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Title: Effects Of Glass Fiber Reinforcement To Tensile Strength İn Epoxy Matrix Granular Composite Materials

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# Effects of glass fiber Reinforcement to Tensile Strength in Epoxy Matrix Granular Composite Materials

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## ABSTRACT

Conventional metal materials are used in every field in industrial applications, but contemporary requirements such as energy savings, environmental factors and carbon footprint increase the importance of composite materials in the industry. This study aims to develop a composite construction material for machine tools that allows easy molding, has lower-cost molding materials compared to existing systems, and requires relatively less finish machining given the comparable materials and systems used in the construction of machine tools. The study examines the effects of fiberglass reinforcement on the tensile strength of the composite material, and the reasons for these effects.

**Keywords:** granular composites, mineral casting, epoxy granite, machine construction

## 1. INTRODUCTION

Due to their high vibration dampening capacity, epoxy matrix granular composite materials are today used in special CNC machine tools for precision machining. They are not used in the bodies of conventional machine tools because columns and beams with much broader cross-sections are required to achieve the required tensile strength compared to metal bodies (Figure1).



Figure 1. Sample machine tool bodies produced using epoxy matrix granular composite materials

Thus, the cost of materials limits their use and applications. In granular composite materials, it is important that the matrix materialand the

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reinforcement materials form a suitable interface. Therefore, the granular material should be distributed homogenously in the matrix, and the matrix material between the granules should have optimum saturation to display the required mechanical properties. In granular composite materials, the basic components of granules and the matrix material are connected with an adhesion bond, which is formed as the matrix material solidifies. The composite material to be developed in this study uses resin as the matrix material, and basalt granules and silica sand grains as the granule materials (Figure 2.). Basalt and silica grains have very low densities when compared with materials such as steel or aluminum, and they help create a light and rigid structure in composite materials. In addition, basalt and silica granules can be used in the composite structure to be developed after some mechanical processing, without undergoing any chemical or thermal treatment.

Figure 2. (a) Basalt granules and (b) silica sand grains

## 1.1 Problem Statement

The disadvantage of using granule materials is that they do not form a cohesion bond with the matrix material. Basalt granules and silica grains create a highly rigid composite structure throughout the material, forming an adhesion bond with the matrix material of epoxy, but the fragility of the material also increases, causing a rapid break as a result of crack propagation. The proposed solution is to increase the tensile strength of the material by creating a fibrous structure by reinforcing the material with 'S' glass fiberglass to support the composite structure. In addition, as it was subjected to tensile force, an examination was made of the effect of the fiberglass reinforcement on the tensile strength of the material.

## 2. MOLD DESIGN AND MATERIAL PREPARATION

### 2.1. Mold Design

Bisphenol A based epoxy resin was used as the epoxy matrix material. When designing molds, the priority criteria are that the mold release agent and the mold are resistant to the 60°C exothermic reaction that takes place as the epoxy matrix material is cured, and do not undergo any deformation that would affect the size of the specimens. Other design parameters taken into account are that the mold should be economic, easy to process and reusable (Figure3).

Figure 3. Molds for the tensile test specimens

Water soluble liquid polyvinyl alcohol was used as the mold release agent, which allows the formation of 0.05 mm and 0.08 mm film layers. The compound used as the mold release agent is water soluble, and can be easily removed by rinsing or wiping the product once it is taken out of the mold, without leaving any traces. The molds and specimens were prepared in accordance with the ASTM D638 TYPE 3 standard.

### 2.2. Material Preparation

Prior to molding, granule materials are washed and dried. If they are not removed, dust particles on basalt granules prevent the adhesion bond that is expected to form between the basalt granules and the matrix material. Dust particles on basalt granules, which form a barrier preventing the adhesion bond, must be removed prior to mixing basalt granules with silica particles and the matrix material. Bisphenol A epoxy matrix material

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consists of two components, the resin and the activator. For ideal curing, it is important to follow the ideal mixing ratio recommended by the producer. As the two components are mixed to achieve the ideal mixture, air bubbles form throughout the material (Figure 4).
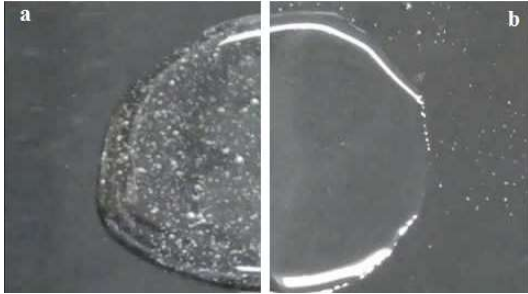


Figure 4. (a) Matrix resin with air bubbles and (b) matrix resin with air bubbles removed

If these air bubbles are not removed from the matrix material, air inside the bubbles expands because of the heat generated during curing, causing the bubbles to become larger and creating air pockets in the composite structure. These air pockets decrease the strength of the composite material, and create discontinuities in the composite material. Air bubbles that form prior to the curing process should be removed from the matrix material using the vacuum method to prevent any harmful effects. $CO_2$ laser cutting machine was used to cut the S glass fiberglass fabric used for reinforcement down to appropriate size (Figure 5).
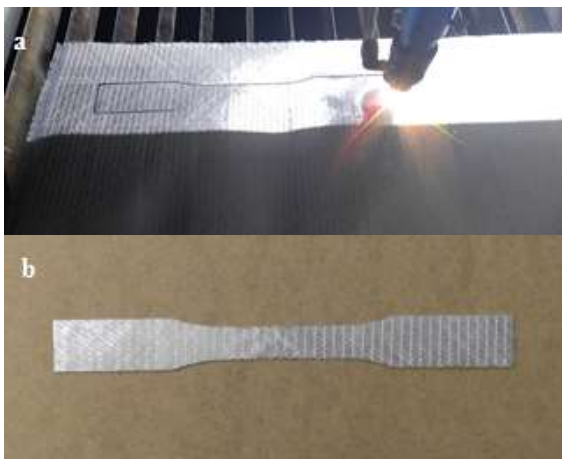


Figure 5. (a) Cutting S glass with $CO_2$ laser and (b) sample fiberglass fabric reinforcement cut with laser

The high precision of laser cutting makes it much easier to place the reinforcement fiberglass into the mold. In addition, compared to other mechanical cutting methods, it does not change the knitting form of the reinforcement S glass fiberglass fabric, ensuring that all layers in the specimens have a smooth and equivalent structure. Warps and wefts on the fabric can be deformed when cutting methods other than laser cutting are used, and thus, any differences that might form between layers can lead to misleading results.

## 3. CREATIING THE COMPOSITE STRUCTURE

For efficient results to be obtained, which can be used in finite element analyses and quantitative calculations, molding should produce the ideal composite structure (Figure 6).
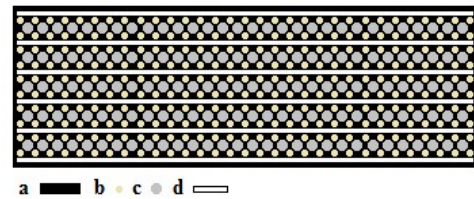


Figure 6. View of the ideal layered composite structure, (a) epoxy bisphenol, the matrix material, (b) silica sand particles, (c) basalt granules, (d) S glass fiberglass reinforcement fabric

To obtain equidistant layers, the height of each layer was controlled during molding to make the material structure as close to the ideal composite structure as possible. For the homogenous distribution of the granules, they were spread as layers inside the mold. During granule spreading, the molds are mounted on a vibration machine specially designed for molding (Figure 7).

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Figure 7. Vibration molding machine

The vibration machine ensures that the basalt granules inside the mold make small movements, eventually settling in places appropriate for their size in the matrix. Silica sand particles, on the other hand, which are smaller compared to basalt granules, fill the potential spaces between basalt granules that might form due to the surface tension of the matrix material, with the effect of vibration and gravity. The frequency of the vibration transferred to the molds by the machine can be varied between 0 and 400 hertz, using the frequency drive on the machine. We have experimented with different frequency values to observe the movements of basalt and silica sand particles inside the matrix. Based on this observation, the most appropriate frequency values for the movement of the particles was selected.

## 4. TENSILE TESTS

The DARTEC tensile test machine with a capacity of 250 KN was used for the tensile tests (Figure 8).



Figure 8. Tensile testing machine and test specimen

To carry out the tensile tests using the machine, the ASTM D638 standard and the sizes of the tensile test specimens were specified, and tensile tests were conducted with a speed of 1.5mm/sec, following the standard. A total of 50 specimens, with 5 identical specimens in each group, were subjected to tensile testing (Figure 9).



Figure 9. Tensile test specimens

Tensile test specimens were given names in accordance with their contents to facilitate the easy recognition of their contents during and after the tests and interpretation following the tests (Table 10).

Table 10. Material contents of tensile test specimens, ratio of volumes

| Specimen code | Epoxy resin ratio | Basalt and quartz granule ratio | Fiberglass ratio |
|---|---|---|---|
| 12S | 12% | 88% | * |
| 14S | 14% | 86% | * |
| 16S | 16% | 84% | * |
| 18S | 18% | 82% | * |
| 20S | 20% | 80% | * |
| 12F | 12% | 78% | 10% |
| 14F | 14% | 76% | 10% |
| 16F | 16% | 74% | 10% |
| 18F | 18% | 72% | 10% |
| 20F | 20% | 70% | 10% |

The letters S and F in the names of the specimens indicate the fiberglass content of the tensile test specimens. The letter S indicates that the tensile test specimen does not contain fiberglass reinforcement. Specimens with the letter F in their names, on the other hand, contain fiberglass reinforcement. The two-digit numbers preceding the letters S and F indicate the ratio of the volume of epoxy matrix material to the total volume of the tensile test specimen.

## 5. RESULTS AND DISCUSSION

Graphs were created using open-source Libreoffice software, based on data obtained from the tensile tests, to visualize the results of tensile tests for specimens with and without fiberglass reinforcement. In specimens without fiberglass reinforcement, material ductility and tensile strength increased in parallel with the increase in the ratio of epoxy matrix material (Figure 11.).
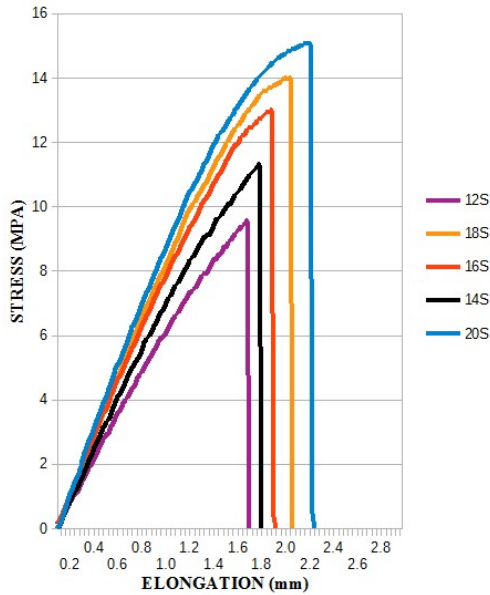


Figure 11. Tensile test graph for specimens without fiberglass reinforcement

With their rigid structure, granules added to the matrix increase the rigidity and fragility of the composite structure. As the ratio of the matrix material increases, so does the amount of matrix material between granules, making the composite structure more ductile. As the distance between granules increases, crack formation and propagation speeds decline. Because the matrix material and the granules form only an adhesion bond and because matrix material ratios above 20% cause the matrix material inside the mold to separate from the composite material and accumulate on the surface, further increase in the ratio of matrix material does not make an additional contribution in terms of strength. In specimens without fiberglass reinforcement, the upper limit of 20% for the ratio of matrix material generates the maximum strength value (Figure 12).
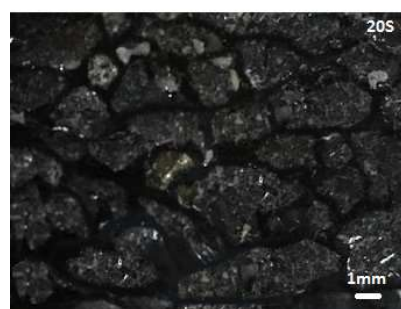


Figure 12. Cross section views of the specimens without fiberglass reinforcement

With the effect of fiberglass reinforcement, material behavior in specimens with fiberglass

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reinforcement was very different when compared with specimens without fiberglass reinforcement (Figure 13).
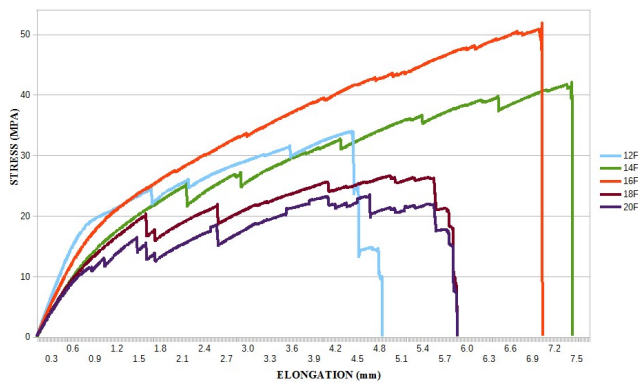


Figure 13. Tensile test graph for specimens with fiberglass reinforcement

Comparing specimens with the same ratio of matrix material, the strength of specimens with fiberglass reinforcement were as high as 4 times the strength of the specimens without fiberglass reinforcement. The intermittent structure of the graph for specimens with fiberglass is a result of fiber breaks. The tensile test graph shows that, as a result of fiber breaks, the elongation ratio increases in specimens with fiberglass reinforcement, as fiberglass reinforcement increases unit elongation amount. Because fiberglass reinforcement is in the form of layers, matrix material between granules located between two granule layers plays a bigger role in increasing strength. Maximum strength is observed in 16F specimens because the distribution of the surfaces that form effective adhesion bonds becomes closest to the ideal in 16F specimens . The matrix material in 12F and 14F specimens is not well-distributed enough for the formation of sufficient adhesion bonds. During the tensile tests, the materials make crunchy separation sounds as they are deformed. 18F and 20F specimens, on the other hand, have a larger amount of matrix material between granules (Figure 14.).
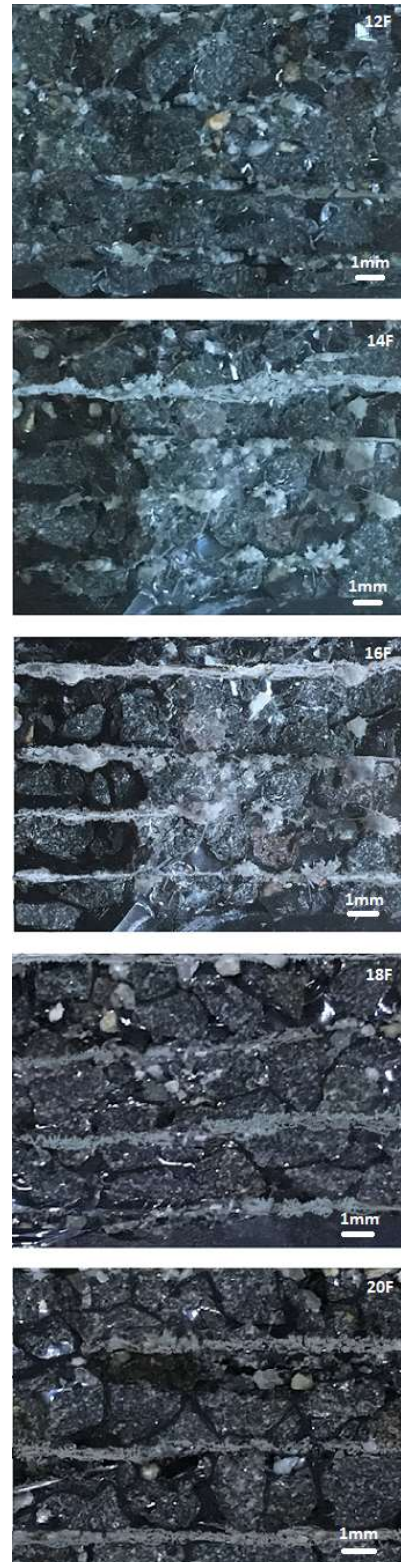


Figure 14. Cross section views of the specimens with fiberglass reinforcement

There is less sound during the tensile tests, and the sounds generated are similar to the soft sounds heard during the tensile tests of polymer based materials as they break. Specimens are expected

to display increased ductile behavior in this case, but granules separate and prevent further ductile behavior. Because basalt granules separate from the structure due to their nature, cross section photographs of the specimens were not successful.

## 6. OVERALL RESULTS

In this study, specimens with and without fiberglass reinforcement were subjected to tensile tests with a speed of 1.5 mm/sec. Specimens with fiberglass reinforcement were observed to have a tensile strength that was high as 4 times the strength of the specimens without fiberglass reinforcement (Figure 15).
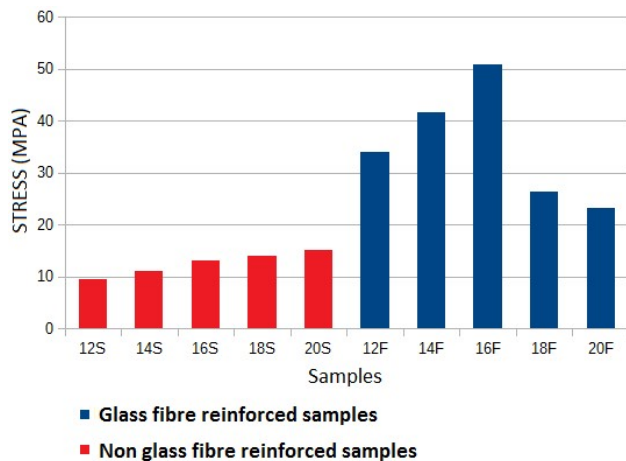


Figure 15. Comparative tensile test graph for specimens with and without fiberglass reinforcement

Specimens with fiberglass reinforcement displayed ductile behavior, whereas specimens without fiberglass reinforcement had high rigidity and no breaking elongation, with the specimens breaking almost without any elongation. During the tensile test, fiberglass fibers broke first as a result of tension, and as the matrix material and fiberglass fibers stretched and the matrix material saturated the fiberglass fibers more fully, the unit elongation amount of the composite material increased. The composite material developed cannot undergo an effective cutting process. However, machining allowance can be left and material removal from the surface can be undertaken following molding.    The rigid

structure created by granules can be supported with fiberglass reinforcement, making it possible to produce thinner beams and columns for machine tool bodies, and have lighter and highly strong machine tool body parts as a result.

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