles and the matrix, the

interfacing adhesion may be too weak to transfer the tensile stress.
- The corner points of the irregular shaped particulates result in stress concentration in the matrix base.

b. Flexural Properties:

The results of flexural test are shown in Fig. II. It shows that the variation of flexural strength with variation of weight percentage of fillers in GFRP composites.

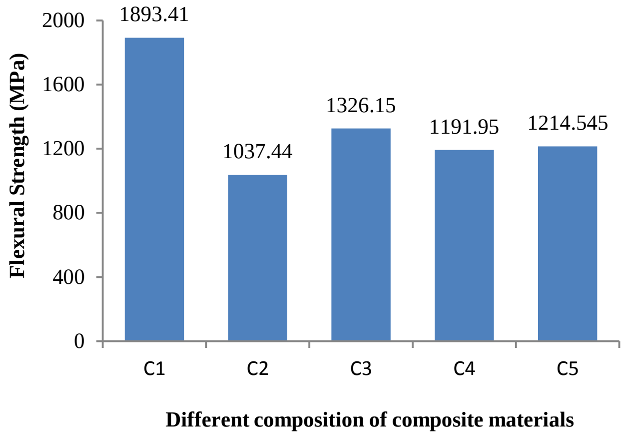

Fig. II. Flexural strength of $CaCO_3$ and Al_2O_3 filled GFRP composites

From the results it observed that in all the samples irrespective of type of filler material the flexural strength of the composite decreases with increase in weight percentage of filler content. The unfilled glass epoxy composite has flexural strength of 1893.41 MPa in bending. This value drops with the addition of filler material. There can be two reasons for this decline in the flexural strength of these particulate filled composites compared to the unfilled ones:

- The incompatibility of the particulates and the epoxy matrix, leading to poor interfacial bonding.
- The lower values of flexural strength may also be attributed to fiber to fiber interaction, voids and dispersion problems.
- However it also depends on other factors such size, shape, type and loading on filler on material.

c. Impact Properties

The impact strength values of composites recorded during the impact test are given in Fig. III.

From the test results it is observed that the resistance to impact loading increases with addition of filler material. The unfilled glass epoxy composite has impact energy of 6J. With the addition of 10wt% of $CaCO_3$, impact strength value raises to 8.5J and for 10wt% of Al_2O_3, impact strength value raises to 8J.

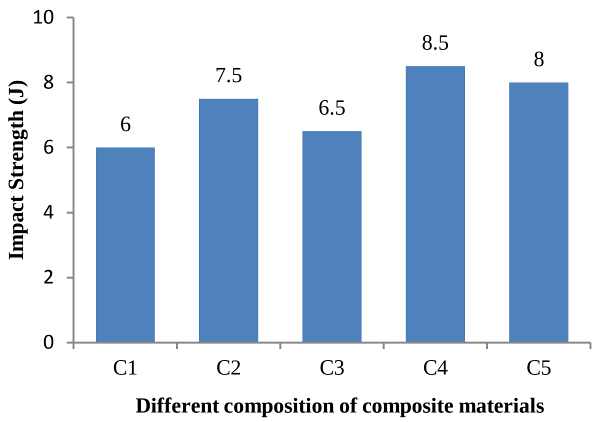

Fig. III. Impact strength of $CaCO_3$ and Al_2O_3 filled GFRP composites

The results also show that impact resistance is more for $CaCO_3$ filled composites. There can be two reasons for this increase in the impact energies of these particulate filled composite compared to the unfilled ones.

- Due to Interfacial bonding in between the Particulate fillers and matrix material.
- The corner points of the regular shaped particulates result in less stress concentration in the matrix base.

d. Hardness

The Hardness values at different weight % of fillers in GFRP composites recorded during the hardness test are given in Fig. IV.

Generally, hardness is a function of the relative fiber content and modulus of the composites. The fibers that increase the moduli of composite materials should also increase the hardness. It is observed from the figure that as the weight percentage of filler in the composite increases, the hardness of composite also increases. Similar trend of increase in hardness of the composites with increase in filler content has also been reported by the researchers. From the results it is also observed that the hardness is more for $CaCO_3$ filled composites i.e., 116.16 HV. The addition of filler content increases the hardness of composite material due to the following reasons: Increase in the resistance strength of polymer to plastic deformation. In this case, the polymeric matrix phase and the solid filler phase would be pressed together and touch each other more tightly.

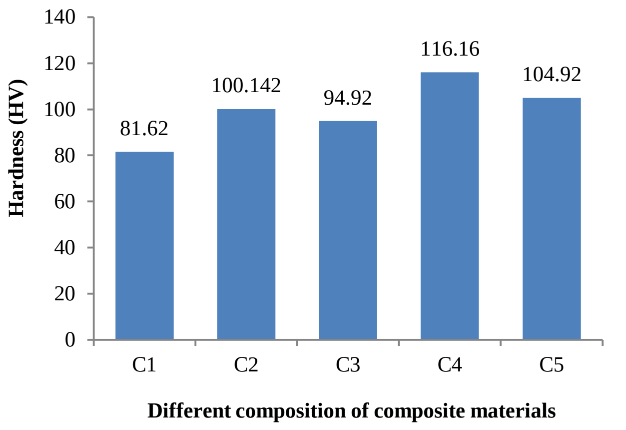

Fig. IV. Hardness of $CaCO_3$ and Al_2O_3 filled GFRP composites

B. Water Absorption Behaviour of composites

Water absorption test is very important to determine the water absorptivity of the water absorption of the material. The percentage of weight gain in various composites with time duration is shown in Fig. V.

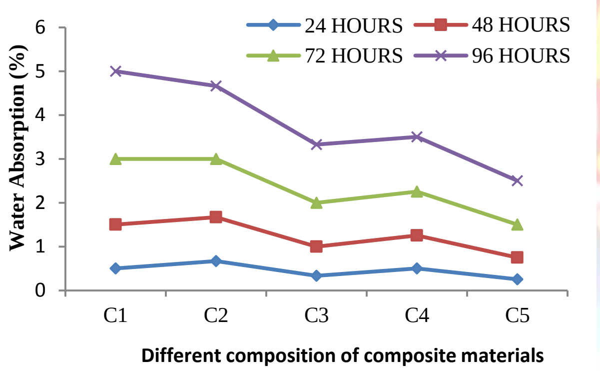

Fig. V. Effect of immersion time on water absorption properties of composites

It is observed from the Fig. V. that with increase in filler loading the water absorption gradually increases irrespective of fibre orientation. This behavior was expected because the water absorption of these composites is mainly due to the presence of glass fibres. There are three main reasons in the composite because of which water can reside in composite. Those are the lumen, the cell wall and the gaps between fibre and resin in the case of weak interface adhesion is found [10]. The maximum water absorption obtains at 45% fibre loading irrespective of uniform distribution of fillers. As far as effect of fibre orientation on the water absorption of composites is concerned there is not much influence is observed.

VI. RANKING OF MATERIALS USING TOPSIS METHOD

TOPSIS method is a powerful technique for selecting the best alternatives from number possible alternatives. By using this technique, the positive ideal solution is found out which is categorized as the best alternative from the set of alternatives/composites [11] and the negative ideal solution is termed as the least/worst alternative. The main aim of the TOPSIS is to select the top ranked composite and comparing it with all the other ranks of the composites that were used. All the composite materials are compared based on the TIOPSIS method and ranking has been done. The decision matrix, normalization matrix, weight normalized matrix, ideal positive and ideal negative solution, separation measure, relative closeness value and ranking are tabulated in Tables II, III, IV, V, VI and VII respectively

II. Decision Matrix

Composites	Tensile Strength (MPa)	Flexural strength (MPa)	Inter laminar strength (MPa)	Compression Strength (MPa)	Impact Strength (J)	Micro hardness (HV)
C1	305.3845	1893.41	22.95	33.568	6	81.62
C2	181.8615	1037.44	16.6	24.16	7.5	100.142
C3	217.3045	1326.15	19.52	29.005	6.5	94.92
C4	153.413	1191.95	19.07	25.968	8.5	116.16
C5	206.281	1214.545	19.62	28.768	8	104.92

III. Normalization Matrix

Composites	Tensile Strength (MPa)	Flexural Strength (MPa)	Inter Laminar Strength (MPa)	Compression Strength (MPa)	Impact Strength (J)	Micro Hardness (HV)
C1	0.414478	0.619564	0.521524	0.496351	0.217536	0.344027
C2	0.246829	0.339473	0.377224	0.35724	0.271919	0.422097
C3	0.294933	0.433945	0.443579	0.42888	0.235664	0.400086
C4	0.208217	0.390032	0.433353	0.383974	0.308175	0.489612
C5	0.279972	0.397425	0.445852	0.425376	0.290047	0.442236

IV. Weight Normalized Matrix

Composites	Tensile Strength (MPa)	Flexural strength (MPa)	Inter-laminar strength (MPa)	Compression Strength (MPa)	Impact Strength (J)	Micro hardness (Hv)
C1	0.06908	0.103261	0.086921	0.082725	0.036256	0.057338
C2	0.041138	0.056579	0.062871	0.05954	0.04532	0.070349
C3	0.049156	0.072324	0.07393	0.07148	0.039277	0.066681
C4	0.034703	0.065005	0.072226	0.063996	0.051363	0.081602
C5	0.046662	0.066238	0.074309	0.070896	0.048341	0.073706

V. Ideal Positive and Ideal Negative Solution

Solution	Tensile Strength(MPa)	Flexural Strength (MPa)	Inter Laminar Strength (MPa)	Compression Strength (MPa)	Impact Strength (J)	Micro Hardness (HV)
A+ (ideal solution)	0.06908	0.103261	0.086921	0.082725	0.051363	0.081602
A- (negative Ideal solution)	0.034703	0.056579	0.062871	0.05954	0.036256	0.057338

VI. Separation Measure

Composites	S+	S-
C1	0.048764372	1.421154053
C2	0.09543356	1.419806028
C3	0.13820898	1.420950992
C4	0.141221469	1.421247165
C5	0.140911162	1.421216365

VII. Relative closeness value and ranking

Composites	Closeness factor	Ranking
C1	0.033174883	5th
C2	0.062982488	4th
C3	0.088643233	3rd
C4	0.090383555	1st
C5	0.090204647	2nd

Finally the ranking of different composite based on their properties is being shown above. It has been observed that ranking of composite materials are as follows: Rank 1(C4), Rank 2 (C5), Rank 3 (C3), Rank 4 (C2) and Rank 5 (C1)

VII. CONCLUSIONS

The experimental investigation on the effect of filler content on mechanical behavior of glass fiber reinforced epoxy composites is performed. Properties such as the ultimate tensile strength, flexural strength, impact energy and Vickers hardness were evaluated. From the experimental results the following conclusions are made:

- Successfully fabricated a new class of $CaCO_3$ and Al_2O_3 filled Glass/epoxy based composites by hand layup technique.
- Ultimate tensile strength and flexural strength of the composites decreases with increase in weight percentage of filler content and these values are lower than unfilled glass/epoxy composites.
- Resistance to impact loading increases with addition of filler material. The results also show that impact resistance is more for $CaCO_3$ filled composites compared to the Al_2O_3 filled composites.
- Hardness of the composites increases with the addition of filler material. The Hardness of $CaCO_3$ filled composites is more than the Al_2O_3 filled composites.
- TOPSIS method is used to select a best alternative from a set of alternatives. It has been observed that ranking of composite materials are as follows: Rank 1(C4), Rank 2 (C5), Rank 3 (C3), Rank 4 (C2) and Rank 5 (C1).

Scope of Future Work

In this work $CaCO_3$ and $Al2O_3$ fillers are used. This can further be extended to other fillers such as carbon black, clay, alumina tri-hydrate, magnesium hydroxide, bone powder, coconut powder, hematite powder, TiO_2, SiO_2, ZnS, graphite, etc. to study the effect of fillers on the mechanical properties of the FRP composites.

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