Asian Journal of Chemistry; *Vol. 24, No. 1 (2012), 76-80*

ASIAN JOURNAL OF CHEMISTRY

www.asianjournalofchemistry.co.in

Effect of Infiltration Pressure on Thermal Conductivity of Al 2014 Matrix Composite Powered by Silicon Carbide

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(*Received*: 8 November 2010; *Accepted*: 9 September 2011) AJC-10374

By using pressure infiltration method, metal matrix composites are produced by saturating Al 2014 aluminum composite to the gaps among SiC powders. SiC powders filled into stainless steel tubes are fastened between the filters conducting only liquid material, dipped into pressurized molten boiler and infiltrated in 3 min under 500-900 kPa pressures at 750 ºC. The image analyses of samples were done by scanning electron microscope (SEM). Densities, porosities and thermal conductivities of them were identified experimentally. It is defined that by the increase of infiltration pressure, porosity amount decreases but the value of thermal conductivity increases.

Key Words: Composite, Infiltration, A1 2014, SiC, Thermal conductivity, Porosity.

INTRODUCTION

It is known that materials are developed together with today's developing technology. The properties not obtained by only one pure material have been developed by using more than one material. Production technique and infiltration pressure temperature of the composite and other conditions are important beside pure properties of materials forming the composite such as lightness, roughness, conductivity and non-conductivity. For producing the metal matrix composites, there are some methods such as casting methods, powder metallurgy technique and infiltration methods[1,2]. Infiltration methods of metal matrix composite materials have been applied as saturating under pressure, with vacuum and without pressure[3,4]. The method of infiltration with pressure is a production technique that applies inert gas pressure to liquid metal instead of mechanical pressure so that liquid metal penetrates into preformed material including reinforcement[5]. Matrix material of metal matrix composites are usually aluminum and aluminum alloys. Matrix materials like magnesium, iron, titanium and super alloys have been used less than aluminum[6]. It is known that reinforcing elements with high thermal conductivity are used for increasing the thermal conductivity of materials. It has been observed that thermal conductivity is affected from changing grain-size of reinforcing material and reinforcing volume ratio[7].

In addition, it has been observed that in terms of the infiltration of SiC/Al composites in different reinforcing volume ratios calculated by powder metallurgy method (PIM), thermal conductivity in different grain sizes varies linearly with reinforcing volume ratio[7]. Packaging materials used in electronics should have low and suitable thermal expansion coefficient, high thermal conductivity, low cost and low density. However, as traditional packaging materials couldn't meet all these properties, ceramic reinforced metal matrix composites have been developed[8]. So, the thermal conductivity of composite materials has been more important in recent years. For the new applications in electronics industry, as a result of small sizes and power increase of electronic devices, materials whose thermal conductivity coefficient is high -about 250-300 (W/mK)- are needed for the materials used in these devices[9]. Industrial powders comprised of refractory compounds such as carbide, nitride, oxide and boride are usually used in the production of composite. More preferred discontinuous reinforcements are SiC and Al_2O_3 comprised of particle and capillary crystal. Silicon carbide has been used as reinforcement material because its rigidity, resistance against breakage and elasticity module is higher than Al_2O_3 and its density and thermal expansion coefficient is lower[10]. Because of the superior properties of silicon carbide ceramics such as high wear resistance and thermal shock resistance, low friction coefficient, suitable thermal conductivity and expansion coefficient, its usage in gas turbines and depreciable automobile parts have become very important[11]. In pressure infiltration technique the most important infiltration parameters are liquid metal heat, reinforcing grain size, infiltration duration and pressure, and the most important of these parameters is infiltration pressure. Chemical composition and physical characteristics[12] of SiC and Al2014 are given in Tables 1-3.

TABLE-1
PHYSICAL AND THERMAL CHARACTERISTICS OF SiC AND Al2014

	Al2014	SiC
Density (g/cm^3)	2.80	3.20
Specific heat (J/kgK)	880.00	670.00
Thermal conductivity (W/mK)	193.00	77.50

TABLE-2
CHEMICAL COMPOSITION OF Al 2014

Element	(%)	Element	(%)
Al	93.60	Mn	0.40
Cr	0.10	Si	0.50
Cu	3.90	Ti	0.15
Fe	0.70	Zn	0.25
Mg	0.20	Other	0.20

TABLE-3
CHEMICAL COMPOSITION OF SiC

Element	SiC	Fe_2O_3	C	SiO_2	Al_2O_3
(%)	99.00	0.30	0.40	0.10	0.20

In the literature, the effect of infiltration pressure to the thermal conductivity value of SiC/Al composites produced by pressure infiltration technique hasn't been searched. In this study, the porosity and thermal conductivity values of Al 2014 alloy which can be hardened by thermal process of 2000 series have been defined under different infiltration pressures. Density, thermal conductivity and porous amount of composites produced under different pressures have been measured experimentally.

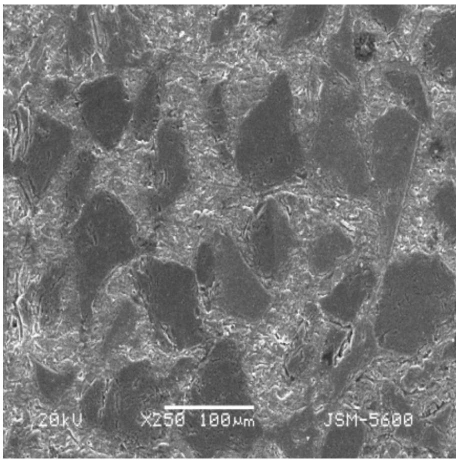
EXPERIMENTAL

In this study, as reinforcing element for the production of metal matrix composite, 105 μm-grain-size SiC powders whose chemical composition is given in Table-3 and as matrix material, Al2014 aluminum alloy whose chemical composition is given in Table-2 were used. Table-1 is about the physical and thermal characteristics of matrix and reinforcing element used in the study. Silicon carbide powders were filled into the tubes made of stainless steel material in 13 mm in diameter and 300 mm height and both sides of them were fixed with filter and ring. Infiltration process was performed in 3 min and under 750 ºC and 5 different pressures (between 500 and 900 kPa) of nitrogen (N_2) used as inert gas. The samples infiltrated were cut in suitable measures for density, thermal conductivity and scanning electron microscope measurements.

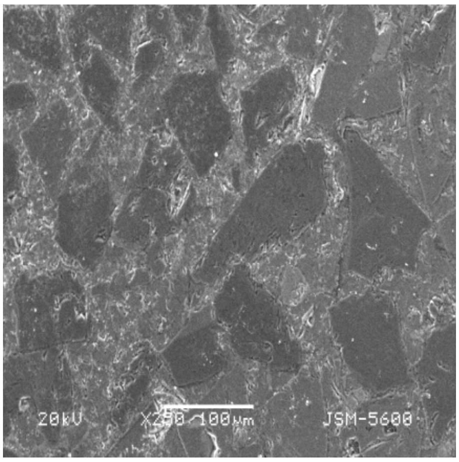
The experimental measurements of samples' densities were done according to Archimedes principle by using density measuring kit in "Sartorius YDK 01" scales with 0.0001 g sensitivity. From the measurements, the following equation No. 1 has been obtained.

$$\varphi = \frac{\rho_e}{\rho_t} \times 100 \qquad (1)$$

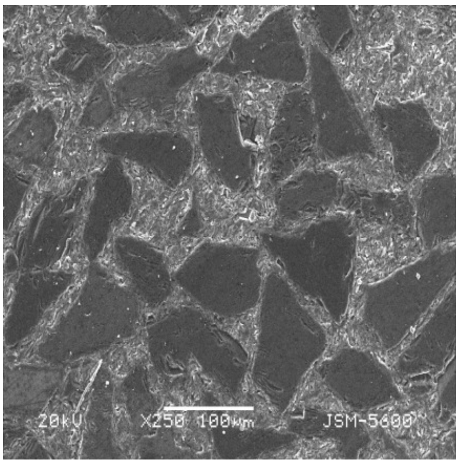
here (φ) is porous amount in material, (ρ_e) is the density obtained experimentally and (ρ_t) is the theoretical density measured from reinforcing value ratio. The micro structure of composites has imaged under scanning electron microscope with 250 magnifying after surfacing and polishing processes (Fig. 1). When the figure is examined, it is observed that infiltration is completely carried out and SiC particles are delivered into the matrix as homogenous.



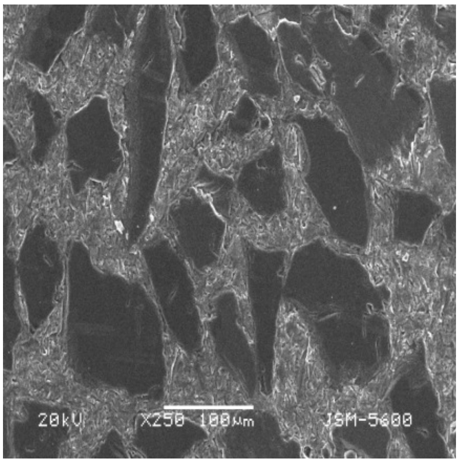
(a)



(b)



(c)



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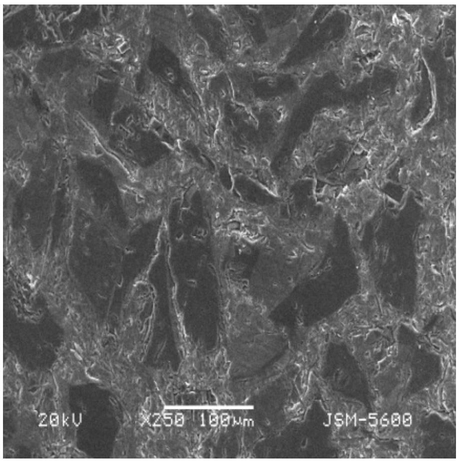


(e)

Fig. 1. SEM images of micro structures of composites in different pressures (a) 0.5 MPa, (b) 0.6 MPa, (c) 0.7 MPa, (d) 0.8 MPa, (e) 0.9 MPa

The thermal conductivity values of the samples were indirectly calculated with the eqn. 2 from heat diffusion coefficient by using Laser Flash technique with "Anter Flash Line 2000" device. The operation principle of this device which is based on time-dependent thermal conductivity measurement is given in Fig. 2. While doing the measurements in this device, Cast 95 was used for median diameter so that the size of samples was compatible to the device. Thermal conductivity measurements were done at 8 different temperature values from 25 °C (known as the normal room temperature) to 200 °C. Each measurement was done for three times and the result was found by the median of them.

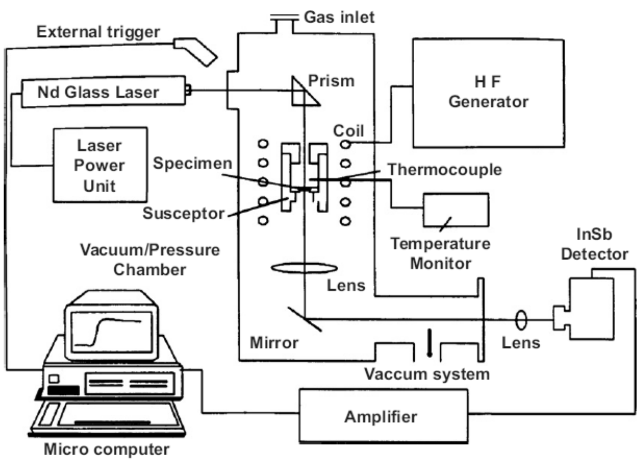


Fig. 2. Schematic image of thermal conductivity measurement experiment apparatus (Laser Flash)

$$\alpha = \frac{k}{\rho \times c} \qquad (2)$$

RESULTS AND DISCUSSION

Composites are saturated better with the effect of pressure. As an expected situation, it is observed that the pressure increases and porosity decreases. Because porosity decreases the thermal conductivity, the effect of porosity to thermal conductivity was determined for every sample. As seen in Table-4, while pressure increases, porosity decreases and its difference with density decreases. The air in pores existing in composites' internal structure is entrained. Because the thermal conductivity value of air is lower than the composite materials, the spaces reduce the thermal conductivity of composite. To determine the density difference, calculated theoretical density and experimentally measured density are used from the point of mix proportion of composite materials. The relationship between porosity and pressure is shown in Fig. 3. Porosity amount shows a change close to the linear with the effect of pressure, but under 800 kPa pressure this linearity is decomposed as the pressure increases slightly. The reason isn't clear but there may be a filtration problem during infiltration or materials which may not be compressed into the tubes well during filling.

TABLE-4
POROSITY AMOUNTS OF METAL MATRIX COMPOSITES

Pressure (kPa)	Experimental density (ρ_e)	Difference ($\rho_t - \rho_e$)	Porosity (%)
500	2.9109	0.0958	1.0329
600	2.9369	0.0698	1.0238
700	2.9575	0.0492	1.0167
800	2.9693	0.0374	1.0126
900	3.0384	-0.0316	0.9896

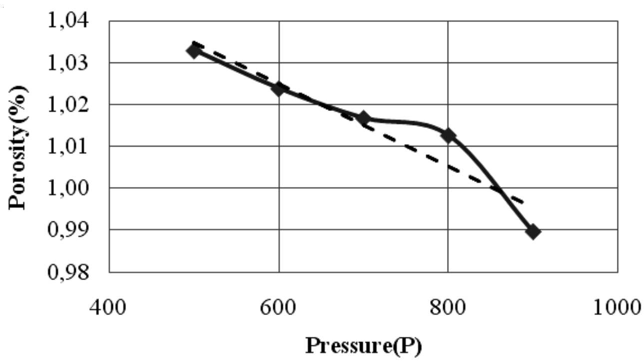


Fig. 3. Change of porosity with infiltration pressure

The thermal conductivity value of composites was measured experimentally by using Laser Flash technique and these values are given in Table-5. The measurements were done at 8 different temperatures for every pressure value of composites. The thermal conductivity was calculated indirectly because the

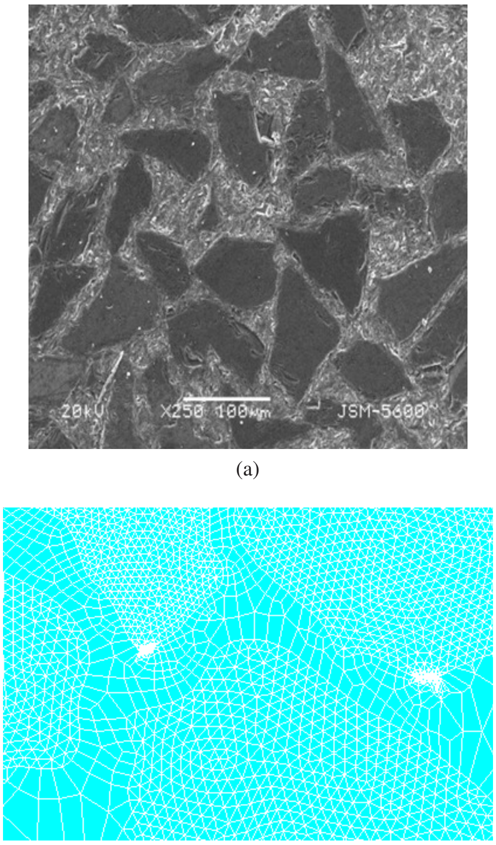
TABLE-5
CHANGE OF THERMAL CONDUCTIVITY VALUE WITH TEMPERATURE AND PRESSURE

Temperature (ºC)	Infiltration pressure (kPa)				
	500	600	700	800	900
25	120.004	124.726	133.007	138.217	142.311
50	118.096	121.144	130.797	136.682	139.59
75	112.002	117.561	126.354	131.402	136.915
100	110.327	112.235	122.725	126.331	131.309
125	102.977	106.954	118.818	123.237	128.075
150	99.767	100.93	111.816	119.027	126.912
175	96.161	97.952	111.327	115.98	123.958
200	93.091	96.254	107.164	112.072	120.353

device measures the thermal diffusion value in experimental measurements. It was assumed that in these calculations, density and specific heat didn't change with temperature.

The change of thermal conductivity value with temperature and pressure is given in Table-5. It is observed that the thermal conductivity increases with pressure, but decreases with temperature. The reason of pressure increase is about porosity as mentioned before. The high pressure provides solution to penetrate into the micro particles better. The decrease of thermal conductivity with temperature stems from SiC. It is known that the thermal conductivity of SiC increases at negative temperatures and decreases at room temperature or higher temperatures[13,14].

SEM image of one of the samples is shown in Fig. 4a and its net structure of its numerical solution based on finite element is in Fig. 4b. Although the numerical solutions were performed on the whole of images, which it doesn't represent the whole



(a)

(b)

Fig. 4. (a) SEM image of composite obtained with 0.7 MPa infiltration pressure, (b) A piece of transformed numeric model

of sample should be noticed. The calculations were done by using superficial ratios in terms of finding the volume ratio in two-dimensional numerical solution. It has been observed that the error proportion for the superficial ratio transformation to volume ratio in two-dimensional solution is under 1 %. So, it can be said that the two-dimensional numerical solution is equal to three-dimensional solutions.

The measurements done experimentally between 25 and 100 ºC were calculated with arithmetic mean (Table-6). The thermal conductivity values of matrix and reinforcing materials used in theoretical and numerical methods are between 0 and 100 ºC in literature. According to these values, experimental results are rather consistent and expected ones. The deviation of numerical results stems from, dependence of the results to the micro structure of region chosen and disregarding of porosity. The results obtained by geometric and parallel methods are quite close values to each other. The deviation on them stems from the solutions about the two-material composites. However, there is about 1 % porosity in real samples. Also, the effect of pressure in theoretical methods is out of question.

TABLE-6
THERMAL CONDUCTIVITY VALUES
OBTAINED WITH DIFFERENT MODELS

Pressure (kPa)	Geometric (k_g)	Parallel (k_p)	Numeric	Experimental
500			121.983	115.107
600			120.765	118.916
700	120.440	133.309	119.396	128.221
800			118.073	133.158
900			121.678	137.531

By the help of micro structure images of SiC/Al2014 composite, numerical method has been generated. This model is defined for boundary conditions in terms of one-dimensional thermal conductivity, temperature distribution and heat flow amounts are calculated and the effective thermal conductivity of composite is determined. The vector image of heat flow on calculation plane of composite's chosen region is given in Fig. 5. According to this image, in accordance with the thermal conductivity of materials forming composite, the difference between vector quantities is obvious.

Conclusion

By the increase of infiltration pressure, porosity amount decreases but the thermal conductivity increases. It is observed that the thermal conductivity values of composite decreases

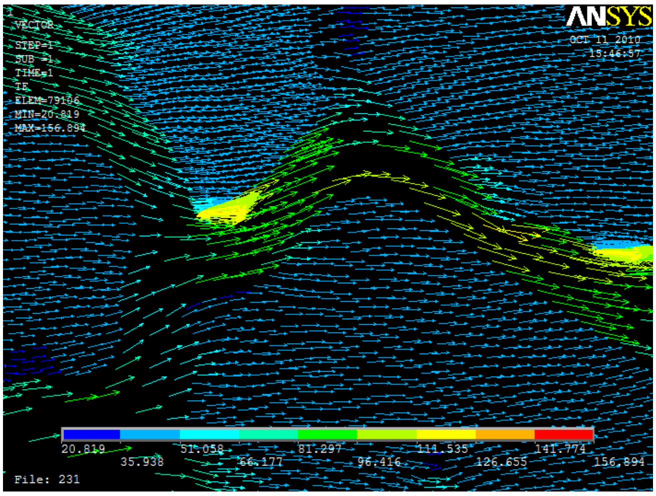


Fig. 5. Enlarged vector illustration of thermal flux in the phase of the rectangle region

while temperature increases. The experimental results were supported by calculating the thermal conductivity with some numerical and theoretical methods. It has been observed that not considering the effect of porosity in numerical and theoretical models is a disadvantage.

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