Production and Optimization of Aluminum-Basalt Composites by Hand Lay-out Technique

Seyyed M. M. Sabet, Farshad Akhlaghi, and Reza Eslami-Farsani

Abstract—**Since basalt fibers possess relatively high mechanical properties, good heat/sound insulating characteristics, low density and inexpensive price, they can be a proper substitute for glass and carbon fibers. Currently, these fibers are used to reinforce concrete, asphalt and Polymer Matrix Composites (PMC's), but little or almost no attempt has been made to use them in metal matrix composites. In this study, fibrous Al-basalt composites were produced for the first time. Basalt fibers were first wound around a fixture and then dipped into molten A413 alloy for a few seconds and taken out quickly to form laminates that contained basalt fibers coated with a thin layer of aluminum after cooling at room temperature. Finally a certain amount of these laminates were weighed and then subjected to hot pressing in a mold to produce composites. The processing parameters were optimized to obtain composites with the least amount of porosity. The optimum pressure and temperature of HP were reported 630 MPa and 400 °C, respectively.**

Index Terms— **Basalt Fibers, Dipping, Fixture, Hot Press (HP), Laminates**

I. Introduction

BASALT fibers were initially manufactured in 1972 and mainly used in military and aerospace applications, but after 1995 they began to be widely used in non-military applications. The raw material for production of basalt fibers is basalt rock, a hard volcanic stone. It is rich in Mg and Fe silicates and is found in both amorphous and crystalline states. Basalt rock is the most wide spread volcanic stone in the earth's crust and is found in areas measuring thousands of square kilometers [1-3].

Basalt fibers are manufactured by crushing and melting basalt rock at 1500 °C. The melt is then transferred onto a rotating disk containing several tiny holes (bushings) and is drawn through the bushings by means of air blowing. The produced fibers are subsequently covered by a polymer sizing for better corrosion and wear resistance [2,5].

Since basalt fibers possess amorphous state and contain approximately 60 wt% SiO_2, they are usually compared to E and S glass fibers; however, they exhibit superior mechanical properties, better chemical stability and improved thermal and electrical insulation compared to glass fibers. Therefore they can be proper substitutes to glass fibers, and even in some cases, carbon fibers. Basalt fibers are used to reinforce concrete, asphalt and Polymer Matrix Composites (PMC's), but since basalt fibers are relatively new among other reinforcing fibers, their properties have not been fully investigated and little or almost no attempt has been made to use basalt fibers in Metal Matrix Composites. This is mainly due to the ceramic properties of basalt and the low adhesion of basalt fibers within a metal matrix [6,7].

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II. Experimental Method

A. Materials

Basalt fibers were purchased from Ukrainian Material's Institute. Fig. 1 shows the macroscopic and SEM micrographs of basalt fibers used in this study. The density of basalt fibers was 2.816 g/cm^3 and their average diameter was 10 μm. The number of filaments in a strand was measured 1124 units and strength of a bundle was 322 MPa.

A 413 alloy was used as the matrix. A 413 is a Eutectic alloy and contains nearly 12% Si and possesses the lowest melting point among Al-Si alloys which minimizes the risk of damage to fibers and also exhibits higher flow ability during casting. The density of this alloy was about 2.732 g/cm^3. The melting point of this alloy was measured around 580 °C using TGA analysis.

B. Composite Production

In order to minimize the damage and strength loss of fibers, the high temperature exposure should be minimized. Therefore, the effect of high temperature exposure on tensile behavior of basalt fibers was first studied.

A two-step procedure was used for composite production: 1) Basalt fibers were wound around a fixture to form a flat surface. Then fibers and fixture were dipped into molten A413 aluminum alloy for a few seconds and cooled at room temperature to produce Al-basal laminates. 2) The laminates were then subject to hot pressing to in a mould to produce composites.

The processing parameters (time, temperature and pressure of hot press) and also fiber content were optimized to obtain composites with minimized porosity by Archimedes method. The composite specimens were first weighed in air and in distilled water using an electronic balance with the

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accuracy of 0.1 mg. The porosity content of the composite specimens was measured by mixture's law.

Microscopic observations were carried out to investigate the adhesion between laminates and also that of basalt fiber and Al matrix using Olympus BX60M Optical Microscope and CamScan MV2300 Scanning Electron Microscope.

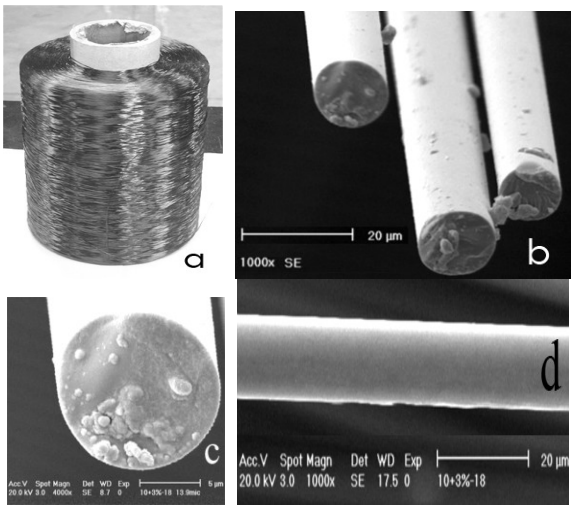

Fig.1. a) A reel and b,c,d) SEM micrographs of Basalt fibers

III. RESULTS AND DISCUSSIONS

A. *Thermal behavior of basalt fibers*

In order to find the range of processing parameters, it is essential to measure the tensile strength of basalt fibers at high temperatures. The effect of high temperature exposure on tensile behavior of basalt fibers was investigated by heating fibers in a electric furnace for determined times and measuring their tensile strength. The temperatures were 300, 400, 450 and 500 °C and the duration of heating was 5, 10, 15 and 20 min.

The strength of basalt fibers was then drawn as a function of holding time (Fig. 2). As it can be seen, the severe loss is observed above 400 °C and 15 min, therefore the processing parameters should not exceed these values.

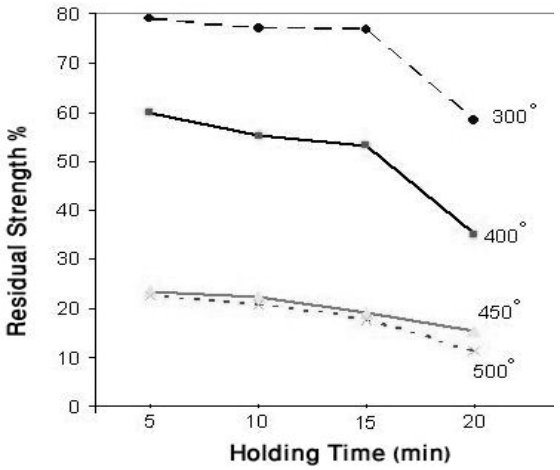

Fig. 2. Strength of fibers vs. holding time at different temperatures.

B. *Production of Al-Basalt Composites*

In order to impregnate basalt fibers with molten with a uniform thickness, they were wound around an H-shaped steel fixture of 6.5 × 8.5 cm^2 and 1 mm in thickness. In order to produce a large number of laminates, 20 fixtures were made. Every fixture was able produce two laminates containing 30, 45 or 60 strands of basalt fibers. Fig. 3 shows a fixture containing 30 strands ready for impregnation.

By knowing the length and weight of the strand in every fixture and also weight of the laminate after impregnation; it is possible to calculate weight and volume percentage of basalt fibers in a laminate and consequently in the final composite.

Fig. 3. A fixture before and after winding.

In order to minimize the risk of damage to basalt fibers, the temperature of the molten alloy was only 20 °C above melting point (600 °C). Fixtures were dipped into molten alloy for only few seconds, and then cooled in room temperature. Fig. 4 shows a resulting laminate.

Fig. 4. A laminate after separating from its fixture.

Since thickness of the Al layer formed on the fiber surface is a fraction of mm, it is easy to separate and cut the resulting laminates by a pair of scissors. Before hot pressing, the laminates are first cut into proper size to fit in the mold. Fig. 5 shows some of these laminates after cutting.

As the amount of basalt fiber in each laminate is relatively the same, the weight of the laminates applied to hot press only changes the thickness of the final composite specimen (not the fiber content). The range of HP temperature and duration were 200~400 °C and 1-15 min, respectively (based

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on thermal tests). The pressure range was 400~630 MPa was according to density value of the composites.

Before hot pressing, density, weight and volume percentages of basalt fibers in the composite should be calculated. The laminates were first weighed and their average weight was calculated. By knowing the length and weight of the strand in every laminate, density of Al alloy and that of basalt fibers, the weight and volume percentage of basalt fibers can be calculated in a laminate and consequently in the resulting composites.

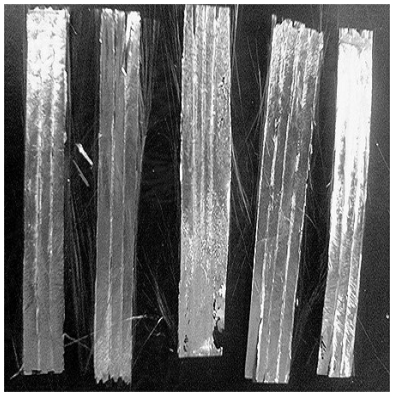

Fig. 5. Al- Basalt laminates for hot pressing.

Having the linear density of the fibers, the average weight of fibers and Al in each laminate and therefore basalt content of the composite was calculated. Using the mixture's law, the density of the composites can also be calculated. Table 1 lists the above mentioned values for laminates and the resulting composites containing 30, 45 and 60 basalt strands.

TABLE 1: FIBER CONTENT AND DENSITY OF COMPOSITES CONTAINING 30, 45 AND 60 STRANDS

No. of Strands	Laminates Mass (g)	Basalt Wt%	Basalt Vol%	Composite Density (g/cm^3)
30	2.9	16.7	16.3	2.745
45	3.47	20.9	20.5	2.749
60	3.42	28.3	27.7	2.755

C. Optimizing processing parameters

In these series of tests, the effect of processing parameters on density of composites specimens was studied and optimized. In order to investigate the effect of pressure on density, the laminates containing 30 rounds of strand were pressed in 300 °C for 15 min. Fig. 6 shows the trend of densification vs. pressure. As it can be seen, nearly full density is obtained at P= 630 MPa. Therefore, increasing pressure will only result in fracture of fibers. As the result, 630 MPa was reported as the optimum pressure for hot press.

To study the effect of temperature, laminates containing 30 strands were pressed for 15 min and P= 630 MPa. The temperature varied between 200~ 400 °C. Fig. 7 shows the trend of density vs. temperature. It can be seen that increasing temperature, results in higher densification; however, this value cannot exceed 400 °C which is due to strength loss of fibers above this temperature.

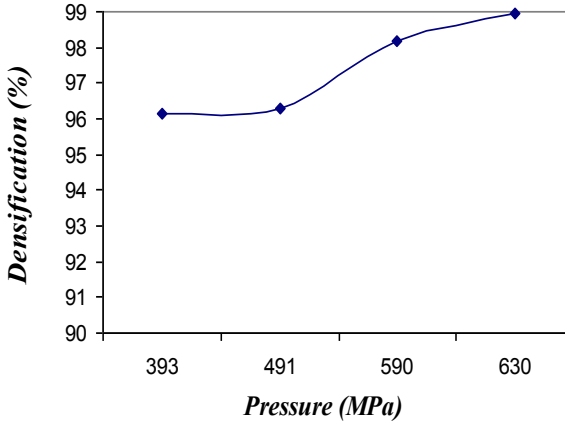

Fig. 6. Density of composites vs. pressure (T=300 °C, t=15 min).

By comparing Fig. 6 and 7, it can also be concluded the effect of pressure on porosity reduction is more dominant than temperature. Since the specimens weld to the steel mold at 400 °C, therefore the optimum temperature of HP was reported as 300°C.

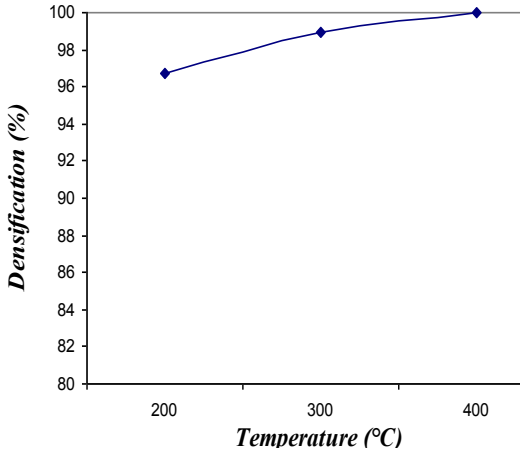

Fig. 7. Density vs. temperature (P=630 MPa, t=15 min).

In order to study the effect of temperature on density of composites, laminates containing 30 strands were pressed at P= 630 MPa and T= 300 °C. The duration of pressing were 1, 7 and 15 min. Fig. 8 shows the curve of density vs. duration of pressure. It can be seen that the porosity content of the specimens t= 7 and 15 min is less than 1%.

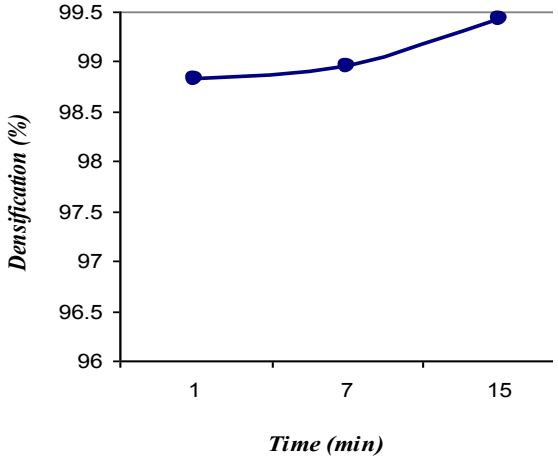

Fig. 8. Density vs. HP time (T=300 °C, P=630 MPa).

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After optimizing the processing parameters, the fiber content was studied using laminates of 30, 45 and 60 strands. Fig. 9 shows the density vs. fiber content of composites. As it can be seen, the density decreases at higher fiber contents. This phenomenon is usually observed in metal matrix composites reinforced with ceramic fiber in which the matrix deforms plastically at a certain pressure, but the rigid ceramic fibers do not.

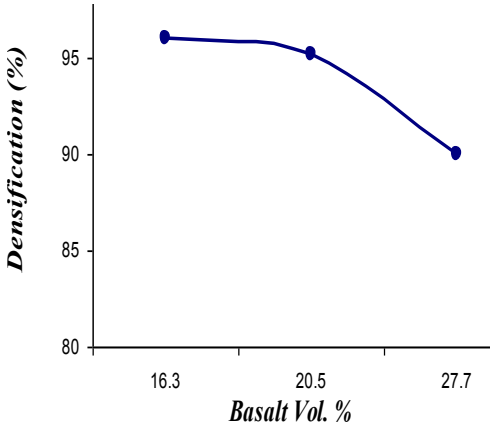

Fig. 9. Density vs. fiber content (T=300 °C, P=630 MPa, t=15min).

D. Microscopic studies

Fig. 10 and 11 show the optical and SEM micrographs of the specimen produced at optimum condition (T=300 °C, P=630 MPa, t=15min). The gray circles represent the cross section of basalt fibers.

As it can be seen, although the matrix has filled all the cavities among fibers, distribution of fibers within Al matrix and their adhesion to the matrix is not satisfactory,

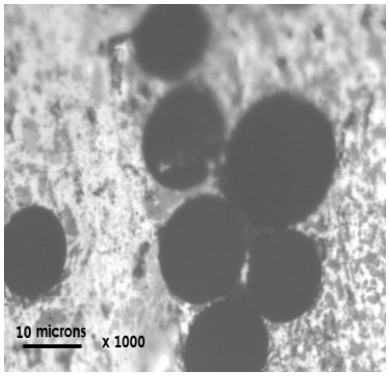

Fig. 10. Optical micrograph of the optimum specimen.

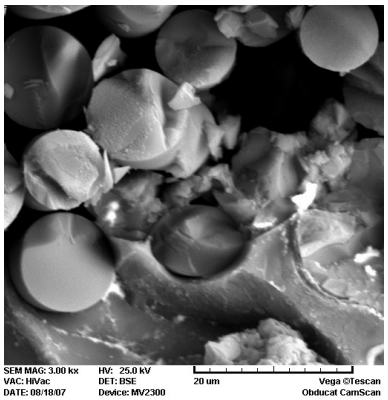

Fig. 11. SEM micrograph of the optimum specimen.

IV. Conclusions

Through the steps of this study, composites containing 16, 20 and 28 vol % of basalt were produced via hand lay-out and hot pressing technique.

The thermal behavior of basalt fibers was first studied to define the processing parameters. It was concluded that temperature and duration of HP should not exceed 400°C and 15 min, respectively.

Density of the composites is a function of pressure, temperature, time and fiber content. Increasing the first three parameters, results in higher densities. The fiber content has a reverse effect on density of composites.

The optimum processing parameters were reported as P=630 MPa, T=300 °C and t= 15 min. The microscopic investigations revealed that dispersion of basalt fibers within the matrix and also their adhesion is not satisfactory, but the Al matrix is able fill the cavities among fibers.

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