Synthesis and characterization of natural fiber reinforced laminated thermoplastic composite

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Abstract. As increase in the use of eco-friendly, natural fibers are used for the reinforcement of polymer composites which has the light weight and low-cost polymer composites with better mechanical properties which offers exceptional properties over glass fiber. In this work, Basalt fiber reinforced Polypropylene (PP) laminated composite was manufactured by the compression moulding process. The variations of impact, flexural and compression strength and modules of the composite according to the number of basalt fiber layers were investigated. Scanning electron microscopy (SEM) and Energy-dispersive X-ray (EDX) conducted on the surface of the composite reveal the superior interfacial linkage between the basalt fiber and PP matrix. Hence, this offers a comprehensive discussion on synthesis and characterization of basalt fiber with polypropylene reinforced laminated thermoplastic composite.

Keywords: Polypropylene, Laminated, Thermoplastic Composite, Basalt Fiber, Scanning Electron Microscopy (SEM).

1. Introduction
The use of natural fibers for the reinforcement of the composites has received increasing attention both by the academic sector and the industries. Natural fibers have many significant advantages over synthetic fibers currently, many types of natural fibers have been investigated for use in plastics. Natural fibers are potential reinforcing materials and their usage till today has been more traditional than technical. They have been serving many useful purposes for a long time but the application of the material technology for the exploitation of natural fibers as reinforcement in polymer matrix happened in relatively recent years.[1] A promising material for usage in various applications is the basalt, which is solidified volcano lava. The basalt fibers are attractive to be used as reinforcement in composites similar to fiber glass, having better physic mechanical properties than fiber glass, but being significantly cheaper than carbon fiber. They also have a high elastic modulus, resulting in high specific strength three times that of steel.

Fiore et al. [2] observed the presence of basalt layers increases the mechanical properties to a highest extent in hybrid laminates in comparison with GFRP laminates. Salvatore et al. [3] stated that the basalt fibers provide potential improvements in interlaminar properties and flexural modulus to hybrid basalt/glass fiber reinforced polymer composite compared with the glass fiber reinforced
polymer composite. Dorigato and Pegoretti [4] found that the addition of basalt fibers in the epoxy-based carbon fiber reinforced composites enhanced the impact properties. Laminated polymer composites have many beneficial properties such as low density, good insulation, environmental resistance and good mechanical properties. Hossain et al. [5] fabricated jute epoxy laminated composite using vacuum assisted resin infiltration technique and characterized the fabricated composites by tensile and three-point bend tests.

Compression moulding is a high-pressure, high-volume method appropriate for moulding high-strength, complex fiberglass reinforcements. Advanced composite thermoplastics can also be compression moulded with chopped strand, randomly oriented fiber mat, woven fabrics or unidirectional tapes. The benefit of compression moulding is its capability to mould moderately intricate large parts. Besides, it is one of the cheapest methods when compared to other methods like injection moulding and transfer moulding. Furthermore, the material wastage is comparatively low giving it a benefit while fabricating expensive components. The process parameters include moulding time, temperature, and pressure. The present investigation deals with the fabrication of basalt fiber reinforced polypropylene laminated composites using the compression moulding method, mechanical characterization like flexural, compressive and impact properties and microstructural analysis through SEM and EDX.

2. Materials and Method
In this study, polypropylene (PP) in sheet form with a thickness of 1 mm procured from Lakshmi Corporations, Chennai, Tamil Nadu is used as the matrix material whereas the reinforcement of Basalt fiber in the mat form supplied by Go Green Products, Chennai, Tamil Nadu is used. The properties of the polypropylene and basalt fiber are shown in Table 1 and Table 2 respectively. The laminated composites are fabricated employing compression moulding process as shown in Figure 1. Two specimens of size 380 x 170 x 17 mm are prepared with different weight fractions of basalt fiber and polypropylene. Sample 1 contains 40% basalt fiber and 60% polypropylene with 8 layers of basalt fiber and 9 layers of polypropylene while Sample 2 contains 30% basalt fiber and 70% polypropylene with 7 layers of basalt fiber and 10 layers of polypropylene. Table 3 shows the process parameters of compression moulding process used in the fabrication of polypropylene laminated composites reinforced with basalt fiber. Each sample is placed in the mould and the required temperature, pressure and curing time are set after applying some amount of release agent on the upper and lower surfaces of the mould to avoid sticking of composites with the mould surface during curing.

Table 1. Properties of Basalt Fiber

| Density (g/cm³) | Tensile strength (GPa) | Elastic modulus (GPa) | Elongation (%) | Maximum temperature (°C) |
|----------------|-----------------------|----------------------|---------------|--------------------------|
| 2.62-3.05      | 3.0-3.5               | 79.3-93.1            | 3.2           | 650                      |

Table 2. Properties of Polypropylene

| Density (g/cm³) | Poisson’s ratio | Thermal expansion (µm/m°C) | Thermal conductivity (W/m-k) | Specific heat capacity (J/g°C) | Heat transfer capacity (J/g°C) | Friction coefficient |
|----------------|-----------------|----------------------------|-------------------------------|--------------------------------|-------------------------------|---------------------|
| 0.9            | 0.42            | 100-180                   | 0.15                          | 1.8                            | 24.5                          | 0.1                 |

Table 3. Process Parameters

| Specimen     | Temperature (°C) | Pressure (bar) | Curing time (min) |
|--------------|------------------|---------------|-------------------|
| Sample 1     | 200              | 100           | 180               |
| Sample 2     | 220              | 100           | 240               |
3. Results and Discussion

3.1. Flexural Properties

Flexural properties denote the material flexibility and better flexural strength illustrates that the materials have high hardness and brittle properties [6]. The specimens for flexural test were prepared in accordance with ASTM D790 standard. A 3-point bending test is carried out for all two samples and the results are presented in Figure 2. The measured flexural strength determines the behaviour of the material under simultaneous compressive and tensile loading. The flexural strength increased from 68.6 MPa to 78.2 MPa as the basalt fiber proportion in the composite increased from 30% to 40% in the composite. Hence the addition of fibres increased the flexural properties of the composites [7].
Figure 2. Flexural behaviour of basalt fiber reinforced PP laminated composites

3.2. Compressive properties
Compressive testing was carried out in accordance with ASTMD95 standards. The results are shown in Figure 3 and 4. The Compressive strength of a material is the maximum amount of compressive stress that it can take before failure. A maximum compressive strength of 0.22 GPa was obtained by Sample 1. The compressive properties of the composites were improved with the increase in the fiber content [8]. A substantial enhancement in compressive strength has been observed due to good interfacial bonding between the matrix and the fiber [9].

![Test results](image)

Figure 3. Compressive behaviour of 40% basalt fiber reinforced PP laminated composite
3.3 Impact properties

Impact energy is the amount of energy absorbed by a specimen during fracture and also it is the measure of toughness of the material. The specimens for the impact test are prepared in accordance with ASTM A-370 standard. The energy required for breaking the material during the test is measured and plotted in Figure 5. A maximum Impact strength of 14 J was shown by sample 1. The composite fails through the following modes namely fiber pull-out, fiber/ matrix debonding, delamination, matrix cracking during the impact [10].

![Graph showing impact strength](image)

**Figure 5.** Impact strength of basalt fiber reinforced PP laminated composite

3.4 Microstructure analysis
To evaluate the condition at failure, surfaces and fracture of material were observed with Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX). Specimen for the SEM were cut (10x10 mm in size) from the sample. Before being analyzed, the surfaces and cross-section were coated. Figure 6 shows the surface morphology of the basalt fiber reinforce PP laminated composite. The surface of the basalt fiber has higher roughness and it increases the bonding area between the fiber and matrix. Hence, there is a good adhesion between the fiber/matrix leading to increase in the mechanical properties of the composites [11]. The failure due to tensile stress is incomplete and improper because of that multi-layer fabrication is used in this composite proving that the multi-layered composites has more strength compared mono layered composites [8].

**Figure 6.** SEM and EDX of basalt fiber reinforced PP laminated composite

### 4. Conclusion

In the present investigation, basalt fiber reinforced polypropylene laminated composites were successfully fabricated through compression moulding process. The mechanical properties of the composites like flexural, compressive and impact are evaluated and also the morphological characteristics are studied using SEM with EDX analysis. The results indicated that the mechanical properties were improved with the increase in the weight proportion of the basalt fiber in the polypropylene matrix. A good bonding between the basalt fiber and the polypropylene matrix is observed through the SEM microstructure analysis.

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