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Research Article

Investigation of Mechanical Properties of Basalt Particle-Filled SMC Composites

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Basalt particles have been investigated as a novel additive for the production of glass fibre reinforced composite using sheet moulding compound (SMC) method. Compared to the $CaCO_3$ that are widely used as filler in the SMC composite, the resulting composites exhibit improved mechanical properties. The tensile strength increased by approximately 15%, whereas the flexural strength was enhanced by 8% in SMC composites prepared by basalt particles. Examination of the surface morphology and interfacial debonding of the specimens is also performed via scanning electron microscopy. Superior strength properties are observed in the basalt particle-reinforced composites compared to those with the $CaCO_3$ fillers.

1. Introduction

Polymer composites are composed of an inorganic reinforcement and a polymeric matrix, providing the desired combination of mechanical, chemical, and thermal resistance features. Due to its distinct advantages such as design flexibility, dimensional stability, consolidation of parts, high strength, light weight, moderate tooling and finishing costs, and corrosion resistance, sheet moulding compound (SMC) is one of the widely used composite preparation methods. The SMC method is a sheet of ready-to-mould composites containing uncured thermosetting resins and uniformly distributed short fibres and fillers. Commonly, glass fibre is used as a reinforcement material and unsaturated polyester as a matrix, along with various fillers and additives in the prepreg formulation. Calcium carbonate ($CaCO_3$) is cheap and easily available filler and thus is the most widely used filler in the composite preparation. Due to its high surface energy, the $CaCO_3$ reduces mechanical properties of the composite materials [1].

Basalt is a rigid, hard, and durable volcanic mineral which is dark grey or black in colour. It consists of approximately 50% SiO_2 basalt and originated from the solidification of hot magma flows rising from volcanoes or cracks in the earth's crust. Recently, basalt fibre is used as an alternative reinforcement material, which exhibits exceptional characteristics and mechanical properties compared to those of glass fibres. Basalt-polymer materials are primarily used in building construction, and then they began to be employed in the automobile, machine, and aerospace industries as a replacement for traditional glass and carbon fibre reinforcements [2–5]. Moreover the basalt fibre is fire resistant and forms insulation against sound and heat and thus presents a more economical alternative to the carbon fibre. For instance, the chopped basalt fibre can also be mixed with cement to provide both lower weight and higher structural strength [6–8]. Similarly, basalt particles have also been used as fillers for polymer composites. An important feature of the basalt particle is its suitability for the moulding process. By adding basalt particles at a specific rate into the polymer matrix the corresponding composites were produced via moulding. The various properties of these materials involving wear, mechanical properties, and chemical resistance are remarkably enhanced and no bubbles or pores were observed in the structure [9, 10].

A novel strategy has been developed to improve the fibre reinforced composite properties by introduction of additional particles in the polymer matrix. For example, the

Table 1: Chemical compositions of basalt particle [12].

Compound	Weight percentage in basalt (%)
SiO_2	51.6–57.5
Al_2O_3	16.9–18.2
CaO	5.2–7.8
MgO	1.3–3.7
Na_2O	2.5–6.4
K_2O	0.8–4.5
Fe_2O_3	4.0–9.5

mechanical properties of carbon fibre reinforced epoxy composites have been enhanced by the addition of graphene nanoparticles, which enhance the interface mechanics via chemical bonding [11]. In another study, Ary Subagia et al. examined the effect of different tourmaline micro/nanoparticle fillers in basalt fibre reinforced epoxy composites produced via vacuum-assisted resin transfer moulding. With the addition of the particles, the composites gained increased tensile and flexural properties [2].

In this study, a comparative study for the SMC composites prepared with glass fibre reinforced composite containing either $CaCO_3$ or basalt particles has been reported based on their microstructure and mechanical properties. The composites produced from basalt particles had better mechanical properties compared with $CaCO_3$ particle-reinforced SMC composites. The mechanical properties of the specimens are investigated in accordance with the standard tests. The surface morphology of the specimens is examined in more detail via scanning electron microscopy.

2. Materials and Methods

2.1. Materials. The basalt particle is purchased from Basaltex (Masureel Group, Belgium) and its chemical composition is given in Table 1.

The E-glass fibre with bundle diameters of 15 μm is provided by Cam Elyaf A.S. (SMC3-2400) and cut into 65 mm length and added into resin randomly at a concentration of 20% by weight. For the unsaturated polyester resin, Polipol™ 347-BMC-SMC (Poliya, Istanbul, Turkey) is used in the experiments, and the resin properties are given in Table 2.

2.2. Preparation of SMC Composites. The SMC composites are produced in two steps. In the first step, the prepreg formulation is prepared according to a given formulation (Table 3) and is incubated for a maturation period (Figure 1). This time period plays a vital role in the bonding between the resin and the fibre. Hence, this bonding also affects the mechanical properties of the composite material.

In the second step, the SMC plates were retained in a specially prepared $140 \times 280\,mm^2$ sheet mould at temperatures of 140–150°C under the effect of 80-bar constant pressure for about 4 min (Figure 2).

2.3. Characterization. A diamond saw is used to cut the manufactured plates and the specimens are prepared according to ISO527 and ISO178, respectively, for tensile and flexural strength tests. The tensile tests are performed with the Shimadzu-AG-I machine at a speed of 5 mm/min and the flexural tests are done using the Zwick-1446 machine (Figure 3) at 2 mm/min.

The morphological features of the broken composite surfaces obtained from the tensile and flexural tests are characterized by SEM (Carl Zeiss EVO 40) with accelerating voltage of 20 kV. The specimen surfaces are coated with gold palladium and observed under reduced pressure.

Table 2: Polyester resin properties.

Property	Value
Density	1.118 gr/cm^3
Tensile strength	52 MPa
Flexural strength	117 MPa
Elongation at break	3.86%

Table 3: The formulation of SMC prepreg.

Compound	Weight percentage (%)
Unsaturated polyester	36
Thermoplastic resin	10
Polymerization catalyst	0.5
$CaCO_3$ or basalt particle	30
Glass fibre SMC3-2400 (65 mm)	20
Other additives	3.5
Total	100

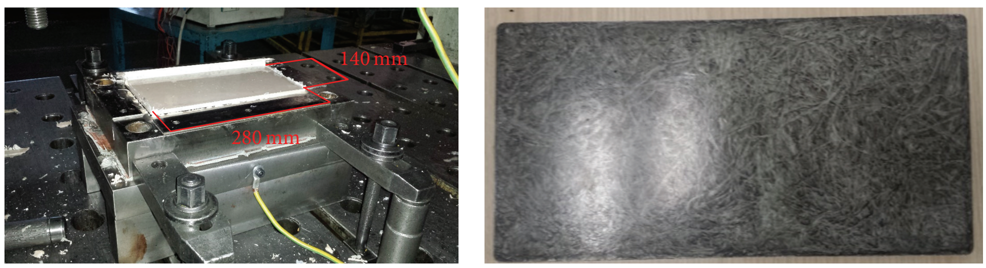
3. Results and Discussion

The strength of the composite materials is directly related to the interfacial mechanics between matrix and fibre. The interface strength increases the composite material strength. In recent years, some attempts have been made to improve these chemical and mechanical bonds. The particle additives are usually aimed at reducing the cost, but the chemical and physical properties of composite materials featuring particles produced with additives are also improved. Basalt fillers are used in road construction and, in mineral form, for heat and sound insulation. As a reinforcing filler material, it is used in composites where improved mechanical properties are desired. Moreover, it is also used to improve wear and corrosion resistance. In this study, the specimens were produced with basalt particles instead of the commonly used $CaCO_3$ filler and the mechanical properties of these new composite materials were investigated. The specimens were broken using testing equipment according to standard procedures, as shown in Figure 4.

Generally, glass fibre provides the greatest strength when used as the reinforcement material in SMC composites, whereas the $CaCO_3$ fillers are useful to tune the paste viscosity and reduce the cost. The main purpose of this study is to improve the mechanical properties of SMC composites through the improvement of matrix properties by the addition of basalt particles instead of $CaCO_3$ fillers. The replacement of $CaCO_3$ fillers with basalt particles brings

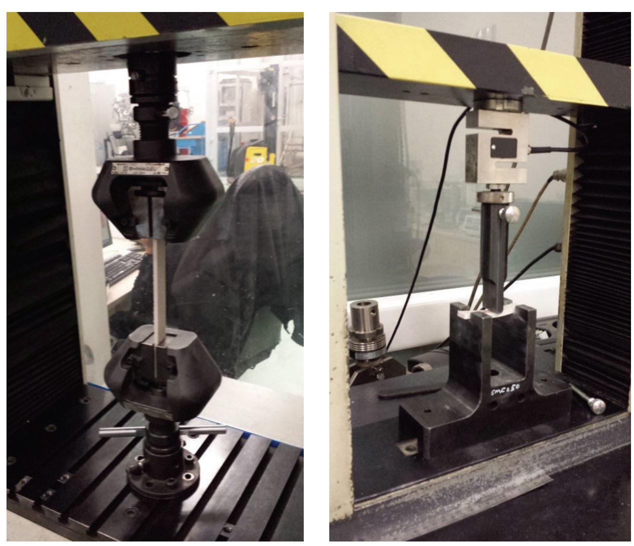
(a) (b)

Figure 1: Prepreg formulations containing (a) $CaCO_3$ and (b) basalt particles.



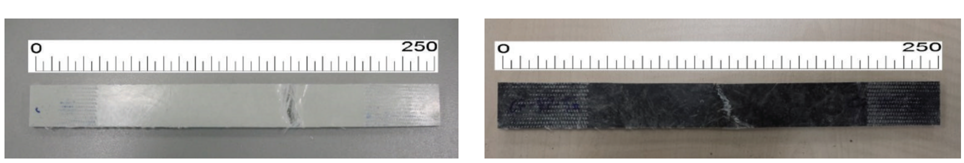
(a) (b)

Figure 2: (a) SMC plate containing $CaCO_3$ filler in the mould and (b) SMC plate containing basalt filler.



(a) (b)

Figure 3: The specimens fixed the testing device (a) tensile and (b) flexural tests.



(a) (b)

Figure 4: Broken test specimens, (a) filled with $CaCO_3$ and (b) filled with basalt particles.

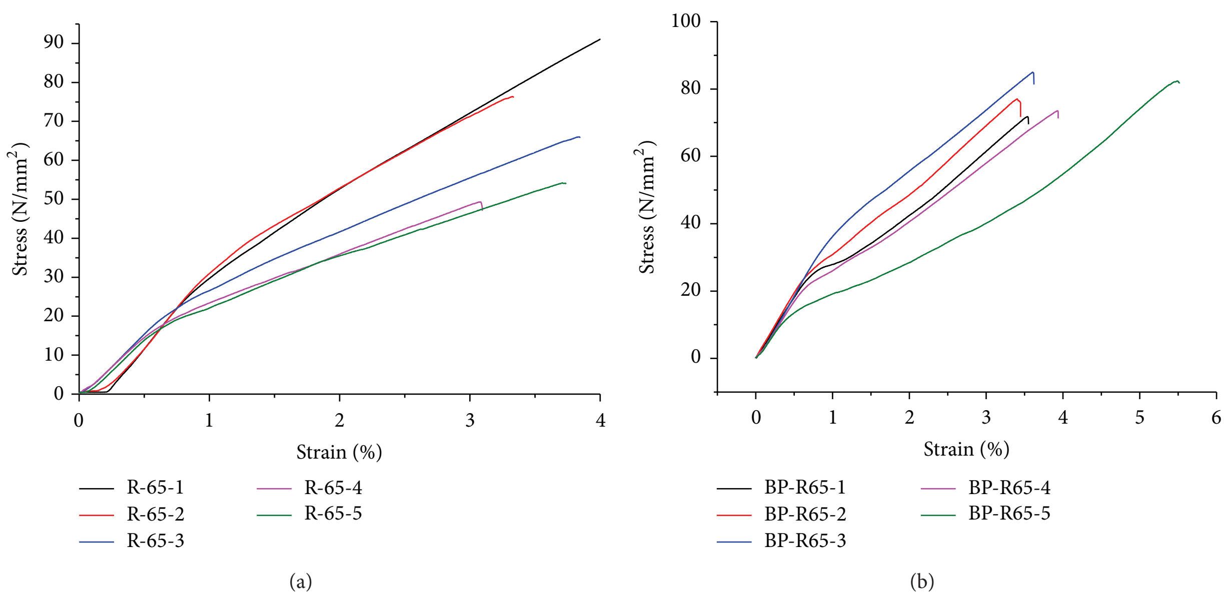


FIGURE 5: Tensile strength values of composite materials filled with $CaCO_3$ (a) and basalt particles (b).

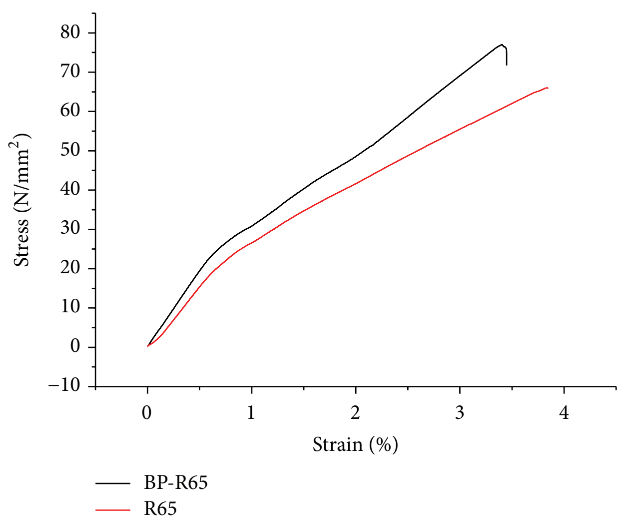
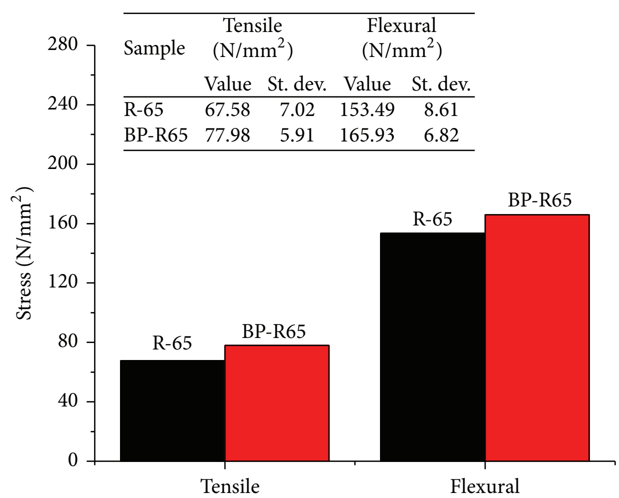


FIGURE 6: Sample tensile strength values of a specimen.



Sample	Tensile (N/mm^2)		Flexural (N/mm^2)	
	Value	St. dev.	Value	St. dev.
R-65	67.58	7.02	153.49	8.61
BP-R65	77.98	5.91	165.93	6.82

FIGURE 7: The average values for tensile and flexural strength values of R-65 and BP-R65 test specimens.

many outstanding features such as being fire resistant, explosion-proof, and nontoxic and not reacting with the air or water in the matrix. Both tensile and flexural tests confirmed that the SMC composite prepared by basalt fillers has better mechanical properties compared to the composite containing $CaCO_3$ fillers. Without changing the reinforcement material (glass fibre), this increase in the mechanical properties by simple matrix modification is a significant finding. The tensile and flexural test results can be found in Figures 5 and 6. The tensile strength increased by approximately 15%, whereas the flexural strength was enhanced by 8% (Figure 7).

In the literature, the failure mechanism of composite materials is usually explained in three stages. In the first stage, microcracks are formed in the matrix, followed by fibre-matrix debonding and interfacial decohesion and eventually by fibre breakage [13–17]. In our case, the basalt particles not only prevent the microcracks of the final composites but also improve the cohesion between glass fibre and matrix; thus the mechanical properties of SMC composites are significantly enhanced. The average tensile and flexural strength values obtained with samples using $CaCO_3$ and basalt fillers are given in Figure 7. This graphic shows that an increment trend in both tensile and flexural stress is obtained.

The morphology of SMC composites is also investigated by SEM equipment using fracture surfaces of the tensile and flexural specimens. In the $CaCO_3$ filled SMC composite, it can be observed enveloping the fibre surface in Figure 8 and reducing the interfacial strength between the fibre and matrix. Due to insufficient interface strength, the pull-out of

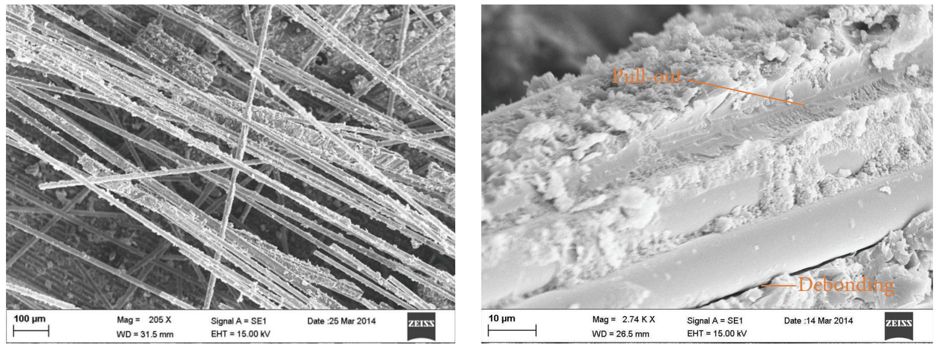


Figure 8: The SEM images of the SMC composite filled with $CaCO_3$.

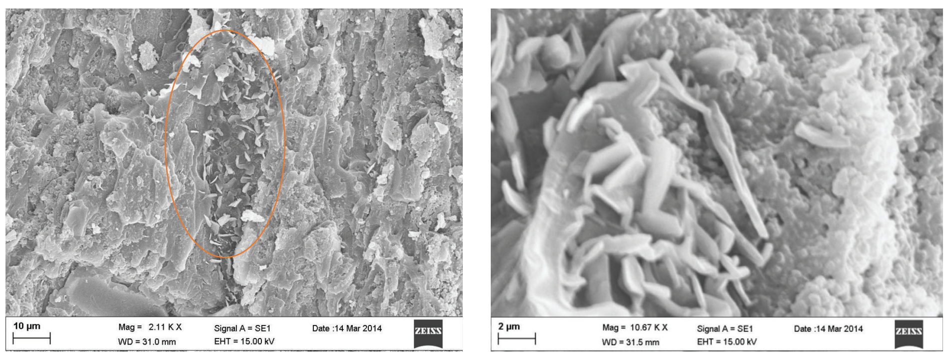


Figure 9: The SEM images of SMC composite filled with basalt particles.

glass fibre easily occurred in the matrix. Consequently, the interfacial debonding results in a decrease in both tensile and flexural strengths.

On the other hand, in the case of basalt particle-reinforced composite, the basalt particles help to hold the glass fibre together with matrix in the composite (Figure 9). Thus, the formation of microcracks in the matrix particles has been relatively delayed in the first stage of damage. Hence, the mechanical properties of the SMC plates are remarkably improved and the failure mechanism has been deferred.

4. Conclusions

In conclusion, basalt particles as an alternative filler for glass fibre reinforced SMC composite has been investigated. Compared to the $CaCO_3$ fillers that are generally used in the SMC composite, the basalt particles filled sample exhibits significant improvement on the tensile and flexural strengths. The morphologies of the obtained SMC materials are investigated by SEM analysis. In the $CaCO_3$ filled composites, fibre pull-out and interfacial debonding more easily occurred due to the high surface energy. This could be responsible for reducing the mechanical properties of the nonpolar matrices. Conversely, the basalt particles hold glass fibre and matrix together and resulted in improved strength properties. In the future studies, the proportion of basalt fillers and new SMC production methods will be examined in order to achieve better mechanical properties.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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