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Experimentation and Investigation of E - Glass Fibre/ Polyester Composites Laminates

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Abstract

This paper centres on the autoclave moulding technique, offering a comprehensive analysis of the specimen fabrication process.The advanced composite manufacturing process involves the use of high temperatures and pressures during the curing step. This results in composite specimens that have a higher density and are devoid of any voids. Polyester, E-glass fibre, and SiC powder are the material components that make up the composite in this study. It is possible to construct composite specimens with nine different compositions by utilising the L9 orthogonal array, which is comprised of nine runs, four factors, and three levels. This array is utilized throughout the production process of the composite laminates. A total of nine distinct compositions were created by adjusting the parameters, which included the amount of time, the percentage of resin, fibre, and powder, and the amount of powder. Mechanical properties such as the specimens' hardness, compression, and impact strength were tested as per the ASTM standard. To locate a superior specimen and determine whether the specimen is suitable for use in automotive applications, Grey Relational Analysis was utilized. The accomplishment was achieved through the optimization of the specimens that were placed throughout the entire testing process and the result was achieved.

Keywords: E-Glass fibre, polyester, SiC, Mechanical properties, Interior carpeting car door

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INTRODUCTION

Fiberglass or carbon fibre reinforced polymeric materials (GFRPs or CFRPs) have proven popular in aircraft and aerospace, industrial applications because of their high strength-to-weight proportion and non-corrosive characteristics, making them ideal for the development of fuel-efficient automobiles for use on land and in the air. [1,2]. The composite carbon/glass laminate bumper beam has been developed through a combination of design optimization and impact analysis. For bumper beams, a lighter alternative to the traditional glass mat thermoplastic (GMT) was developed a carbon/glass matting thermoplastic (GCMT) [3]. Based on the expected mechanical characteristics of GCMT for design optimization, impact simulation was used to find an ideal design for the bumper beam [4]. It has been studied how Grewia Monticola Sond (GMS) fibers look, how they react to chemicals, and how they heat up.Several methods were used to do this, such as X-ray diffraction (×RD), thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), atomic force microscope (AFM), and 13C nuclear magnetic resonance (NMR). The findings showed that GMS fibers have a high cellulose content (55%), with a 33.5% crystallinity index and a crystallite size of 4.89 nm. They also have lower amounts of hemicellulose (14%), and lignin (15%) [15].This study analyzed the unique aerial root of Ficus retusa L. (FRL) fiber's physical, chemical, thermal, crystalline, surface, mechanical, and morphological properties. The aerial root fiber dimensions of the FRL are 495 μm in diameter and 1376 kg/m3 in density, according to physical studies. It had better specific strength and bonding because to its higher cellulose (64.12%) and low wax (0.33%) [16]. For testing the impact and mechanical characteristics of basalt and flax fiber-based thermosetting reinforced composites with vinyl ester resin [5], the manufactured laminates using the autoclave moulding process. . When using the autoclave process to fabricate laminates, tensile, flexural, and falling weight impacts were observed [6]. To enhance the mechanical characteristics, jute fibre has been hybridized [7] with glass fibre in a study to examine the mechanical and thermal characteristics of glass, and raw jute fibre strengthened epoxy composites [8]. It has been determined that the machinability of Al-based composites reinforced with 5 percent SiC and Al-based Hybridized composite materials enhanced with 5 percent SiC, 1 percent, and 2 percent Graphite powder (Solid lubricant) is dependent on the speed, feed, depth of cut, and material composition. The Design of Experiments method has been used to conduct experiments. The Grey relational-oriented Taguchi technique has been used for multi-objective optimization. Turning processes, such as cutting force and abrasive surface roughness, can be considerably improved using GRA [9]. From the above literature survey, it can be concluded that glass fibres can improve mechanical properties and the strength-to-weight ratio of hybrid composites. Moreover, the grey relational oriented Taguchi method can enhance the performance characteristics of composite material. Also, the autoclave moulding method can improve mechanical properties.

Therefore, in the present paper suitability of glass fibre/SiC/polyester composites for automotive body building applications has been studied by conducting experimental tests and optimization using GRA.

MATERIALS AND METHODS

E-Glass fibre

To preserve a defect-free formation by the extrusion process, E-Glass fibres have been formed besides having drawn molten glass into very fine threads is shown in Fig.1 and instantly safeguarding those from contact with the environment or hard surfaces. E-glass fibres were as strong as any relatively new inorganic fibres, but they lacked rigidity due to their molecular structure. E Glass fibre Properties is shown in Table 1.

Figure 1. E-Glass Fibre.

Table 1. Properties of E – Glass fibre

Properties	Tensile strength (MPa)	Compression Strength (MPa)	Density (g/cm3)	Thermal expansion (µm/m·°C)	Softening T(°C)
E-glass	3444.78	1080	2.58	5.4	846

Polyester

Polyester is a polymer in which each repeating unit of its main chain contains an ester functional group. Typically, it refers to a substance characterized as polyethylene terephthalate (PET). Polyesters were seen in nature and include the cutin element of plant cuticles, composed of omega hydroxy acids that play an important role in creating polyester polymers of variable size via ester linkages.

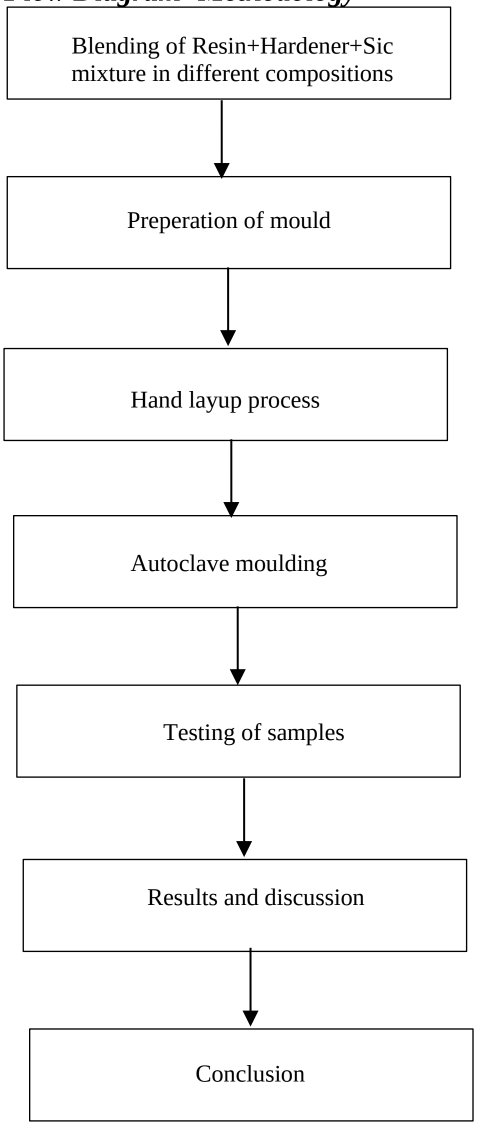
Silicon Carbide

Its chemical formula is SiC, and it is made up of silicon and carbon. Ceramics used in automobiles can be made from extremely hard SiC grains by sintering.

EXPERIMENTAL METHODOLOGY

The specimens are fabricated in the following way is shown in below flow chart.

Flow Diagram- Methodology



Autoclave moulding

The chamber of an autoclave is a hard container where a vacuum pump eliminates air as well as other gases. This results in a low-pressure environment within the chamber, commonly known as a vacuum, and the temperature is controlled using a temperature controller.

In this study, composite specimens were fabricated using the autoclave moulding process. The specimens were made at a vacuum pressure of 1 bar. A closed chamber with a hollow cylindrical heater was utilized, with the chamber insulated with glass wool to prevent heat emission from the heater. The heater had a 1,000 W rating and could heat up to 200 ˚C. An external temperature controller controlled the temperature of the chamber. The long fibres were sliced into 100 mm and then used in the mould (100 × 100 mm). The hand layup method was initially used to prepare layers of fibres and fibres stacked upon the mould surface, followed by coating the phenolic resin on each layer. The mould was then placed inside the vacuum chamber to fabricate the specimen is shown in Figure 2.

RESULT AND DISCUSSION

Hardness

A solid object's resistance to various types of permanent form change when compressed is measured by its hardness [10]**.** Here used a 5mm indenter ball diameter of the hardened steel, and the 500kg load was maintained constant for a 10seconds. Then the indentation of the specimen is measured by a Brinell hardness.

Compression and Impact strength

Measuring a material's compression strength is possible by measuring how well it can sustain stresses that diminish its size [11]. In this work, a universal testing machine is utilized to identify the compression strength.Compression test specimens are shown in Fig.3. Furthermore, impact tests are used to study material's toughness [12]. It is calculated by the Charpy impact test using ASTM D256 standard specimen is shown in Figure 4.

The fabricated specimens were subjected to various mechanical testing, such as compression strength, hardness, and impact strength.

Figure 2. Fabricated specimens.

Figure 3. Compression tested Samples.

Figure 4. *Impact-tested Samples.*

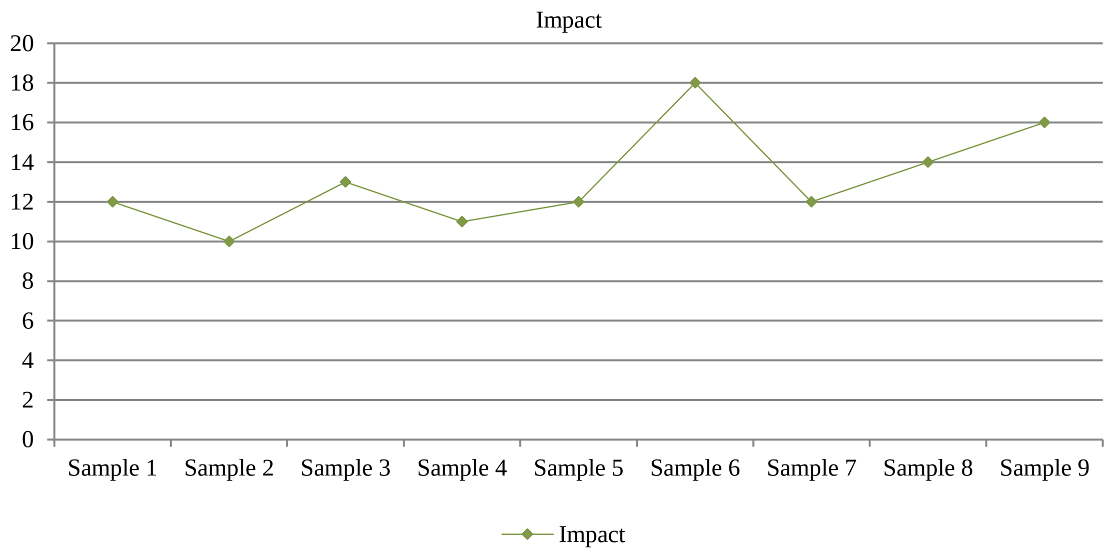


Figure 5. No of Samples Vs Impact Strength (J).

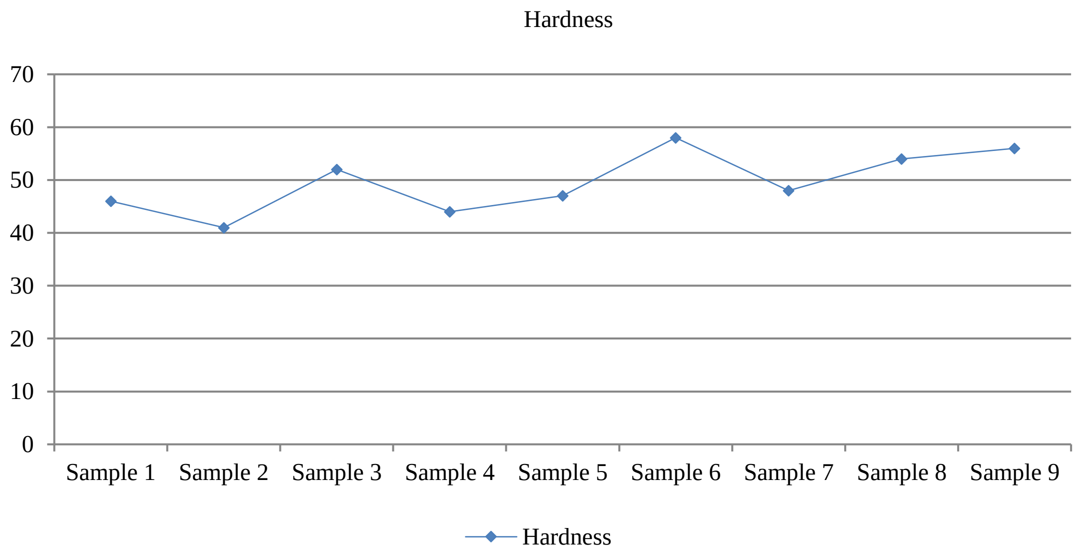


Figure 6. No of Samples Vs Hardness (BHN)**.**

Impact strength and Hardness

From the above Figure 5 & Figure 6, it is concluded that the best one out of 9 samples was sample 6. It is because of the weight percentage of reinforcements such as glass fibre & SiC. Sample 6(resin 120 gm, fibre 50 gm, SiC 5 gm, and Time duration 10 min) has high impact and hardness values of 18J & 58BHN, respectively.

Compression

From Figure 7, it is observed that sample 1 (resin 90gm, fibre 30gm, SiC 2.5gm, and Time duration 10min) is the best among the nine samples. The compression strength value is 65.72MPa.

GREY TAGUCHI METHOD

The Taguchi method entails reducing variation in a process through robust experiment design. Overall, the method's objective is to give the manufacturer a greater quality product at an affordable price. Design of input parameters and their ranges are shown in Table 2.

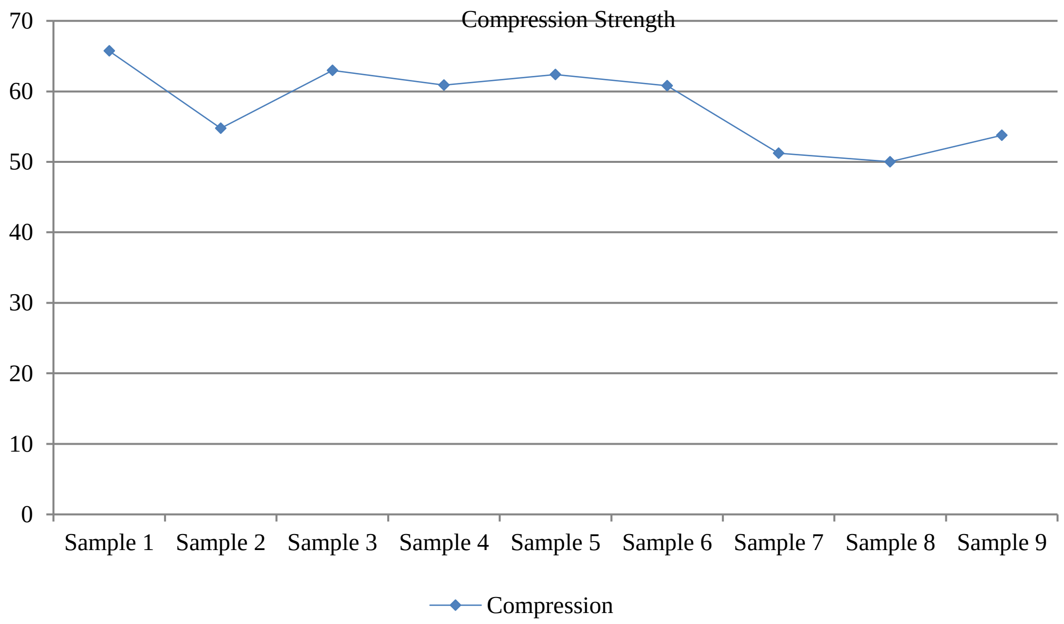


Figure 7. *No of Samples Vs Compression Strength (MPa)***.**

Table 2. Design of input parameters and their ranges

Parameters	**Units**	**Levels**		
		-1	0	1
Resin	(gm)	90	120	150
Fibre	(gm)	30	40	50
SiC	(gm)	2.5	5	7.5
Time	(min)	10	15	20

Orthogonal Arrays

Dr. Taguchi's quality engineering methods, which use the design of experiments (DOE), are high-quality systems designed at low cost using TQM's statistical techniques.

Experimental runs and results

Experiments were conducted as per the Taguchi L9 orthogonal array designed with 9 runs 4 parameters, and 3 levels is shown in Table 3.

Grey Relational Technique

Normalization

In grey relational analysis, Normalization is a data pre-processing method of transfer comparison of the original sequence with a similar sequence [13]. An experiment's data is normalized between zero and one for this. Three methods are available for normalizing as. 1. Lower the better, 2. Larger the better, 3.Nominal the better. In this present work, Larger the better approach was used because our output properties Hardness, compression and Impact strength is shown in Table 4.

It has the property of 'the-larger-the-better' if the value of the original sequence is endless [14]. The following mathematical formula is used for normalization is shown in equation 1

$$\mathrm{Xi(k)} = \frac{\mathrm{Xi\ (k)} - \mathrm{minXi\ (k)}}{\mathrm{maxXi\ (k)} - \mathrm{minXi\ (k)}} \ (1 \qquad (1)$$

Grey relational Coefficient and Grey Relational Grade

A grey relational coefficient is mathematically determined using normalized values is shown in Table 5. The following formula is used for the grey relational coefficient is shown in equation 2.

$$\varepsilon i(k) = \frac{\Delta \min + \varsigma.\Delta max}{\Delta oi(k) + \varsigma.\Delta max} \tag{2}$$

Table 3. Experimental runs and their results.

Ex. No:	Resin (gm)	Fibre (gm)	SiC (gm)	Time (min)	Hardness (BHN)	Compression strength (MPa)	Impact strength (J)
1	90	30	2.5	10	46	65.72	12
2	90	40	5	15	41	54.75	10
3	90	50	7.5	20	52	62.95	13
4	120	30	7.5	15	44	60.88	11
5	120	40	2.5	20	47	62.36	12
6	120	50	5	10	58	60.74	18
7	150	30	2.5	20	48	51.24	12
8	150	40	7.5	10	54	50.02	14
9	150	50	5	15	56	53.77	16

Table 4. Normalization.

Ex. No:	Normalization		
	Hardness (BHN)	*Compression strength (MPa)*	*Impact strength (J)*
1	0.2941	1	0.25
2	0	0.3012	0
3	0.6471	0.8235	0.375
4	0.1765	0.6917	0.125
5	0.3529	0.7859	0.25
6	1	0.6828	1
7	0.4117	0.0777	0.25
8	0.7647	0	0.5
9	0.8823	0.2388	0.75

Table 5. Grey relational coefficient.

Ex. No:	Grey relation coefficient		
	Hardness(BHN)	*Compression strength (MPa)*	*Impact strength (J)*
1	0.4146	1	0.4
2	0.3333	0.4171	0.3333
3	0.5862	0.7391	0.4444
4	0.3777	0.6185	0.3636
5	0.4358	0.7003	0.4
6	1	0.6118	1
7	0.4594	0.3515	0.4
8	0.6799	0.3333	0.5
9	0.8096	0.3965	0.6666

Table 6. Gray grade.

Ex. No:	Grey grade			
	Hardness (BHN) (0.3)	***Compression strength (MPa) (0.4)***	***Impact strength (J) (0.3)***	***Grey grade***
1	0.1244	0.4	0.12	0.6444
2	0.0999	0.1668	0.0999	0.3668
3	0.1758	0.2956	0.1333	0.6048
4	0.1133	0.2474	0.1091	0.4698
5	0.1307	0.2801	0.12	0.5308
6	0.3	0.2447	0.3	0.8447
7	0.1378	0.1406	0.12	0.3984
8	0.2040	0.1333	0.15	0.4873
9	0.2428	0.1585	0.1999	0.6014

Grey grades were calculated based on the weightage given to grey relational coefficient values from Table 6. Compression strength is an important factor to be considered for automotive body building applications. So, 0.4 weightage has been given to it. At the same time, hardness & impact strengths were given 0.3 weightage.

The above results were obtained by grey relational analysis. From the result in Table 6 it is observed that sample 6 is the best one among the 9 samples. This GRA shows that sample 1 has a good compression strength of 65.72 MPa. It was 5 MPa higher than sample 6 (60.74 MPa). But the other output parameters hardness and impact strength were higher for sample 6 compared to other samples. Moreover, sample 6 has the highest grey grade value in GRA. So sample 1 was not chosen. Sample 6 was chosen as best after optimization using GRA.

MICROGRAPH (SEM)

SEM image was taken by using a VEGA3 TESCAN SEM machine at The Gandhigram Rural Institute in Dindigul. The surface micrograph was studied for E-GFRP composites as well as natural fibre composites by changing the view field and image magnification.

Nature of Sample: dry condition
Sample Size : 1 cubic cm & thin film 1*1 cm

GFRP Micrographs

The surface micrograph's SEM image shows a uniform mixture and distribution of resin (polyester), silicon carbide, and glass fibre throughout the sample is shown in Fig.8. Thus it results in better bonding and coherence between glass fibre and resin. SEM images at 5 µm magnification revealed detailed fiber surface properties, such as fine surface roughness and micro-textures on E Glass fiber. The matrix was found to permeate into the fiber surface grooves, possibly improving mechanical coupling. The fine-scale characteristics visible at this magnification were crucial in determining surface topography and resin penetration at the fiber/matrix contact. While the E Glass fiber had rough surfaces, which could aid in adherence. At 10 µm magnification, the fiber-matrix interaction became more evident. The interface revealed a more visible interfacial transition zone (ITZ), where the polyester resin began to merge with the E glass fiber. At this scale, it was simpler to pinpoint locations where the polyester resin entered the E glass fiber surface more efficiently, resulting in better bonding. SEM pictures at 20 µm magnification revealed more detail about the fiber-matrix interaction. The polyester resin material was more evenly dispersed, and regions of good adhesion were readily visible. The fiber-matrix interface was more visible at a bigger scale at 50 µm magnification, making it possible to examine larger sections of the composite material. Overall, the matrix distribution was more consistent, but it was easy to identify weak bonding locations.

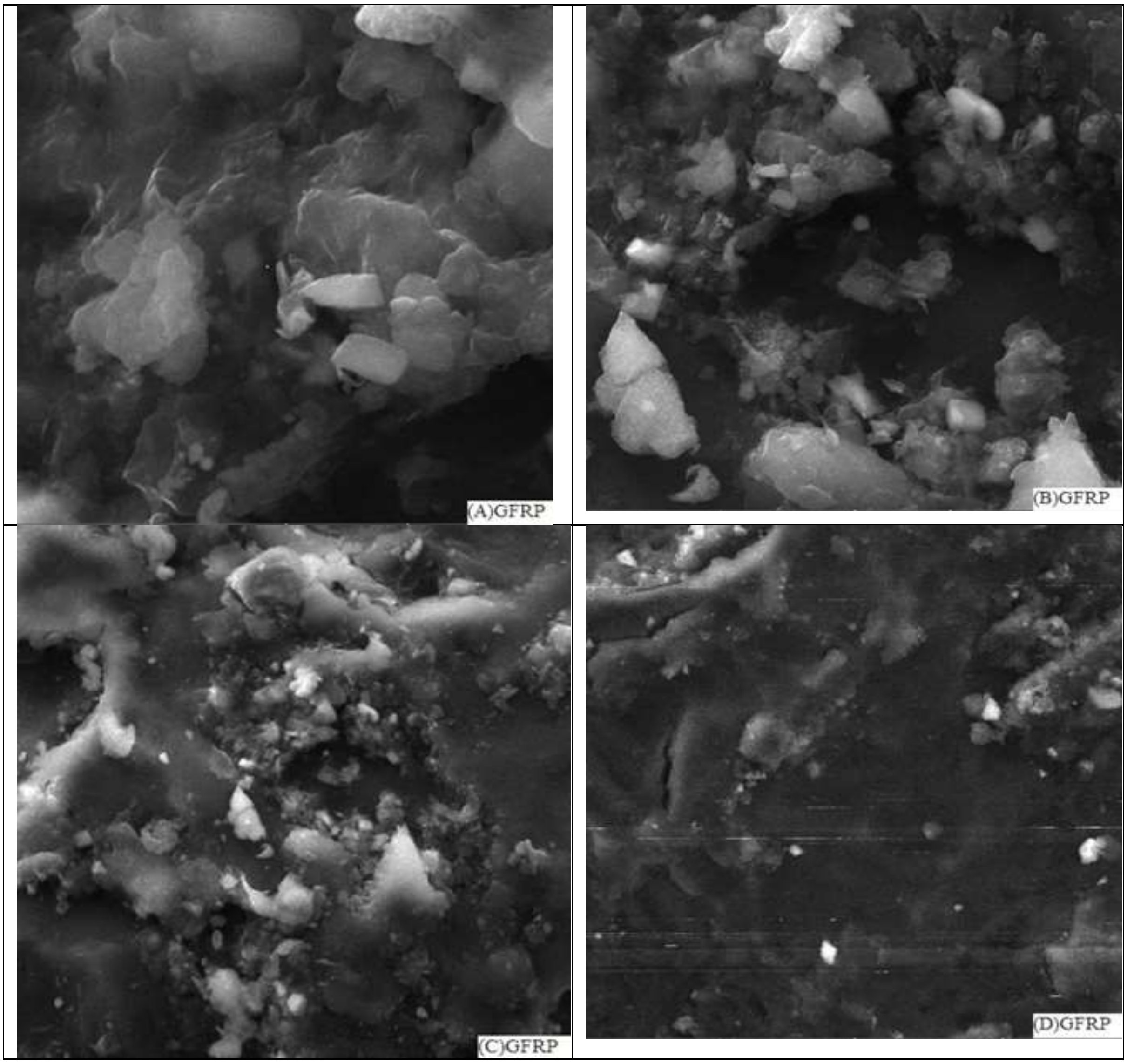


Figure 8. SEM micrograph images showing the top surface of specimens at various magnification: (A) 5µm (B) 10µm (C) 20µm (D) 50µm.

CONCLUSIONS

This research has studied the effect of composition & method of fabrication on the mechanical properties of composite material based on E-glass fibre/SiC/polyester. It has been discovered that the E-glass fibre content enhances compression and impact strengths. Moreover, the hardness has increased while fabricating the composite laminae by the autoclave moulding method. This is because of the accelerated curing process and controlled application of pressure & temperature. Hence this work has concluded that composites' composition and method of fabrication have an influence on their mechanical properties like hardness, compression, and impact strength and improve the same.

In addition GRA, an optimization technique, can be applied to find the suitability of using a particular composite material for automotive applications. Grey relational analysis has concluded that sample 6 with influencing parameters such as resin 120gm, fibre 50gm, SiC 5gm, and time duration 10 min has the optimum mechanical properties. Since the mechanical properties of hardness, compression, and impact strength have been improved the, sample 6 mentioned above can be used for automotive body building applications like interior carpeting of car door.

FUTURE SCOPE

In place of E-glass fibres natural fibres can be used as reinforcement. And the same fabrication method, testing, and optimization can be done.

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