

Effect of Fillers on Mechanical, Thermal and Fire Resistance Properties of E-Glass/Epoxy Composites

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Abstract: Composites have the ability to meet diverse design requirement with significant strength to weight ratio as compared to conventional materials. Composites have a greater tensile strength, higher fatigue, endurance limit, lower embedded energy, good impact properties, environmental and corrosion resistance which can be tailored to meet performance needs and complex design requirements. The study of thermal, mechanical and fire resistance properties are desirable, when the Fiber Reinforced Composites are exposed to heat above the glass transition temperature of resin matrix, which leads to reduction in stiffness and strength of the material and hence degrades the mechanical properties due to thermal degradation and combustion of the resin. This poor fire resistance of glass fiber reinforced composites has been a major factor to limit their wide spread of applications.

This work deals with the study of the effect of filler materials on the mechanical, thermal and fire resistance properties of E-glass fiber reinforced epoxy composites. Magnesium Hydroxide ($Mg(OH)_2$) and Aluminium Oxide (Al_2O_3) are used as filler materials. The obtained result shows that the presence of Aluminium Oxide enhances the mechanical properties but lowers the thermal properties. Aluminium Oxide filled composites exhibits the low tensile and high impact and Brinell hardness strengths. Magnesium Hydroxide filled composites exhibits high thermal conductivity and thermal expansion coefficients and possesses flame retardant properties, consumes more time for ignition and flame propagation time and exhibits less mass loss rate when compared with neat and Aluminium Oxide filled composites.

Keywords— Composites, Resins, E-glass fiber, Filler Material, Material Properties

I. INTRODUCTION

A composite is a synergistic combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other. The objective is to take advantage of the superior properties of both materials without compromising on the weakness of either. The synergism produces material properties unavailable from the individual constituent materials. Due to the wide variety of matrix and reinforcement materials available, the design potentials are incredible. Composite materials have successfully substituted the traditional materials in several light weight and high strength applications. The reasons why composites are selected for such applications are mainly

their high strength-to weight ratio, high tensile strength at elevated temperatures, high creep resistance and high toughness. The strength of the composites depends primarily on the amount, arrangement and type of fiber and /or particle reinforcement in the resin.

Fiber reinforced composites play an incredible role in almost all spheres of day to day life and in the field of glass composites is one of the prime research area in recent decade. The formulation of the matrix and reinforcement were obtained using hand layup process [1]. The properties of the polymer composites can be improved largely by varying the type of filler materials and its volume percentages, which improves the mechanical properties as fillers play a significant role in determining the key properties such as strength and toughness [3]. Available references suggest investigations on a large number of materials to be used as fillers such as fly ash, stone powder and silicon carbide which exhibits high thermal properties such as thermal conductivity, coefficient of thermal expansion, specific heat and fire resistance properties like ignition time, mass loss rate and flame propagation rate [4, 5, 6]. Glass fibers are most frequently used because of their specific strength properties in evaluation of material properties [7]. The thermal properties of filler based fiber composites are however less than the pure composites [2].

Work involves fabrication of E-glass epoxy based composites using Magnesium Hydroxide ($Mg(OH)_2$) and Aluminium Oxide (Neutral) (Al_2O_3) as filler materials, and to study the effect of these fillers for the mechanical, thermal and fire resistance behavior properties on composites. In order to develop and characterize a new combination of composites to suit wide range of applications.

II. MATERIAL SELECTION

In this work, E-Glass is chosen as the reinforcement material and Epoxy resin as the matrix material, as they fulfill majority of the requirements which are desired in this work. The properties of E-Glass fiber and Epoxy resin are as detailed below:

TABLE I. Properties of E-Glass fiber and Epoxy resin

Properties	E-glass	Epoxy
Specific gravity	2.54	1.28
Young's modulus	70 GPa	3.792 GPa
Ultimate tensile strength	3447 MPa	82.74 MPa
Coefficient of thermal expansion	5.04 $\mu\text{m}/\text{m}^{\circ}\text{C}$	-

Fillers are ingredients added to enhance the properties such as strength, surface texture, and ultraviolet absorption of a polymer and to enhance the flame retardancy and lower the cost of polymers. Magnesium Hydroxide (Mg(OH)_2) and Aluminium Oxide (Al_2O_3) are used as filler materials.

Hardeners are substances which are added to polymers for aiding in curing of composites. Approximately 10% of hardener is added while fabricating the composite materials. In this work K-6 (Epoxy hardener) is used as hardener.

III. METHODOLOGY

Fabrication of composites was done at room temperature by hand layup technique and the composites were cured at room temperature. The proper volume fraction of fiber, epoxy, fillers and orientation of fibers were controlled. Hand lay-up technique is a low volume, labor intensive method suited especially for larger components. Glass or other reinforcing mat woven fabric or roving is positioned manually in the open mold, and resin is poured, brushed, or sprayed over and into the glass plies. Entrapped air is removed manually with squeezes or rollers to complete the laminates structure. Room temperature curing epoxies and polyester are the most commonly used matrix resins. Curing is initiated by a catalyst in the resin system, which hardens the fiber reinforced resin composite without external heat for a high quality part surface; pigmented gel coat is first applied to the mold surface.

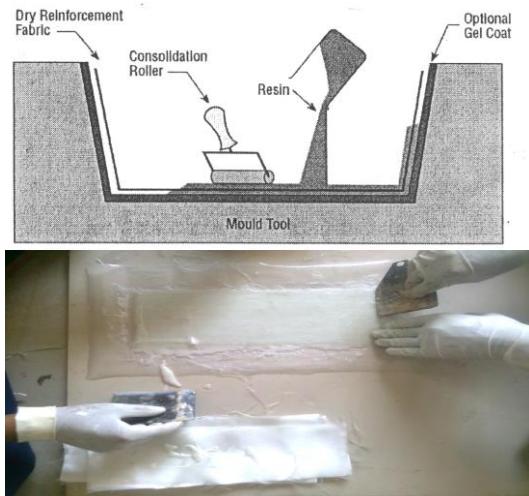


FIGURE 1 Schematic Representation of Hand Lay-Up Technique

Six specimens each were prepared for different test from the below composites materials based on ASTM standards.

TABLE II. Nomenclatures of composite materials fabricated

Material Designation	% of glass fiber (Volume)	% of epoxy (Volume)	% of Filler materials (Volume)
GE	50	50	Nil
GEM ₁	50	40	10 % of (Mg(OH)_2)
GEM ₂	50	35	15 % of (Mg(OH)_2)
GEA ₁	50	40	10 % of (Al_2O_3)
GEA ₂	50	35	15 % of (Al_2O_3)
GEMA	50	35	7.5 % of (Mg(OH)_2) and 7.5 % of (Al_2O_3)

TABLE III. ASTM Standards

Test	ASTM Standards	Dimensions (mm)
Tensile	ASTM D3039	250*25*2.5
Impact resistance	ASTM E23	55*10*10
Thermal conductivity	ASTM E 1530	φ50* 10
Fire test (UL94V)	IEC60695-11-10	127*12.7*3.2
Brinell hardness test	ASTM E10-00a	-

The fabricated specimens were tested for **Mechanical properties**-Tensile strength, Impact strength, Brinell hardness

Thermal properties-Thermal conductivity, Thermal expansion coefficient

Fire resistance properties- Mass loss rate, Flame propagation rate, and Time to ignite.

The Impact strength test were done using Charpy impact test and Fire resistance test were done using the set of UL94V. All the tests were conducted based on ASTM standards.

IV. RESULTS

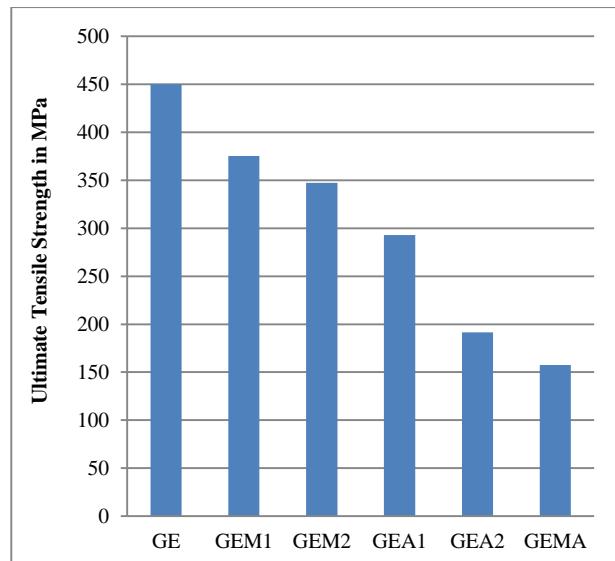


FIGURE 2 Composite Materials vs. Ultimate Tensile Strength

The mechanical properties of composite materials depend primarily on the strength and modulus of the fibers, the strength and chemical stability of the matrix and the effectiveness of the bonding between matrix and fibers in transferring stress across the interface. The obtained results show that the tensile strength of GE, GEM₁ and GEM₂ is greater than the other composites such as GEA₁, GEA₂ and GEMA. This is due to the reason that good bonding strength between fiber and matrix in GE, GEM₁ and GEM₂ compared with other composite materials.

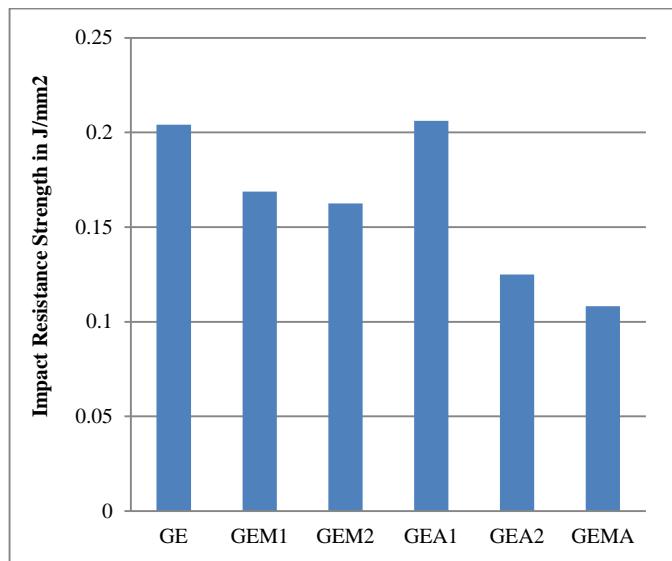


FIGURE 3 Composite Materials vs. Impact Resistance Strength

Charpy impact test results show that the impact strength decreases with increase of percentage of addition of aluminium oxide; this is again because of its low adhering nature. And increasing the concentration of Magnesium Hydroxide also affects adversely the impact strength.

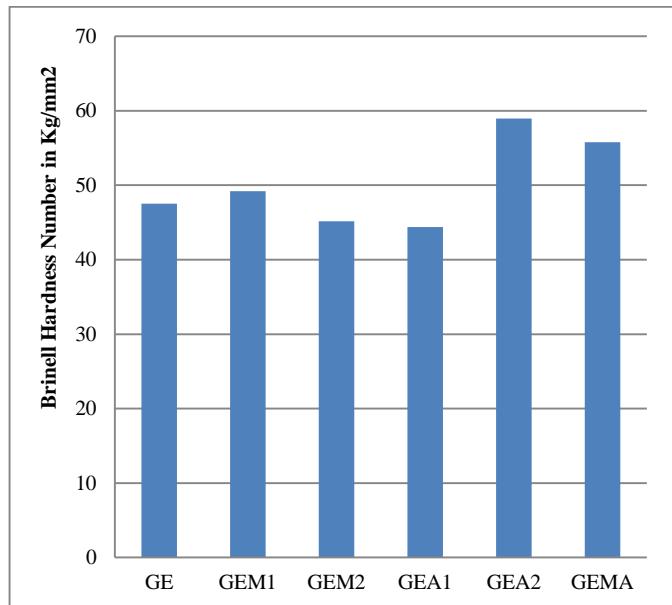


FIGURE 4 Composite Materials vs. Brinell Hardness Number

Brinell hardness test results shows that the BHN value decreases with increase of percentage of addition of Magnesium Hydroxide; this is because of the presence of high loading of solid particles embedded in the polymer matrix results in reduced ability to absorb impact energy. And also BHN value increases with increase of percentage of addition of Aluminium Oxide.

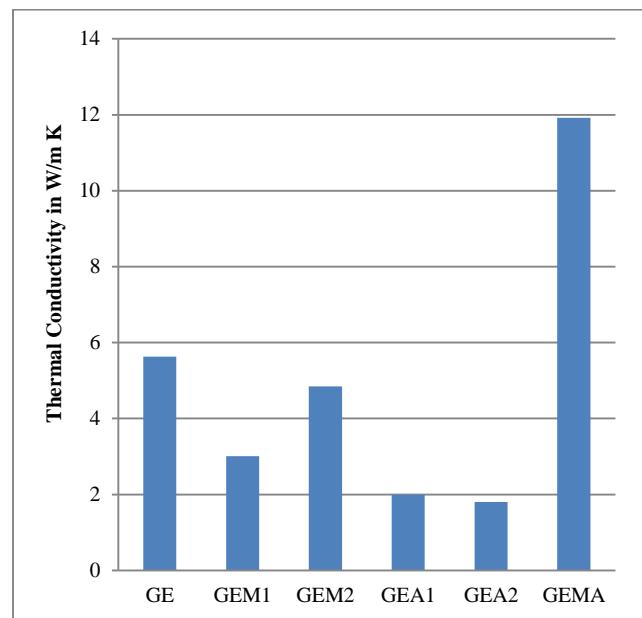


FIGURE 5 Composite Materials vs. Thermal Conductivity
From the above graph it is evident that the thermal conductivity of composite materials increases with increase of percentage of addition of Magnesium Hydroxide, this is because that the particles of the Magnesium Hydroxide have high heat carrying capacity when compared with neat and Aluminium Oxide filled composites. The obtained results show that the thermal conductivity of GEMA, GE and GEM₂ is greater than the other composites like GEM₁, GEA₁ and GEA₂.

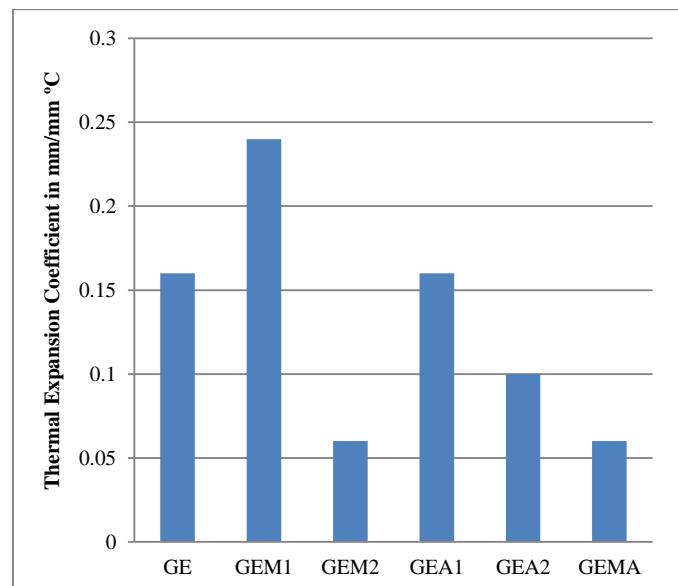


FIGURE 6 Composite Materials vs. Thermal Expansion Coefficient

It is observed that the thermal expansion coefficient is high for GE, GEM₁ and GEA₁ composites when compared with other composite materials like GEM₂, GEA₂ and GEMA. This is because of high expansion coefficient and thermal conductivity of GE, GEM₁ and GEA₁ is higher than the other composite materials.

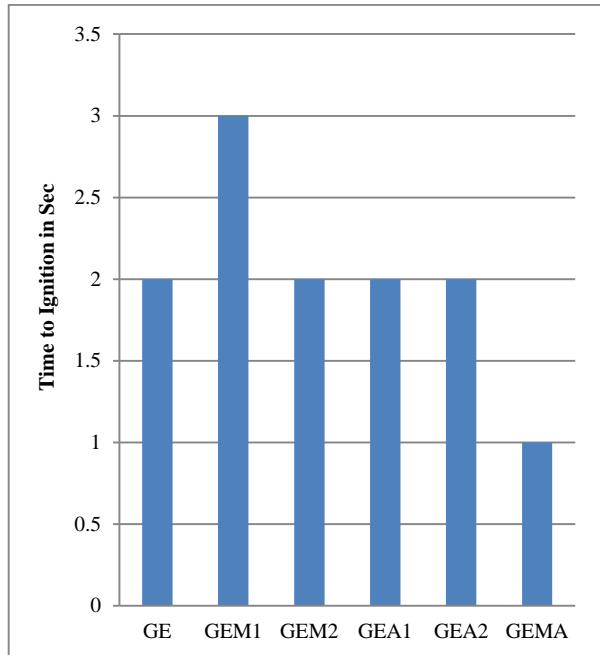


FIGURE 7 Composite Materials vs. Time to ignition

It can be observed that ignition time is more for Magnesium Hydroxide based composite materials. Magnesium Hydroxide acts as flame retardant because its endothermic decomposition cools the condensed phase and the released water also cools and dilutes the flammable products in the vapour phase. So the ignition time is more for Magnesium Hydroxide filled composites.

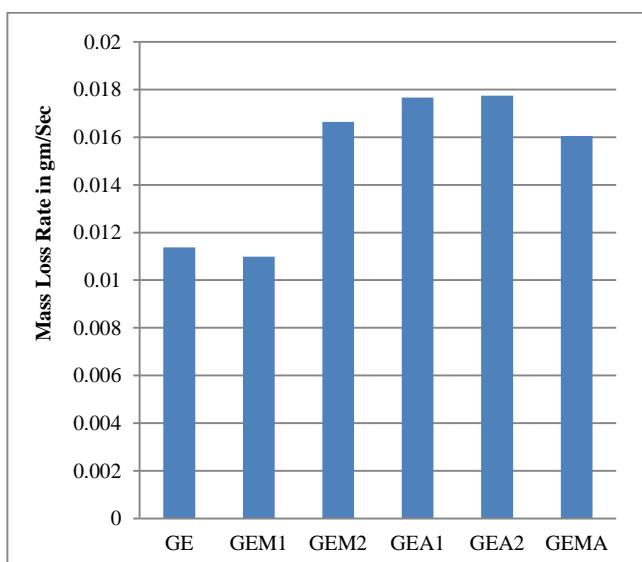


FIGURE 8 Composite Materials vs. Mass loss rate

It is seen that the mass loss rate of GE and GEM₁ composite materials are less compared to other composite materials like GEM₂, GEA₁, GEA₂ and GEMA. The function of Magnesium Hydroxide as flame retardant fillers is that its endothermic decomposition cools the condensed phase and the released water also cools and dilutes the flammable products in the vapour phase. The residue of Magnesium Hydroxide crust after combustion can also protect the under lying polymer from the outside heat. So the burning of material is reduced hence the mass loss rate is low.

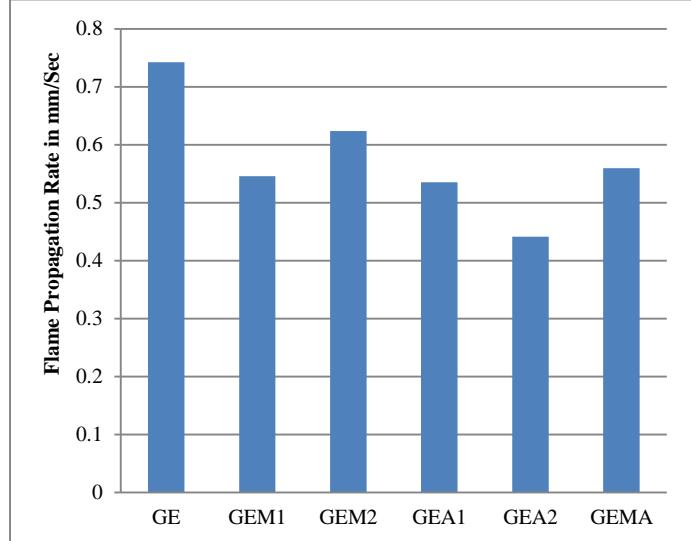


FIGURE 9 Composite Materials vs. Flame propagation rate

the flame propagation rate for composite materials GEM₁, GEA₁ and GEA₂ are lesser than the other composite materials like GE, GEM₂ and GEMA. This is because that Magnesium Hydroxide in GEM₁ acts as flame retardant so less flame propagation rate was observed. And Aluminium in GEA₁ and GEA₂ acts as a barrier for the fire growth. From the obtained results it can be observed that all the six specimens have burn time more than 60 sec, it means all the six specimens do not come under UL94 rating.

V. CONCLUSION

TABLE IV. Comparison of all the properties with composite material

Properties	GE	GEM ₁	GEM ₂	GEA ₁	GEA ₂	GEMA
Ultimate Tensile Strength in MPa	450.24	375.36	347.2	292.8	191.52	157.44
Charpy Impact Strength in J/mm ²	0.2042	0.1687	0.1625	0.2062	0.125	0.1083
Brinell Hardness Number in Kg/mm ²	47.52	49.196	45.15	44.39	58.96	55.76
Thermal Conductivity in W/m K	5.628	3.008	4.848	2	1.801	11.917
Thermal Expansion Coefficient in mm/mm °C	0.16	0.24	0.06	0.16	0.1	0.06
Time to Ignition in Sec	2	3	2	2	2	1
Mass Loss Rate in gm/Sec	0.01137	0.01099	0.01664	0.01766	0.01775	0.01605
Flame Propagation Rate in mm/Sec	0.7424	0.5456	0.6239	0.5354	0.4412	0.5595

In this work E-Glass/Epoxy based composites using Magnesium Hydroxide ($Mg(OH)_2$) and Aluminium Oxide (Al_2O_3) as filler materials were fabricated and investigated.

- The results shows that the Aluminium Oxide filled composites like GEA₁ and GEA₂ exhibits low tensile strength and high impact strength and Brinell hardness when compared with neat and Magnesium Hydroxide filled composites.
- Aluminium Oxide filled composites such as GEA₁ and GEA₂ exhibits low thermal conductivities and thermal expansion coefficients when compared with neat and Magnesium Hydroxide filled composites.
- It is observed that Magnesium Hydroxide filled composites consume more time to ignition and flame propagation time and exhibits less mass loss rate.
- All the six specimens have burn time more than 60 seconds and do not come under UL-94 rating.

VI. REFERENCES

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