Production of Hybrid Reinforced AA7075 Matrix Composite with Investment Casting

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Abstract

Aluminium matrix composites which are the most widely used in metal matrix composites have a wide range of use in the aerospace and automotive industry due to their superior properties such as high specific strength, chemical stability, high wear resistance and low density. In order to increase the desired mechanical properties in metal matrix composites and to create a wider usage area; hybrid composites were developed by adding more than one reinforcement material. The desired strength values in the hybrid composite are provided by various combinations of reinforcement elements.
In this study, production conditions of SiC, Al_2O_3, B_4C reinforced hybrid composites with AA7075 matrix were researched and the effect of different preform properties and infiltration conditions on composite properties were investigated. In order to examine the composite effect of the reinforcement material ratio, preform optimization studies were carried out using reinforcement elements in different combinations. Composite production was carried out under vacuum with investment casting method.
In order to investigate the effect of liquid metal-reinforcement interaction time on composite interface formation the casting process was carried out in three different ways.
The produced composite materials were characterized by light metal microscopy, Brinell hardness tests.

1. Introduction

The materials to be used in the application areas such as aerospace and defence industry should be high specific strength and wear resistance[1-5]. Metal-matrix composite materials which have high specific strength and wear resistance properties allow them to be used frequently in these areas[6]. Metal matrix composites have 2 basic components; reinforcement which supports to the structure's specific strength, hardness, abrasion resistance, fatigue and creep resistance and the matrix material which holds the reinforcing elements together, transmits the charge to the reinforcing material. The addition of reinforcement material into the structure occurs with in four different ways. These; particle, short fibber (whisker), continuous fibber and sheet form[1,7]. Reinforces commonly used in metal matrix composites; ceramic based materials such as Al_2O_3, B_4C boron, tungsten, graphite, fly ashes, silicon carbide, titanium carbide, ZrO2, SiO2, and TiO2. Recently, researchers have focused on aluminium, magnesium and titanium matrix composites and their use in various areas of these composites. It has been determined that there is a perfect harmony between Al_2O_3 particle and Al metal among the mentioned reinforcement and matrix materials, in addition the metal matrix composites produced with these components have high wear resistance [8].

AA7075 is a matrix metal alloy which has the main alloying element of zinc. This aluminium alloy has the equivalent strength, good fatigue strength and easy workability with some steel types. However, corrosion resistance is lower than compared to many other aluminium alloys. Having a relatively high cost are limited its use. T173, T7351 heat treatment significantly increase the tensile corrosion of AA7075 alloy, which causes the aluminium 7075 alloy to replace the 2024, 2014 and 2017 alloys in critical applications. Metal matrix composites are obtained by using ceramic reinforcement materials to increase some properties of the aluminium 7075 alloy[9,10].
A high pressure compression moulding technique is commonly used in the production of particulate reinforced composite materials. With this technique, the liquid metal can be easily infiltrated into the prepared preform. In addition, errors such as gaps and air entrainment that occur after casting are reduced with this technique[6,5]. In the production of metal-matrix composite, the liquid metal must be able to wet the reinforcement material well. The low wettability of most carbides and nitrides makes the production of carbide and nitride reinforced composites difficult. Therefore, pressure casting is preferred to increase wettability and to create an efficient interface in the composite in the production of metal matrix ceramic reinforced composites[3,11,12].
In this research, metal matrix composite was obtained by using A7075 alloy. The infiltration technique was used to increase wettability and to reinforce matrix-reinforcement interface in the production of metal matrix composites. In this composite production method, casting and preform conditions were changed and the effects of these changes on the properties of the composite were investigated.

2. Experimental Procedure

A7075 alloy and an average 50 µm size of SiC, B_4C and Al_2O_3 powders were used for metal matrix composite production. The chemical composition of the A7075 alloy is given in Table 1.

Table 1. Chemical composition of A7075 (% weight)

Mg	Mn	Si	Cu	Fe	Cr	Ti	Zn	Al
2.5	0.3	0.4	1.6	0.5	0.23	0.2	5.6	Bulk

Preform production

SiC, B_4C and Al_2O_3 powders are produced as preforms with a mixture of polyvinyl alcohol (PVA) and colloidal silica components. Water based PVA solution is prepared with %20 ratio. It is used as volatile binder in preform production. The amounts of the components used in the preform are given in Table 2.

Table 2. Chemical composition of the produced preform

SiC(g)	B_4C (g)	Al_2O_3 (g)	Colloidal(ml)	PVA(ml)
10	15	5	4	30
10	10	10	4	30
15	5	10	4	30
15	10	5	4	30

Reinforcement powders, PVA and colloidal silica were mixed in the ratio given in the table and ceramic slurry was prepared. The resulting ceramic slurry was poured into the silicone mold. The ceramic slurry was dried at room temperature for 24 hours. The mixture was removed from the silicone mold and it is baked at 1000 ° C for 3 hours. The preform production flow chart is given in Figure 1. During the sintering process, the PVA added as a volatile binder was removed from the structure. Thus, preforms with a height of 15 mm and a diameter of 17 mm were obtained in a porous form and in Fig. 2. The PVA used as the volatile binder directly affects the preform pore quantity. A large increase in PVA results in the formation of non-uniform pores in the preform. As a result, the reinforcing particles show a non-homogeneous distribution in the composite structure.

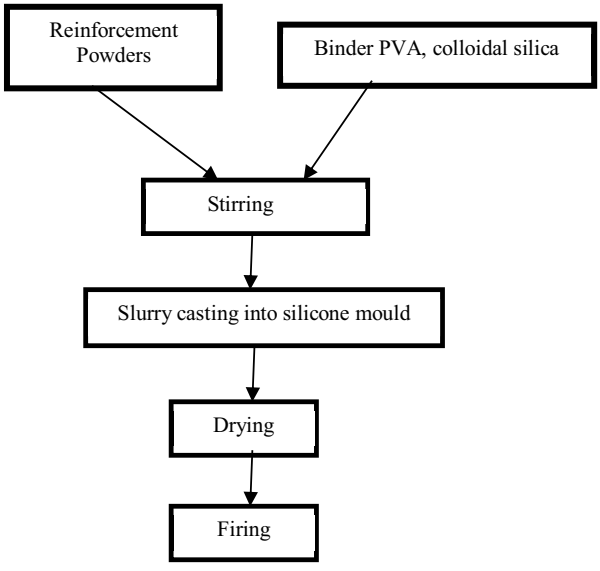


Figure 1. Preform production flow chart

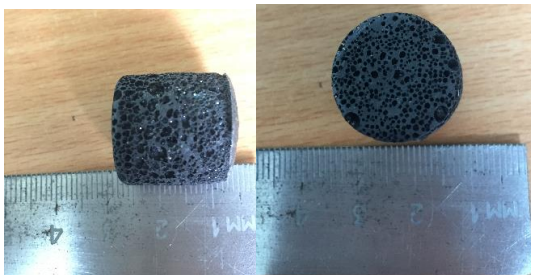


Figure 2. Photograph of preforms given chemical composition in Table 2

Mold Making

The wax used in plaster mold is prepared by pouring into the silicone mold having a gap of 50 mm in height at a diameter of 25 mm at 85 ° C. Water/powder ratio is 40%. 500 g of precision casting powder was mixed with 200 ml of water to obtain plaster slurry. The wax model was put into the perforated degree with using the rubber base. Under vibration, the slurry was poured into the hole. After the pouring process, the vibration continued for 15 minutes, then the plaster was left at room temperature for 1 hour. Wax removal was carried out at 110 ° C for 1 hour to form the mold cavity. The mold was heated to 700 ° C to increase the strength of the plaster mold and to ensure complete removal of the remaining waxes in the mold cavity. Due to the high wall thickness and low heat conduction coefficient, the plaster mold is gradually heated to 700 ° C as shown in Figure 3. Thus, the internal and external heating of the mold is homogenized as much as possible and the risk of cracking is reduced.

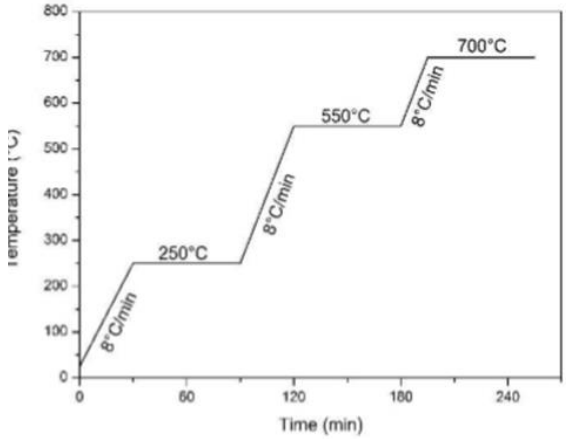


Figure 3. Gradual cooking of precision casting mold[13]

Casting Process

In the casting process after mold making, A7075 alloy was chosen as matrix material. A schematic representation of the cast at 750 ° C with a pressure of -10^5 Pa is taken from the furnace at 700 ° C and placed in the vacuum device. Electric resistance furnace is used to melt the specified alloy.

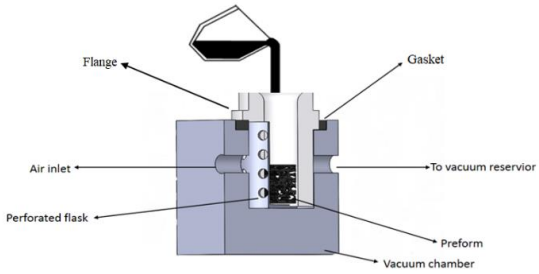


Figure 4. Schematic representation of the casting process

3. Results and Discussion

In this study, the production of SiC, Al_2O_3, B_4C reinforced AA7075 matrix composite were manufactured using the vacuum assisted block investment casting technique. Porosity ratio of the preforms was investigated using Archimedes' test. Open porosity of the preforms was determined according to the standard ASTM C 20-80a. At the same time, microstructure analysis and hardness tests of the samples were obtained. According to the Archimedes test, the pore amount was determined as 55 ± 5%. In Figure 5, the microstructures of the hybrid composites produced by the parameters specified in Table 2 are given. The light regions show the matrix material and the dark regions show the reinforcement materials. Whenl the parameters of the samples that cannot be wetted are compared with others, the amount of B_4C in the structure is higher and the amount of SiC is less. Since the temperature and the applied vacuum did not change the wetting angle of B_4C much[14], the wetting problem was experienced in the composite samples obtained as the amount of B_4C added to the structure increased. The increase in temperature and the application of the vacuum decreased the of SiC in high amounts[14], so wetting problems were not observed in samples with high amount of SiC.

In Figure 5, it is seen that the reinforcing materials are homogeneously dispersed in the structure and the liquid metal is almost completely infiltrated. Figure 5a shows the microstructure of the composite sample containing the 15g SiC-10g Al_2O_3-5g B_4C reinforcement materials. In this sample, the amount of SiC was kept the most and the amount of B_4C was kept to a minimum. In Figure 5b, the amount of Al_2O_3 was decreased while the amount of B_4C was increased. Increasing the amount of B_4C caused a partial wetting problem. The microstructure of the sample obtained by adding all of the reinforcing materials used in the hybrid composite production to an equal amount of structure is given in figure 5c. The increase of B_4C in the structure and the decrease of SiC caused the increase of non-wetted regions. In Fig. 5d, the maximum amount of Al_2O_3 from the reinforcing materials was used, while B_4C was added to the structure at least.

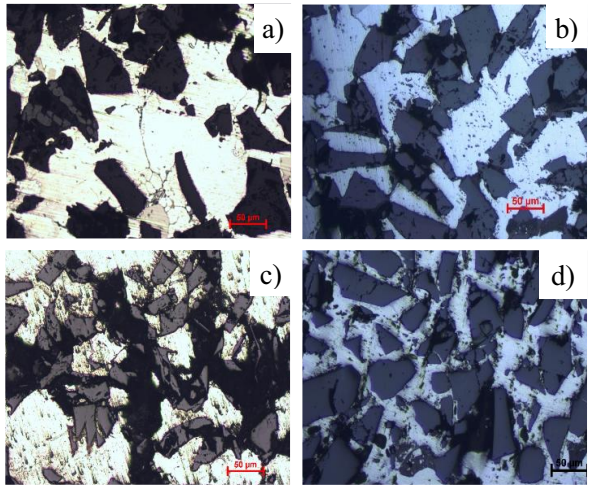


Figure 5. Microstructure of composites prepared in different reinforcement combinations **a)** 15g SiC-10g Al_2O_3-5g B_4C **b)** 15g SiC-5g Al_2O_3-10g B_4C **c)** 10g SiC-10g Al_2O_3-10g B_4C **d)** 10g SiC-15g Al_2O_3-5g B_4C

Brinell hardness test was applied under 62.5 kg load using 2.5 mm diameter indentation tip to investigate the effect of different reinforcement combinations on the mechanical properties of the hybrid composite produced. The highest hardness value was obtained by preformed casting with high SiC content. As a result of the wetting of the reinforcement material by the liquid metal, the composite strength values have increased. It has been observed that the strength of the composite has decreased as a result of the increase of B_4C which is a different reinforcement combination and reduction of Al_2O_3. As a result of the addition of equal reinforcements to the structure, both infiltration and wetting problems were experienced and the lowest hardness value was obtained. During the production of preforms, an increase in hardness values was observed in the composite sample produced by increasing Al_2O_3. However, it was found that the hardness value increase was less than the hardness value obtained with excess of SiC.

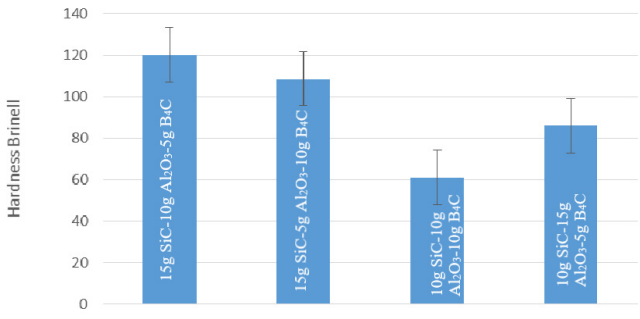


Figure 6. Brinell hardness values of the specimens.

4. Conclusion

SiC, Al_2O_3, B4C reinforced, AA7075 matrix composite material, samples obtained under different reinforcement combination conditions were characterized by hardness test, and microstructure image analysis.

The use of infiltration technique increased infiltration into the preform pores of the molten metal. 15g SiC-10g Al_2O_3-5g B_4C parameters prepared with the preform casting was the best results. The high SiC in the structure and the low B_4C reduced the wettability of the hybrid composite obtained.

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