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Effect of matrix temperature and powder size on the infiltration height of SiO_2-reinforced Al 7075 matrix composites produced by vacuum infiltration

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Abstract: In this study, the effect powder size and matrix temperature on the physical and mechanical properties of SiO_2-reinforced Al 7075 matrix composites were investigated. It was observed that with increasing powder size and temperature, infiltration height was increased. Optimum parameters of full infiltration that were determined for particle size and temperature were d_{50}=150 µm and 800°C, respectively. It was also observed that the porosity of the produced composites changed in the range of 3.2–14.6%, and the lowest porosity was obtained from the composite having 105 µm SiO_2 particle size. The highest fracture strength (263 MPa) was obtained from the composite produced at a matrix temperature of 800°C and a particle size of 420 µm. It was concluded that particle size and temperature are effective parameters to reach full infiltration, and this method is more suitable for producing the composites that have high reinforcement volume fractions than conventional casting methods.

Keywords: infiltration height; nonferrous metals; porosity; SiO_2; vacuum infiltration.

1 Introduction

The ability of aluminum-based materials to exhibit high specific mechanical properties has been instrumental in attracting the attention of manufacturers for their possible use in automobile, aerospace, and electronics industries [1, 2]. In particular, aluminum matrix composites (AMCs) have been used for the automobile products, such as engine piston, cylinder liner, brake disc due to their light weight, high strength, high specific modulus, and good wear resistance properties [3, 4]. Many metals have been considered as a possible matrix: lithium, magnesium, silicon, aluminum, titanium, copper, nickel, zinc, lead, etc. [5–8]. Light metals offer the greatest potential in terms of strength-to-density ratio. As reinforcement, ceramics and refractors such as Al_2O_3, SiC, TiC, MgO, and SiO_2 are used commonly [9–12]. However, these reinforcements cannot be added to matrix, especially high-volume fractions with conventional fabrication methods. The fabrication processes can be divided as solid-state and liquid-state fabrication techniques. Among the liquid-state techniques, the infiltration process stands out as one of the most economical and versatile processes for producing AMCs containing high-volume fractions of reinforcement. Infiltration methods have also a few different application techniques [13–15]. These are pressureless (free) infiltration, pressure infiltration, and vacuum infiltration techniques. The relatively small investment in tooling required is an important advantage. Depending on the process and the materials, disadvantages occur in some cases, such as degraded reinforcement by chemical attack during the infiltration process, or a second phase could be formed and left in the matrix. Molten metal temperature, reinforcement powder size, reinforcement volume ratio, vacuum or pressure value, molten matrix composition, infiltration atmosphere, and time are important parameters in the infiltration of molten metal into preformed reinforcement [15, 16].

In view of this information, aluminum alloys and SiO_2 are widely used in engineering applications. However, no attempt has been made to manufacture Al 7075/SiO_2 composite with vacuum infiltration method and to investigate the effect of powder size of SiO_2 on the physical and mechanical properties of them with different matrix temperatures. Therefore, the aim of this work was

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to investigate the effect of powder size and matrix temperature on the physical and mechanical properties of SiO_2-reinforced Al 7075 matrix composites produced by vacuum infiltration.

2 Materials and methods

Commercially pure silica (SiO_2; Yılmaz Kimya Ltd., Istanbul, Turkey) with d_{50}=105-, 149-, 210-, and 420-µm particle sizes and Al 7075 (Öz-Ka Metal Ltd., Turkey) have been used as reinforcement and matrix, respectively. Chemical compositions are given in Tables 1 and 2. The particle size was determined using laser diffraction (Model mastersizer Hydro 2000e, Malvern, UK) connected to a computer. Samples for microstructural examinations were prepared using standard metallographic techniques. The polishing process was performed in two stages. Diamond particles, 6 µm (coarser polishing) and 1 µm (finer polishing) in diameter, were used to produce a smooth surface. Samples were examined by optical (Nikon MA-100, Nikon, Japan) and scanning electron microscopy (Jeol JSM-6060 LV, Jeol, Munich, Germany).

Infiltration has been carried out with quartz tube, as shown in Figure 1, with 10 mm outside diameter, 1 mm wall thickness, and 300 mm length. Stainless steel filter was placed at the bottom of the tube, and Al foil was placed on the filter. SiO_2 powders with different particle sizes were filled to form 50 mm height freely. To prevent vacuuming of powders, stainless steel filter, alumina blanket, and weight were placed on the powder.

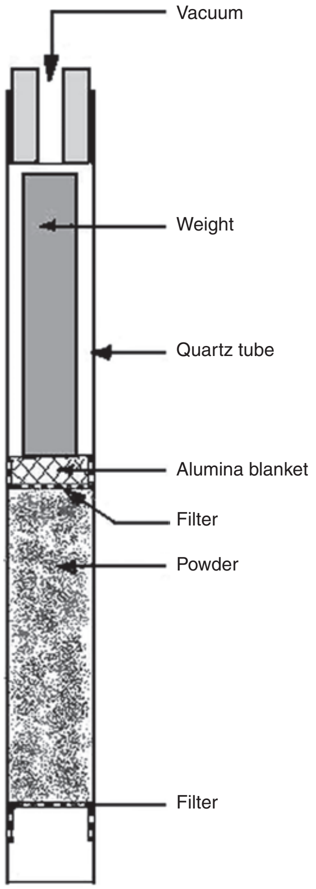

Figure 1: Infiltraation tube.

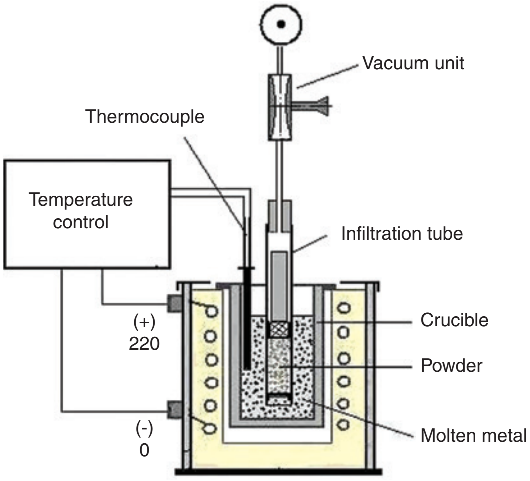

Figure 2: A prototype vacuum infiltration apparatus.

Table 1: Chemical composition of SiO_2 used as reinforcement (wt.%).

Fe_2O_3	MgO+CaO	Al_2O_3	Na_2O	SiO_2
0.35	0.05	0.7	0.13	Balance

Table 2: Chemical composition of A7075 used in infiltration tests (wt.%).

Zn	Mg	Cu	Cr	Al
5.6	2.6	1.6	0.3	Balance

A prototype vacuum infiltration apparatus (Figure 2) was used the produce the composites. The molten metal temperature is kept at 700°C, 750°C, and 800°C±5°C; 550±10 mm Hg vacuum was applied to the tube, and the tube was dipped in liquid metal in normal atmosphere. Vacuum was kept under these conditions for 3 min. After 3 min of vacuuming, the tubes were taken out and cooled down to room temperature in normal atmosphere. Then the tubes were broken, and the composites were removed from tubes. The composite samples were obtained by machining (turning). The attained geometry was a cylinder with a diameter of 7.9 mm and a length of

48 mm. The porosity was determined in accordance with experimental and theoretical densities using the law of mixtures. Fracture strengths were determined using a prototype three point fracture tester. Microstructure and fracture surfaces of composites were investigated by SEM analysis.

3 Results and discussion

3.1 Infiltration height

Particle size, weight of the SiO_2 powders, and reinforcement volume ratio at 50 mm height in preform are given in Table 3. It was observed that increase in the particle size causes an increase in the preform weight. It was also observed that as the particle size increased, reinforcement volume ratio increased. It can be said that SiO_2 powders with small size produce more pores with dimension smaller than that of bigger particle size.

The change in infiltration height as a function of the particle size of SiO_2 under different matrix temperatures is shown in Figure 3. It was observed that the infiltrated height was increased with increasing particle size and

Table 3: Weight of the SiO_2 powders with different particle sizes forming 50 mm height.

Particle size (μm)	105	149	210	420
Weight (g)	3.4575	3.6785	3.8766	3.8579
Reinforced volume ratio (%)	52	54	57	58

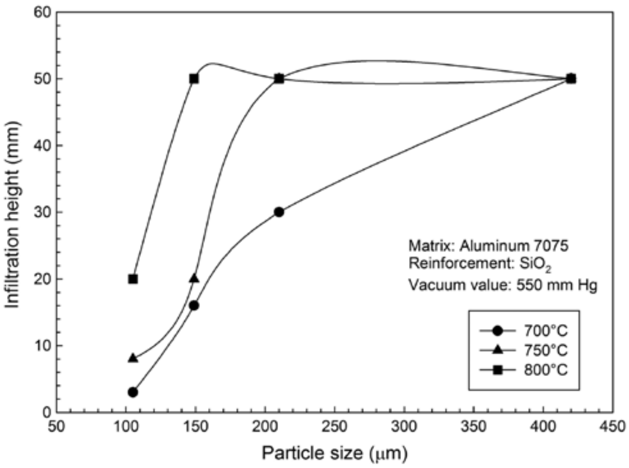

Figure 3: Infiltration heights against reinforcement particle size and matrix temperature.

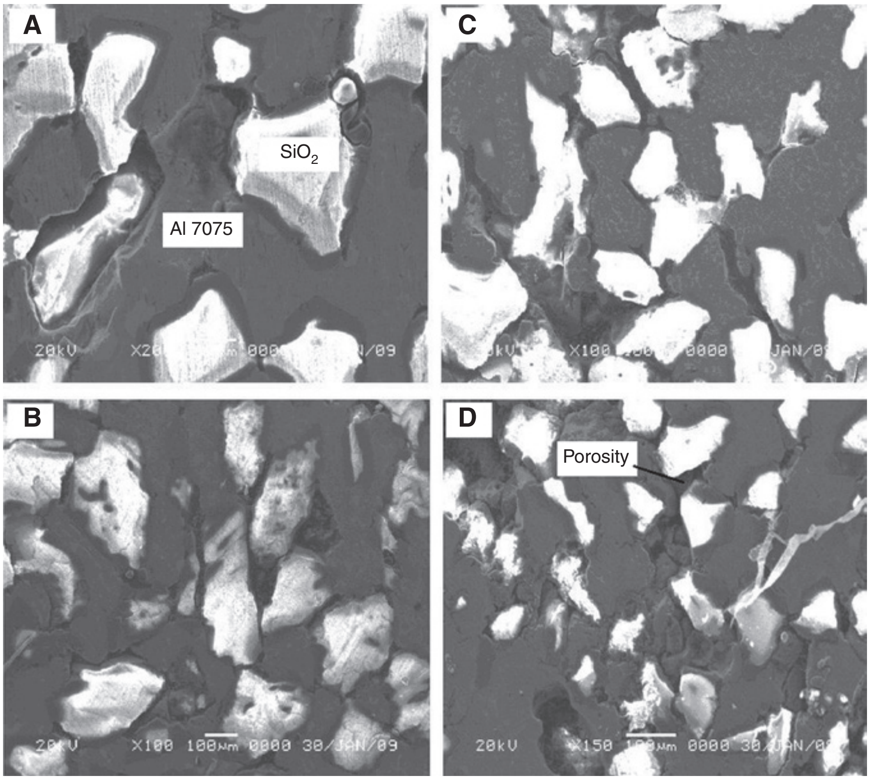

Figure 4: SEM micrographs of composites with reinforcement sizes of (A) 420 μm, (B) 210 μm, (C) 149 μm, and (D) 105 μm.

matrix temperature. Full infiltration achieved a matrix temperature of 800°C with a reinforcement particle size more than 149 µm. In powders with a particle size of 105 µm, no full infiltration could be achieved. SEM micrographs of composites with different particulate reinforcement sizes are given Figure 4A–D. When the particle size is increased, the pore dimension in the preform increased. It can be said that larger pores aid the forced infiltration. When molten metal temperature goes up to higher values, infiltration is done more easily. Similar results have been reported by different authors [15–17].

3.2 Porosity and fracture strength

Density and porosity values with the reinforcement particle size of the produced composites are given in Table 4. It was observed that the porosity of the produced composites changed in the range of 3.2–14.6%, and the lowest porosity was obtained from the composite having 105 µm SiO_2 particle size. This can also be seen in SEM micrographs given in Figure 4. These results can be attributed to smaller pore dimensions in composites with small reinforcement particle size. The variation in fracture strength as a function of particle size is given in Figure 5. Al 7075 with SiO_2, which have a reinforcement size composite of 105 µm, did not full infiltrate tested temperatures. Therefore, this specimen could not be provided.

Table 4: Density and porosity values with reinforcement particle size.

SiO_2 particle size (µm)	Theoretical density (g/cm³)	Experimental density (g/cm³)	Porosity (%)
420	2.71	2.62	3.22
210	2.71	2.51	7.64
149	2.72	2.47	8.96
105	2.72	2.32	14.6

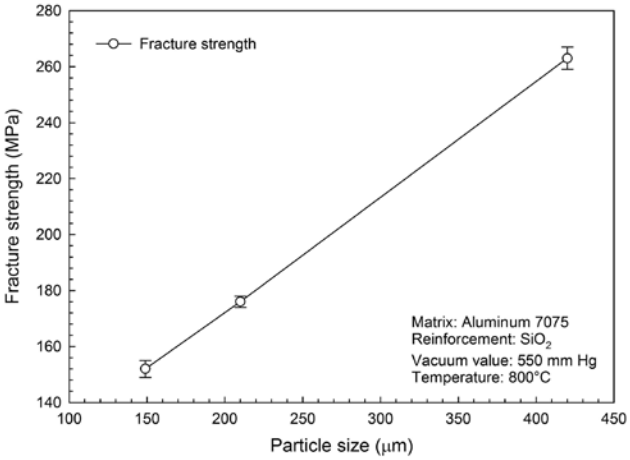

Figure 5: The relationship between reinforcement particle size and fracture strength.

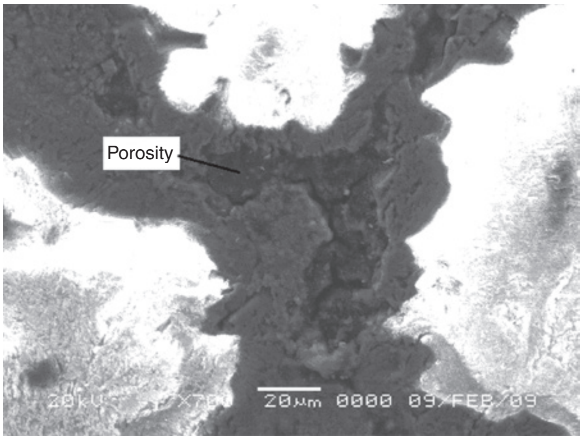

Figure 6: SEM micrograph of the composite with a reinforcement size of 149 µm.

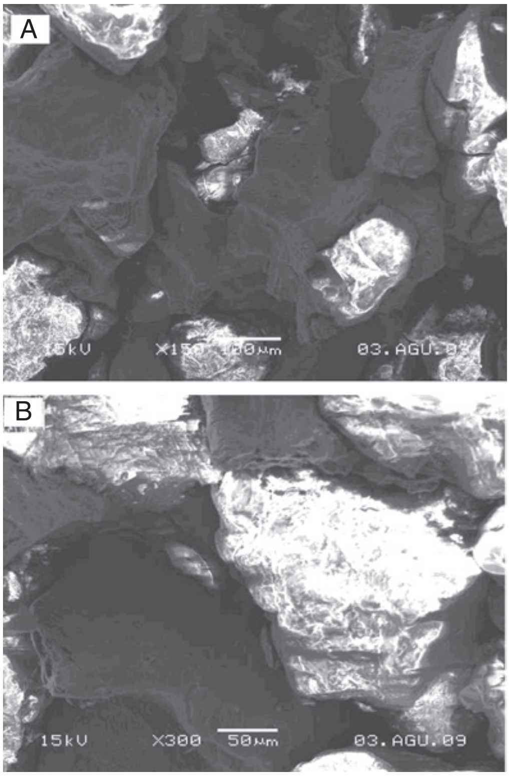

Figure 7: Fracture surface of composite with a 210-µm reinforcement particle size; (A) composite and (B) matrix-reinforced surface.

The fracture strength showed approximately a linear change with particle size. The highest fracture strength (263 MPa) was obtained as the composite with a 420-µm particle size. Fracture strength is related to pores and pore configurations in materials. This behavior can be attributed to amount of pores in composites. Similar results in different systems of Al matrix composites have been reported by some researchers [2, 5, 10, 17].

Micrographs of the microstructure and fracture surfaces of the composites are given in Figures 6 and 7A,B. It was observed that pores are generally in the narrow interstices of reinforcement particles or around reinforcement particles. Molten metal cannot infiltrate small pores; thus, small pores remain as a void. The fracture behavior of composites is generally brittle, although some ductile fracture appears in some areas. It was also observed that fractures take place in matrix-reinforced interfaces.

4 Conclusion

Vacuum infiltration method can be an applicable method for producing Al 7075/SiO_2 composites, especially high-volume fractions. Temperature and particle size are important and effective parameters to reach the full infiltration. For engineering applications, the optimum temperature and reinforcement particle size could be used, that is, 800°C and 420 μm, respectively, for these composites. The fracture strength of composites increases with increasing reinforcement particle size, depending on less porosity of product composite with larger reinforcement size.

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References

[1] Surappa MK, Rohatgi RK. *J. Mater. Sci.* 1981, 16, 983–993.
[2] Srivatsan TS, Ibrahim IA, Mohamed FA, Lavernia EJ. *J. Mater. Sci.* 1991, 26, 5965–5978.
[3] Tsunemichi I, JianFu M, Shangli D, Ichinori S, Naobumi S, Gilles L. *Mater. Sci. Eng. A. Struct. Mater.* 2004, 364, 281–286.
[4] Shibata K, Ushio H. *Tribol. Int.* 1994, 27, 39–44.
[5] Shorowordi KM, Laoui T, Haseeb ASMA, Celis JP, Froyen L. *J. Mater. Process. Technol.* 2003, 142, 738–743.
[6] Laurent V, Chatain D, Eustathopoulos N. *J. Mater. Sci.* 1987, 22, 244–250.
[7] Ramesh CS, Seshadri SK, Iyer KJL. *Indian J. Technol.* 1991, 29, 179–185.
[8] Miyajima T, Iwai Y. *Wear* 2003, 225, 606–616.
[9] Venkataraman B, Sundararajan G. *Acta Mater.* 1996, 44, 461–473.
[10] Mandal A, Chakraborty M, Murty BS. *Wear* 2007, 262, 160–166.
[11] Kerti I. *Mater. Lett.* 2005, 59, 3795–3800.
[12] Kouzelli M, Marchi CS, Mortensen A. *Mater. Sci. Eng. A. Struct. Mater.* 2002, 337, 264–273.
[13] Bai L, Xiujuan L, Mingjun L, Zhenyu Z. *Mater. Manuf. Process.* 2011, 26, 1339–1345.
[14] Qin QD, Zhao YG, Liu C, Zhou W, Jiang QC. *Mater. Sci. Eng. A. Struct. Mater.* 2007, 460–461, 604–610.
[15] Calin R, Citak R. *Mater. Sci. Forum.* 2007, 546, 611–614.
[16] Bhagat RB. *Mater. Sci. Eng. A. Struct. Mater.* 1991, 144, 243–251.
[17] Abd-Elwahed MA. *J. Mater. Process. Technol.* 1999, 86, 152–158.