Effect of Marble Powder Concentration on Mechanical Properties of Unsaturated Polyester Resin for the Development of Rock Climbing Holds

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Abstract—The introduction of climbing holds has given rise to indoor climbing facilities. Climbing holds arranged in the form of a route are used to simulate an artificial environment for rock climbing, often similar to that found in nature. This paper highlights the significance of material composition for the application of rock climbing hold manufacture. A particle reinforced composite material, comprising an unsaturated polyester resin, reinforced with marble powder was developed and the effect on mechanical properties was studied with varying powder concentration, beginning from 0% reinforcement to 30%, 40%, 50% and subsequently 60 % reinforcement. Test specimens were made according to ASTM standards and were tested for tensile, Izod impact strength and Rockwell hardness. Trends were established based on the results obtained. Furthermore, hardness values were also compared with commercially available climbing holds.

Keywords: Climbing Holds, Marble Powder, Particle-Reinforcement, Polymer-Matrix Composites

INTRODUCTION

Over the past three decades, artificial climbing walls have become extremely popular. One element that has played a key role is the climbing hold. A climbing hold is a grip which when fixed on a climbing wall enables a climber to hold or step on it. Climbing holds are available in different shapes such as jugs, pinches, slopers, crimps, etc, each involving a different set of muscles for gripping [1]. Holds are therefore designed, keeping in mind the nature of forces they encounter [2]. In the 80's, holds made from resin were introduced and have since become the most desirable choice for artificial climbing. The main advantage of resin holds is that a hold having any shape and size can be designed and manufactured. Resin holds are manufactured by first carving a master pattern using an easily formable material such as floral foam, polyurethane foam [3], whose impression is permanently registered in a silicone rubber die to form a permanent mould.

A climbing hold should feel hard to the skin, resist failure due to sudden impact load such as in the case of a dynamic move like a dyno [4], have sufficient strength to resist deformation such as stress due to tightening as well as the weight of the climber. Holds should also have a mild abrasive texture to aid gripping. A climber can further enhance gripping by the use of chalk which consists of magnesia and magnesium carbonate [5].

Strength to a climbing hold can be provided by reinforcing the polymer matrix phase with fiber. Fiber reinforced composites provide higher strength, improved resistance to impact load and at times an increase in hardness is also observed as compared to no reinforcement. Therefore, conventional fibers such as glass fibers [6-10] or natural fibers [9, 11-14] made from jute 15, banana [16, 17], coconut, bamboo [18] and even palm fibers [19] may be utilized to reinforce the polyester matrix phase [8, 20, 21]. But making climbing holds, using only fiber to reinforce the resin matrix would make the process more labor intensive and create problems during mixing and pouring. Moreover, a realistic and dense feeling of the rock would be missing. A solution to this problem may be provided by the addition of fine mineral powder such as marble powder, silica sand [22, 23], etc.

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The aim of this work is to analyze the effect of particle reinforcement on the unsaturated polyester matrix phase for the manufacture of resin based rock climbing holds. Marble powder is chosen to be the reinforcing material which is a by-product of the marble industry. Marble powder finds its use in industries dealing with structural applications [24], cement [25], paint, polymer concrete [10, 26-29], brick industry [30], etc. In order to study the effect of reinforcement, tensile, Izod impact and Rockwell hardness tests were carried out.

EXPERIMENTAL SETUP

MATERIALS

Isophthalic unsaturated polyester resin was realized as the matrix phase, owing to its higher mechanical properties, corrosion resistance and thermal stability compared to orthophthalic polyester resin, commonly known as General Purpose (G.P.) polyester resin. Both, methyl ethyl ketone peroxide (MEKP) as catalyst and cobalt octoate as accelerator were added as 2% of the resin by weight [31]. Marble powder used for reinforcement was sourced from the region of Makrana in Rajasthan, India. Fig. 1 shows a scanning electron microscopy (S.E.M.) micrograph of the marble powder used, revealing reinforcement on the micron scale. Table 1 reports the chemical properties of makrana marble [36], according to the Department of Mines and Geology, Rajasthan. The powder was dispersed homogeneously in the polyester matrix with the help of a rotary paddle.

Table 1: Chemical Composition of Makrana Marble

Marble	CaO	MgO	SiO_2	Fe_2O_3	LOI
Makrana	50-56	0.8-1.8	0.33-1.20	0.10-0.28	34.8-43.2

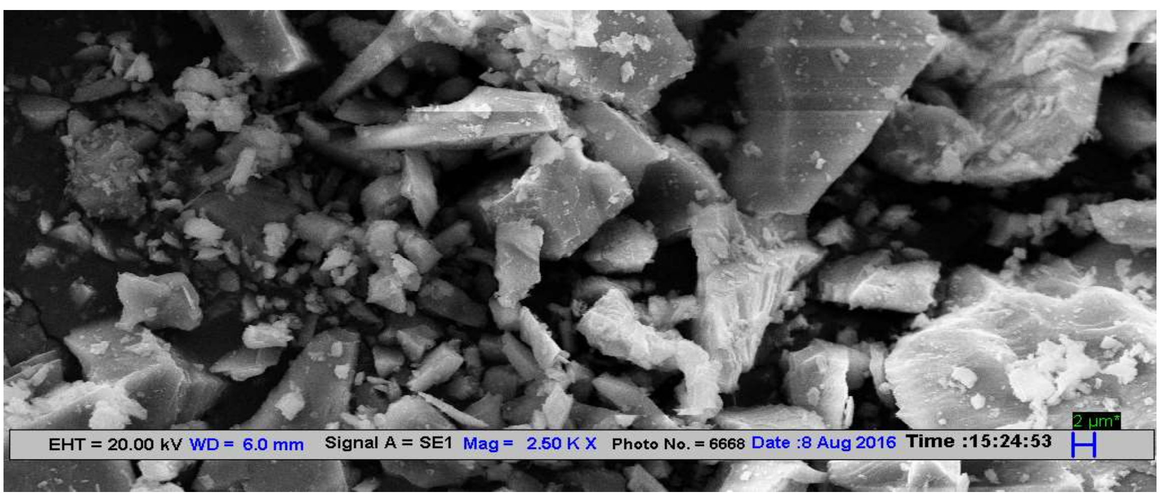

Fig. 1: Scanning Electron Microscopy Micrographs Showing the Size of Marble Powder Particles

Wooden master patterns having required dimensions were molded using silicone rubber. Test specimens with different concentrations of marble powder (0%, 30%, 40%, 50%, 60%) were cast and demolded after 24 hours. For post cure, specimens were kept in an oven at a temperature of 60°C for 4 hours.

EXPERIMENTAL TESTS

Tensile Test

Samples were made according to ASTM D638-10, having a thickness of 9 mm [32]. Tensile testing was performed on Zwick Roell 25T universal testing machine with the crosshead moving at a speed of 2 mm/min. Five samples, for each varying concentration of marble powder, were tested.

Izod Impact Test

Izod impact testing of the samples was performed with the impact energy of the hammer set to 2.7 J. Samples were made in accordance with ASTM D256-10, with dimensions 12.7 x 9 x 63.5 mm. For each of the six varying concentration of marble powder, five samples were tested at room temperature [33].

Rockwell Hardness Test

Samples having dimensions 50 × 25 × 9 mm, conforming to ASTM D785-65 [34], were tested for Rockwell hardness on the R Scale. Procedure a was used in determining the hardness of the samples. Two samples with five readings per sample were tested for each varying concentration of marble powder [34].

RESULTS AND DISCUSSION

TENSILE TESTS

Figure 2 shows the variation of the tensile strength of polyester resin with varying marble powder concentration. It can be observed that at 30% addition of powder, the tensile strength is comparable to the samples having no reinforcement. Further addition of marble powder reduces the tensile strength of the composite. Specimens having a higher fraction of marble powder show a significant reduction in tensile load bearing capability of the composite, which is observed quite evidently for 50–60% powder addition. Reduction in tensile strength on increasing marble powder reinforcement can be due to the lower bond strength of the polyester matrix and the reinforcing marble powder. Thus when a tensile load is applied, the weaker bonds between the matrix and the reinforcing phase break first, thereby transferring the entire load to the remaining polyester–polyester bonds.

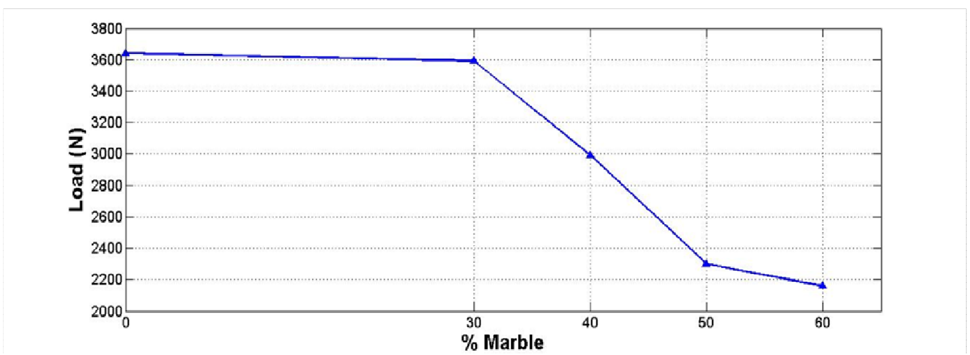

Fig. 2: Variation of Tensile Strength as a Function of Marble Powder Concentration

As shown in Fig. 3, polyester samples with no powder addition, display a brittle mode of failure. Fig. 4a shows a failed cross section of a pure polyester sample, revealing V-shaped chevron markings and radial fan-shaped bridges which are synonymous to brittle failure. White regions may also indicate crazing prior to fracture [35].

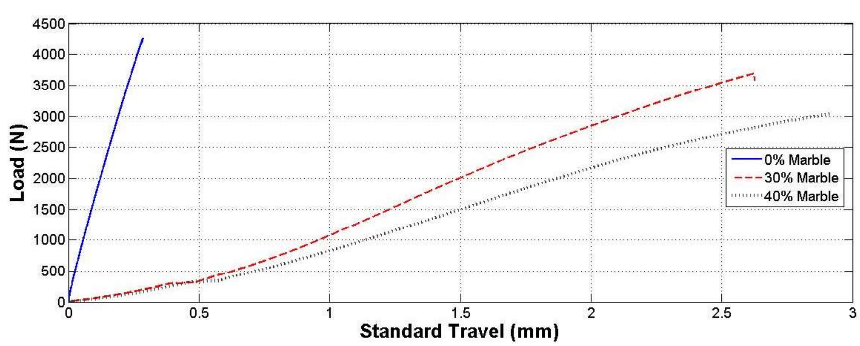

Fig. 3: Load/Standard Travel Curves for Varying Concentration of Marble Powder

On the contrary, polyester samples reinforced with marble powder exhibit plastic deformation before failure. In these samples, the phenomenon of yielding can clearly be observed, as shown in Fig. 5. The composite also experiences an enhancement in the magnitude of engineering strain on the addition of powder. From the photographs shown in Fig. 4, one may differentiate the fractured surfaces of specimens having reinforcement to that with no reinforcement.

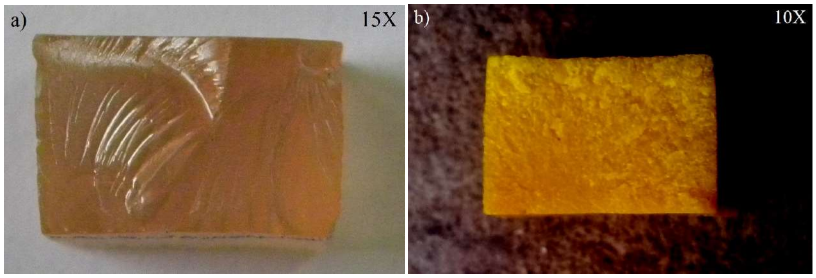

Fig. 4: Cross Section of Fractured Samples after Tensile Failure. (a) 0% Marble; (b) 30% Marble

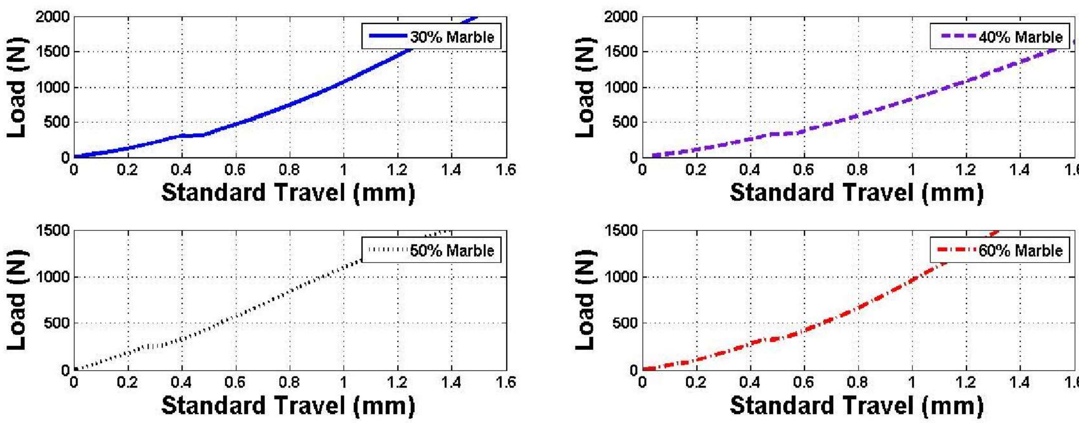

Fig. 5: Load/Standard Travel Curves Showing Yielding of Polyester Specimens Containing Marble Powder

IMPACT TESTS

The variation of the Izod impact energy of polyester with varying concentration of marble powder is shown in Fig. 6. The addition of marble powder greatly increases the toughness of the composite. As observed, the resistance to an impact is maximum when the reinforcement is 60% and decreases as the marble fraction is reduced. Cross sections of fractured surfaces of specimens with 0% and 40% marble respectively, after sustaining an impact blow are shown in Fig. 7. White regions in Fig. 7b represent marble rich areas. There is a noticeable difference in the break of the two specimens.

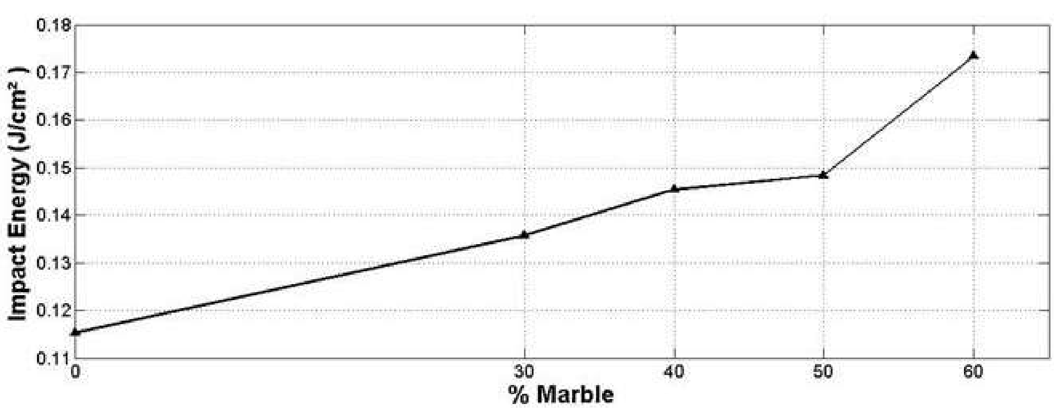

Fig. 6: Variation of Izod Impact Strength as a Function of Marble Powder Concentration

The improvement in Izod impact strength with subsequent marble powder addition can be attributed to the restraining of the polyester matrix in the proximity of each marble particle [35].

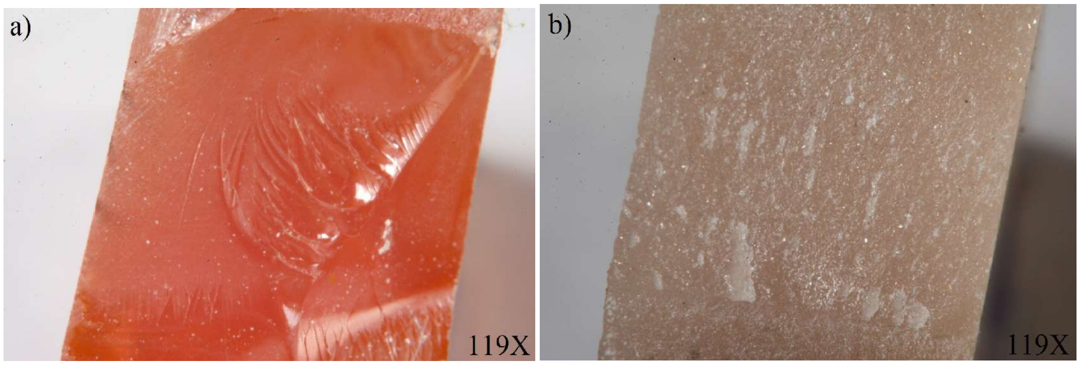

Fig. 7: Cross Section of Fractured Samples After Izod Impact Test. (a) 0% Marble; (b) 40% Marble

Hardness Tests

The hardness of the samples with an increase in marble powder content is reported by Fig. 8. Samples with no reinforcement exhibit maximum hardness among the tested samples. The value of Rockwell hardness decreases gradually as the degree of reinforcement increases. It can be inferred from the figure that the reduction in hardness is not very profound. Hardness values of climbing holds made commercially are reported by Table 2. These values may indicate the presence of other additives or a larger fraction of marble powder, if present.

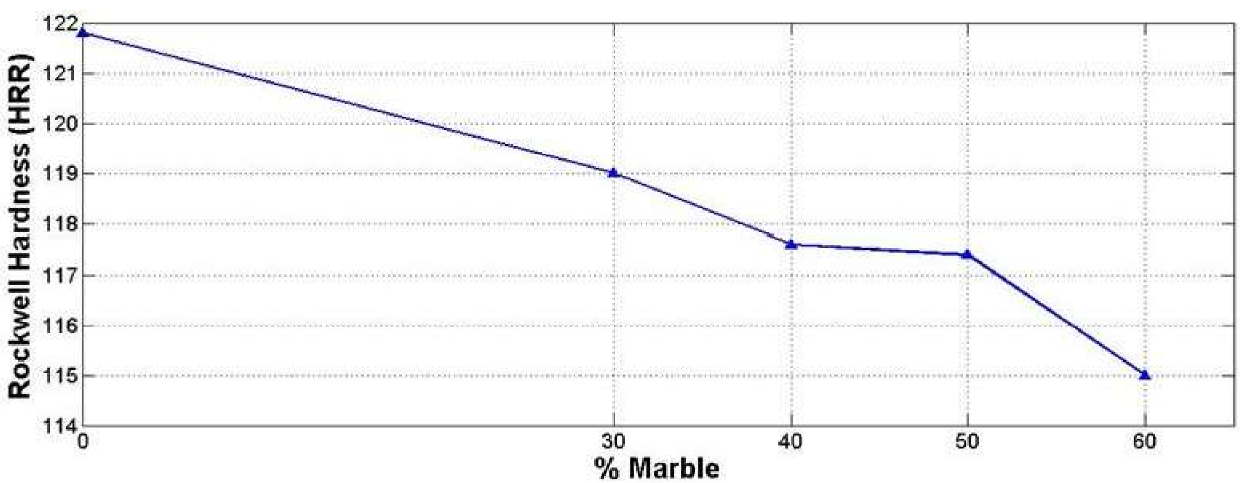

Fig. 8: Variation of Rockwell Hardness as a Function of Marble Powder Concentration

Samples with 40% and 50% reinforcement, observed under the microscope at 400X magnification, reveal a microstructure shown by Figs. 9a & b respectively. The polyester matrix is represented by black arrows, while white arrows indicate the reinforcing marble phase. It is possible to say that the reinforcing marble phase can be found in the form of lumps and also can be present as finely dispersed particulate throughout the polyester matrix.

Table 2: Rockwell Hardness of Some Commercially Available Climbing Holds

Manufacturer	Hold Type	Hardness(HRR)
Entre Prises	Sloper	113
Ibex Climbing Holds	Chip	116

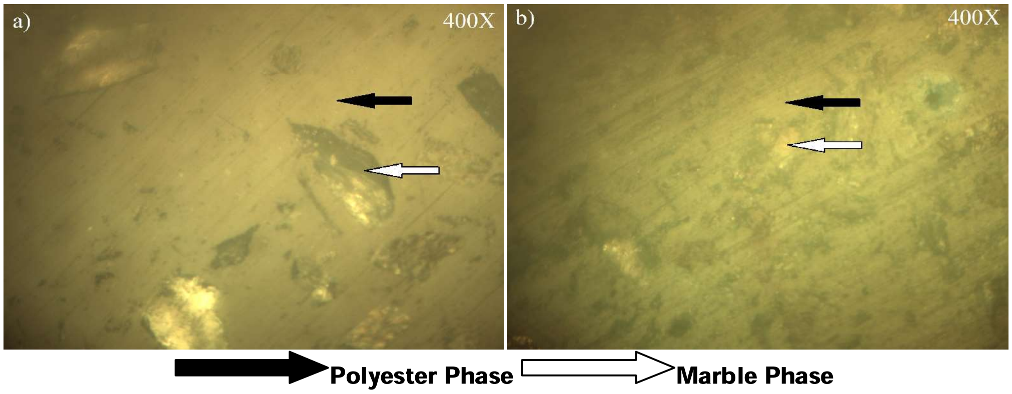

Fig. 9: Micrographs Showing the Distribution of Marble in the Polyester Matrix. 400X. (a) 40% Marble; (b) 50% Marble

CONCLUSIONS

The addition of powder to the polyester resin has a sound effect on the energy absorption of the composite. Tensile tests reveal a notable increase in the area under the stress-strain curve for samples reinforced with marble powder which corresponds to higher energy being required to break the specimens and a substantial improvement in strain. Moreover, yielding of marble reinforced specimens is also observed before ultimate tensile failure. The degree of reinforcement affects the Izod impact strength such that, increasing marble fraction enhances the resistance to impact loads, while the composite experiences a slight reduction in hardness with an increase in marble content.

Thus, a climbing hold made by adding marble powder to polyester resin rather than simply using the latter would be more susceptible to sustain impact loads, strain to a higher extent without sudden brittle failure. The introduction of marble would also give the climbing hold, a denser feel while gripping.

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