Impact of Filler on Mechanical and Dynamic Mechanical Properties of Waste Marble Dust Filled Aramid Fibre Reinforced Polymer Composite

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Impact of Filler on Mechanical and Dynamic Mechanical Properties of Waste Marble Dust Filled Aramid Fibre Reinforced Polymer Composite

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Abstract: The present examination describes the development and analysis of different classes of aramid fibre reinforced polymer composites using marble dust as particulate filler. In this paper, hand lay-up practice is used for fabrication and the investigation is done by altering the weight% of marble dust ranging from 0-15wt% with a gap of 5wt% and by keeping fibre loading constant at 40wt%. Experiments are conducted to investigate mechanical and dynamic mechanical behavior of material. Consideration of hard particles modifies malleable, bending, inter laminal shear qualities of aramid fibre reinforced composites.[1)] Indentation property and thermo-mechanical properties are additionally impacted with the consolidation of hard particals.[2)]

Keywords: Aamid Fibre, Polymer Composite, Marble Dust, Mechanical and Dynamic Mechanical Analysis

1. Introduction

Polymer composite materials reinforced with fiber are judged as a vital category of reinforcement, because of fulfillment of required conditions[3)] and reciprocate strength to matrix component inducing and improving material's mechanical characteristics as required. In order to increase the mechanical properties filler materials (as third phase) are added to the polymer composites called as hybrid composites that consist of fibre, matrix, and particulate filler.[4)] In Rajasthan the natural contamination is expanded because of the development of leftover marble dust[5)] at the time of processing of marble chunks, and in the event that it isn't utilized then it can make ecological issues and financial misfortune. In India about 6 Mega Tonne of waste is generated from marble industries as a result of marble cutting, grinding, polishing and processing. Rajasthan is the world's largest marble deposited state as it produces 95% of the total marble waste from approx. 4000 marble mines.[6)] Hard particles of marble dust as filling material is utilized in varied scope of regions and utilization in earthenware, concrete, color, construction material and in purification and the process of removing sulfur.[7)] For blended cement and for industrial brick applications an experimental study has been done to check the usability of waste marble dust as an additive material and concluded that in cement manufacturing 10 Wt% of waste marble dust can be used as an additive material.[8, 9)] It has been observed that with marble dust filler concrete has higher compression strength, young's modulus and ductile strength.[10)] In case of filled reinforced material tensile and flexural strength decreases as % of hard particles changes from 10wt% to 20wt% but for unfilled polymer composite material tensile and flexural strength increases as fibre loading increases.[4)] The thermal properties of aramid fibre composite under cyclic mechanical stresses are analysed by conducting thermo-mechanical analysis. Ritesh Kaundal and Amar Patnaik presented a comparative study of SiC filled and unoccupied glass polymer composite with respect to the dynamic mechanical properties and concluded that better dynamic properties were observed with SiC filled composites.[4)]

The current exploration work is formed to manufacture marble dust filled composites and to examine the impact of hard particles on mechanical and thermo-mechanical significance of marble dust filled aramid fiber supported polymer composite material. At long last, the outcomes are investigated to choose the best appropriate creation of polymer composite material loaded up with marble dust.

2. Materials and Methods

2.1 Materials

In existing study composites are manufactured from aramid fabric (actual density 1.46 gm/cc, tensile modulus 106 GPa and tensile strength 3098 MPa) and epoxy as thermoplastic resin provided by Hindoostan Composite

Solutions. In organic fibres Aramid fibre (called aromatic polyamide fibre) has high tensile modulus and strength properties at high temperature compared to others.[11)]

Functioning of polymer composites can be improved by the addition of particulate fillers. Some of the fillers used are talc, silicon carbide, fly ash[12)], marble dust, granite powder[13)] and metals as aluminium flake and stainless-steel fibres. Out of this as a hard particulate matter marble dust is consumed in several variety of fields and usages like, construction substance, glass, plastic-elastic industries, cleansing specialist, purification and desulfurisation methods. In Rajasthan the natural contamination is expanded because of the development of leftover marble dust produced in the process of development of marble chunks. In present work marble dust residue (density as 2.69 gm/cc and grain size as 20.00 µm) was taken. Hardener (Hinpoxy C, density 0.95-0.96 gm/cc) is consumed in the proportion of 3.0:10.0 using epoxy resin, whose Gel timing at 26 degree-C is 120 minutes and full cure timing at 26 degree-C is 24 hrs.

2.2 Methods

Composite examples (EAF-1 to EAF-4) are ready in four distinct varieties using 0wt%, 5wt%, 10wt%, 15wt% of marble dust utilizing hand-layup method [14, 15)] keeping the aramid fiber at steady level of 40wt%. For mechanical and dynamic mechanical test, the samples are prepared of reasonable aspects. Table 1 indicates description and constituents of different samples.

Table 1: Description and constituents of samples.

Composites	Constituents
EAF-1	Epoxy + Aramid (40wt%) + Filler (0wt%)
EAF-2	Epoxy + Aramid (40wt%) + Filler (5wt%)
EAF-3	Epoxy + Aramid (40wt%) + Filler (10wt%)
EAF-4	Epoxy + Aramid (40wt%) + Filler(15wt%)

2.3 Mechanical Characteristics

Mechanical properties are characterized through mechanical investigation of polymer composites reinforced with aramid fibers with the incorporation of hard particles of marble dust. Addition of particulate fillers to the fibre reinforced composites alters mechanical properties of the composites. Experimental tests are conducted as per ASTM standards on composite samples are cut after fabrication. Mechanical properties investigated for composite samples[16)] (EAF-1 to EAF-4) are compared with the properties of unfilled aramid fibre reinforced composites.

2.3.1 Hardness

Hardness estimation is finished utilizing Rockwell hardness tester of Rockwell type. A 120-degree diamond cone indenter is constrained on to the surface of test specimen, subjected to a minor burden of 10 kgf initially. An extra significant heap of 150 kgf is applied through switch and reading of hardness is Rockwell hardness number is recorded at B scale shown at dial marker. Greatest worth of hardness is noted for composite EAF-3. Fig. 1 shows variety of hardness with weight fraction of composites.

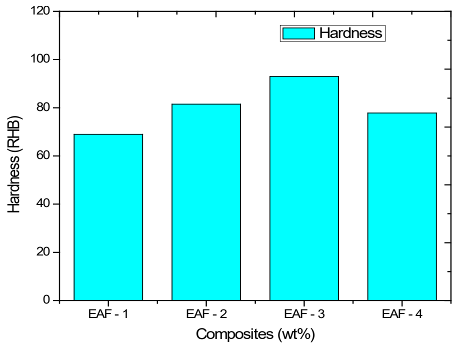

Fig. 1: The variation of hardness values for different fraction of filler content

It can be seen that, consideration of hard particles to the 40 wt% composite, hardness increments from 68.9 RHB to 94 RHB for filler percentage of 5-10wt% yet extra reductions from 94 RHB to 78 RHB due to expansion in filler percentage till 15 wt%. Expansion of marble particles altogether builds hardness of samples up as far as possible (10 wt%), yet additional expansion in filler percentage past 10 wt% declines mechanical properties because of expansion in moisture retention and expansion in permeability.[19)]

2.3.2 Density and void fraction

In this present work the composite is composed of three phases, one is fibre known as reinforcement, second is matrix and third is particulate filler, so the equation used for unfilled composite can be written in modified form as by Agarwal and Broutman[16)]

$$\rho_{ct} = \frac{1}{\left(\frac{w_f}{\rho_f}\right)+\left(\frac{w_m}{\rho_m}\right)+\left(\frac{w_p}{\rho_p}\right)} \quad (1)$$

Here, w stands for weight percentage, ρ stands for density. Suffix m is taken for matrix, f is taken for fiber, p is taken for particulate filler. and ct is taken for composites.

With the help of water immersion technique, we can calculate the actual density (ρ_{ce}) of the composite material experimentally. The following equation can be used to determine the volume fraction of voids (v_v) in the composite materials.

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

Due to the presence of voids and pores in the composite theoretical densities vary from experimental values. It is additionally noticed that void content increases with expansion in filler percentage from (5-15wt%) because of the abrupt change in shape and lack of moisture absorption capability.[18)]

2.3.3 Tensile Strength

Tensile test is performed using UTM (Instron 1195) on samples prepared as per ASTM standard has the designation D3039-76. The filler content of marble dust is taken as 0wt%, 5wt%, 10wt% and 15wt% respectively. Size of composite samples is 150 mm*10 mm*2 mm for all the particulate filled composites. The Crosshead speed is taken as 10 mm/min. As the filler percentage upsurges from 0-15 wt% leads to increase in tensile strength of composites. Fig. 2 shows the test results of tensile strength.

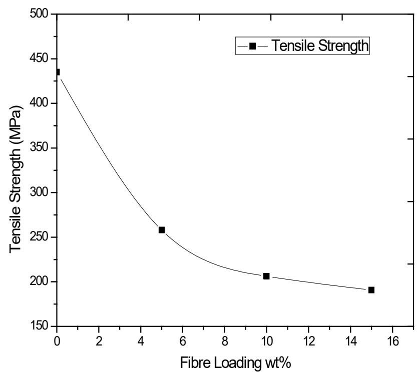

Fig. 2: Fibre loading vs. tensile strength

The unfilled aramid fibre composite with 40wt% fibre possesses 433.0 MPa tensile strength, it reduces to 258.0 MPa, 206.0 MPa, and 190.0 MPa due to increment in filler percentage progressively from 0wt% to 5wt%, 10wt%, and 15wt%. The main reason contributed in decrement of tensile strength is due to very low bonding between filler chunks and fiber material. Another probable cause is very crisp ends of the irregularly molded hard particles promote high-stress accumulation. The same behavior was observed for polymer composites filled with particulate filler.[19)]

2.3.4 Flexural and inter-laminar shear strength

Inter-laminar shear strength (ILSS) of composite is calculated using a short-beam shear (SBS) test. It is a 3-noded bend test conducted using UTM as per ASTM standard D2344-84. The size of composite samples is taken as 100 mm*10 mm*(1.3 to 2.4 mm). Crosshead speed and span lengths are taken as 10 mm/min and 60 mm respectively. It tends to be recorded from figure 3 that ILSS of unfilled with 40wt% fiber diminishes from 3.0 MPa to 2.83 MPa due to the inclusion of filler up to 5 wt%. Due to an expansion in filler percentage from 5-10 wt%, there is an abatement seen in the value of ILSS to 2.31 MPa. An expansion in filler percentage equal to 15 wt% prompts a minor expansion in ILSS worth 2.98 MPa. The inter-laminar shear stress is termed as the load exerted on to the portion of two neighboring layers per cross-sectional area.[20)] Thus, the conceivable explanation of diminishing in ILSS up to 10 wt% filler content is because of the weak interface.[21)]

2.3.5 Impact Strength

Impact testing machine is used to carried out impact test by taking sample specimen as per ASTM D 256. Size of composite samples is 50 mm*10 mm*2 mm, for all composites and a 2 mm V notch is created on the sample specimen.

The addition in the toughness is noted with the inclusion of marble dust in the aramid fibre-reinforced composite (40wt% fiber). Fig. 4 shows the constant enhancement in the value of toughness from 8 kJ/m^2 to 13 kJ/m^2 of samples because of an increment in the value of filler percentage from 0-15wt%. In several engineering applications polymer composites with hard particulate filler shows promising result when they are subjected to impact loading.[22)]

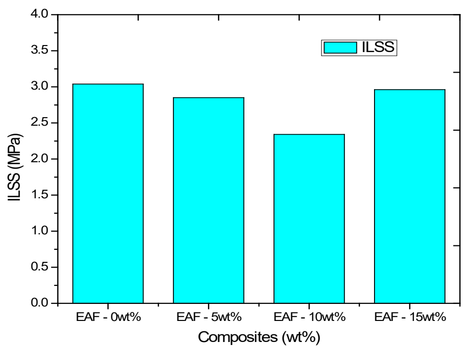

Fig. 3: Composites vs. inter-laminar shear strength

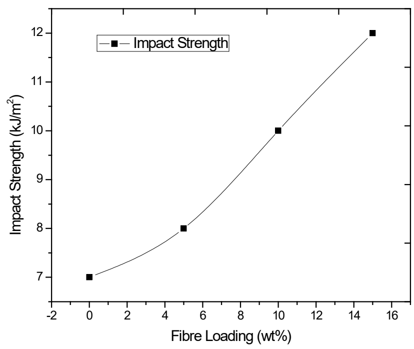

Fig. 4: Filler content vs. impact strength

2.4 Dynamic Mechanical Analysis of Marble Dust Aramid Composites

Dynamic mechanical analysis (DMA) as per ASTM D4065 is conducted for unfilled aramid epoxy composite in 3-point bending mode using Perkin Elmer DMA 8000 to analyze thermomechanical properties of composites. Dynamic mechanical analysis is performed to investigate dynamic properties like: Storage modulus (E'), Loss modulus (E") and Damping factor (tan delta). Test if performed at a heating rate of 3˚C/min, frequency of 1 Hz and temperature range of 25-120˚ C. Size of composite sample is taken as 50.1 mm*10.1 mm*(1.3 to 2.4 mm).

2.4.1 Storage Modulus (E')

At low temperature the value of elastic-storage modulus of the samples is in increasing order with addition of filler percentage from 0-15wt%. This is because of promising effect on the stiffness of the composite with increasing filler content.[23)]

The highest value of the storage modulus i.e., E''_{max} is observed for composite (EAF-4) filled with 50wt% marble dust. as the temperature increases beyond glassy transition temperature storage modulus E' decreases and above 70°C no change in the value of storage modulus is recorded. Improvement in the data of elastic-storage modulus value of 4000 MPa, 5600 MPa and 6750 MPa is recorded with the addition of 5wt%, 10wt% and 15wt% respectively as compared to the data of elastic-storage modulus of 3000 MPa of unoccupied aramid composite reinforced with 40wt% fibre.

2.4.2 Loss Modulus (E")

The toughness of the composite is related to the complex modulus or energy indulgence capacity of composites under cyclic stresses. The influence of temperature over loss modulus E" of composite is shown in Fig. 6. For composite with 5wt% marble dust filler the peak loss modulus gives the lower value as compared to unfilled composite.

As the filler content changes from 5wt% to 10wt% and 15wt% respectively the peak loss modulus shifts towards higher value as compared to unfilled composite and this is due to the enhancement in the energy dissipation capability of the composite with increase in filler content.[24)]

The value of Tg is independent of the filler loading on composite.

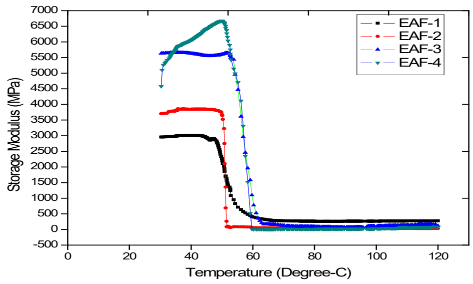

Fig. 5: Variation of storage modulus of marble dust filled composite

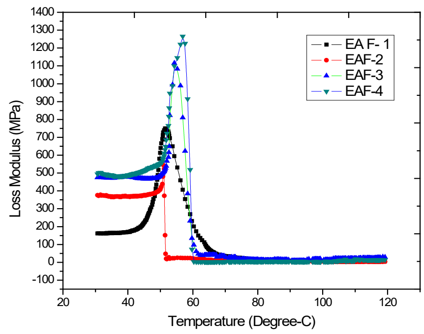

Fig. 6: Variation of loss modulus of marble dust fill composite

2.4.3 Damping Factor (Tan δ)

The variation of damping factor (Tan δ) with temperature of marble dust filled composites is shown in fig. 7 Factors like filler type, filler distribution, particulate fibre interaction and void content influence the damping properties of composites. Figure shows that peak values of damping factor increase with advancement in filler percentage and with this the glassy modulation temperature swings towards larger side of temperature.[25)] A reduction in peak value of the damping factor is reported.

with increase in filler content to 5wt% as compared to unfilled composite reinforced with 40wt% fibre. As the filler content increases peak damping factor increases but this increase in value is less than the damping factor of unfilled composite. Filler content does not give some promising effect on the damping factor of the composite.

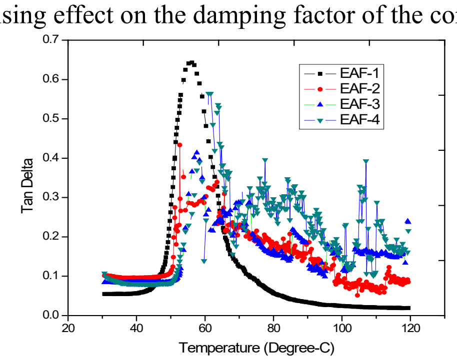

Fig. 7: Variation of damping factor of marble dust filled composite

Table 2: Mechanical characterization of marble dust filled composites

S. No.	Composite	Rockwell Hardness	Tensile Strength	Tensile Modulus	Flexural Strength	Flex Modulus	ILSS	Impact Strength
	Unit	(RHB)	(MPa)	(GPa)	(MPa)	(GPa)	(MPa)	(kJ/m²)
1	EAM- 1	68.9	434	11.41	200.62	14.197	3	7.1
2	EAM- 2	81.5	258	9.193	258.89	87.251	2.83	8
3	EAM- 3	93.01	206	16.96	283.66	83.778	2.31	10
4	EAM- 4	77.53	190	16.32	290.1	67.835	2.98	12.2

Table 3: Comparison of the dynamic mechanical properties of hybrid composites.

Composites	Temperature = 50.3˚C		
	Storage Modulus (MPa)	Loss Modulus (MPa)	Damping Factor
EAF-I	2113.14	666.45	0.3042
EAF-2	3523.89	422.70	0.1159
EAF-3	5608.62	492.33	0.0869
EAF-4	6660.19	557.74	0.08363

3. Conclusion

The current review confirms that consideration of hard particles modifies mechanical properties like tensile, bending, impact, and Inter-laminar shear strength of aramid fiber-reinforced polymer matrix composites. Thermo-mechanical properties, density, and Rockwell hardness are likewise impacted because of the inclusion of hard particles. Composite with 15wt% marble dust shows an increment in flexural strength but a decrement in the values of tensile strength. At 30-degree temperature the values of storage modulus of samples are comparable with similar values of flex modulus. Thus, the focus is to be made to choose appropriate hard particulate filler material and respective constituent for any specific practical approach of material.

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