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Studying the Effect of Sintering and Porosity on Electrical Conductivity of Composite Materials

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Abstract

This research was carried out to study the effect of sintering temperature and porosity on the electrical conductivity of metal matrix composites. Aluminium powder was reinforced with ceramic particles alumina and silicon carbide using fixed weight fraction (10%) and deferent grain sizes. The specimens were prepared by hydraulic press after that the specimens fired at deferent sintering temperatures. The results show the electrical conductivity was increased with increasing sintering temperatures and time and the highest value of electrical conductivity at 500^{0}C and six hours for Al-SiC composites. While the electrical conductivity of the composite decreases by increasing the AL_2O_3 and SiC porosity that the lowest value of electrical conductivity at 125µ for Alumina particles.

Key word: aluminium, Alumina, silicon carbide, electrical conductivity &composite materials

Introduction

Composite materials consist of two or more different materials incorporated into a matrix to obtain performance characteristics beyond those that could be achieved by the constituents individually. Composites typically contain one or stronger, stiff reinforcement constituent's material embedded within a continuous constituent material (matrix). In the case of metal matrix composites (MMCs), the most common matrices are aluminum, copper, magnesium and titanium. Metal matrix composites reinforcements can be metallic (such as tungsten and cobalt), non-metallic (most often carbon, graphite or boron) or ceramic (for example, silicon carbide (SiC), aluminum oxide (Al_2O_3), boron nitride, tungsten carbide and boron carbide)[1].

The materials which conduct electricity when an electrical potential difference is applied across them are known as conducting materials. The most important property of a material is the electrical resistance, which characteristics the electrical properties more lucidly. The conductivity (σ) of a material depends on the presence of free electrons or conduction electrons, which move freely in the metal and do not correspond to any atom [2].

Sintering is the process of heating the green compact at sufficient by high temperature (800-1500)^{0}C for sufficient amount of time (12 to 60)

minutes, in order to have permanent cohesion of metal particles into a solid. The heating temperature is below the melting point of the principle powder. But in some cases, sintering is done above the melting point of the binder metal. Sintering is done in the furnace. The furnace may be gas fired, oil fired or electric resistance furnace. Electric resistance furnace is most suitable because the temperature can be controlled uniformly and accurately [3].

Luisa studied the composite materials with copper matrix particulate reinforced with alumina by powder metallurgy. She was found that the maximum values of electrical conductivity at $(880)^0$C for/(6) hours of alumina reinforced copper [4].

EXPERIMENTAL WORK

Material

Aluminum powder (99.9)

SiC

Al_2O_3

Equipments

LCR-meter model HP4284A1988 (20Hz-1MHz).

Hydraulic Press (Herzog).

Die (stainless die with diameter 1cm and thickness 3cm)

Experimental setup

The composite studies were aluminium matrix reinforced with 10% weight fraction of each SiC & Al_2O_3 at particles size (45, 106 &125μm) using powder metallurgy technique:

The process of powder metallurgy involves:

Preparing the powder of metal.

Mixing the powder metal with reinforcement materials in proper proportions.

Pressing the powder in a suitably shaped die (compacting) at room temperature and the pressure used was (2 ton/cm^3) for (2min.).

Sintering the specimen at different temperatures for aluminium (380, 430, 480 &530) C° at time (0.5, 2, 4 &6) hour.

Test specimens have (1 cm) diameter and (0.5 cm) thickness.

The device precision LCR meter was accurately adjusted then used to measure the resistance (R) values on the electronic screen. From these value can be found an electrical conductivity by equation 1.

Electrical Conductivity is calculated by taking the inverse of electrical resistivity is given in units of S\cm [5].

$$E.C.(\sigma) = \frac{d}{R.A} \quad \text{---------1}$$

$$B = \frac{1}{\sigma} \quad \text{-----------2}$$

Where

B: electrical resistivity, Ω.cm.

E.C: electrical conductivity, S\cm

R: electrical resistance, Ω

d: diameter, cm

A: cross- section area, cm^2

Porosity of composite was calculated using the following equations [6].

$$\rho_s = \frac{M}{V} \quad \text{---------------------3}$$

$$\rho_B = (M_d / M_w)\, \rho_0 \quad \text{-------------4}$$

$$p_r = [1 - (\rho_B / \rho_s)] \quad \text{----------5}$$

Where:
ρ_s: density of specimen, gm / cm^3
M: mass of specimen, gm
V: volume of specimen, cm^3
M_d: is the specimen weighted dry, gm
M_w: is the specimen weighted wet, gm
ρ_0: density of water (1gm/cm^3)
ρ_B: bulk density.
p_r: porosity.

Figure 1: photo the specimens

Results and Discussion

Effect of sintering on the temperature

As shown in figures (2 and 3) and tables (1 and 2) the electrical conductivity increases with increasing sintering temperatures and time, while the electrical conductivity of Al-SiC composites increases more than of Al-Al_2O_3.

This is according to the lower conductivity value of SiC and Al_2O_3 more than that of AL that restricts the motion of the electrons which are responsible for the conductivity [7].

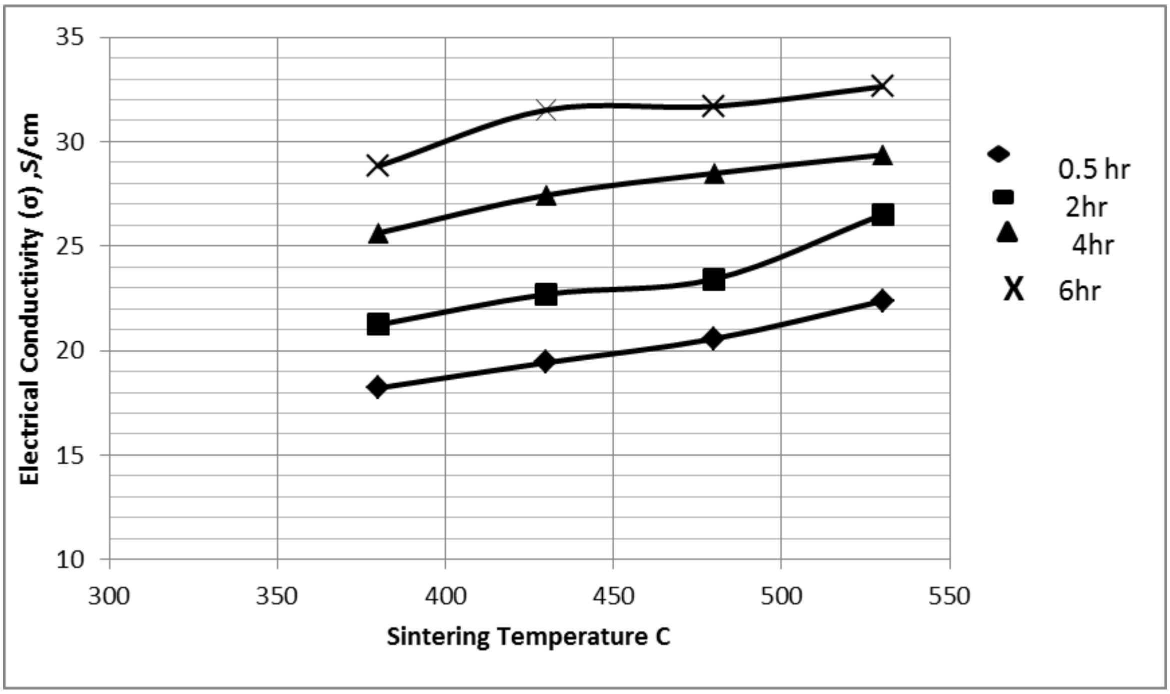

Fig.2: Electrical conductivity of Al-SiC with deferent temperature and time.

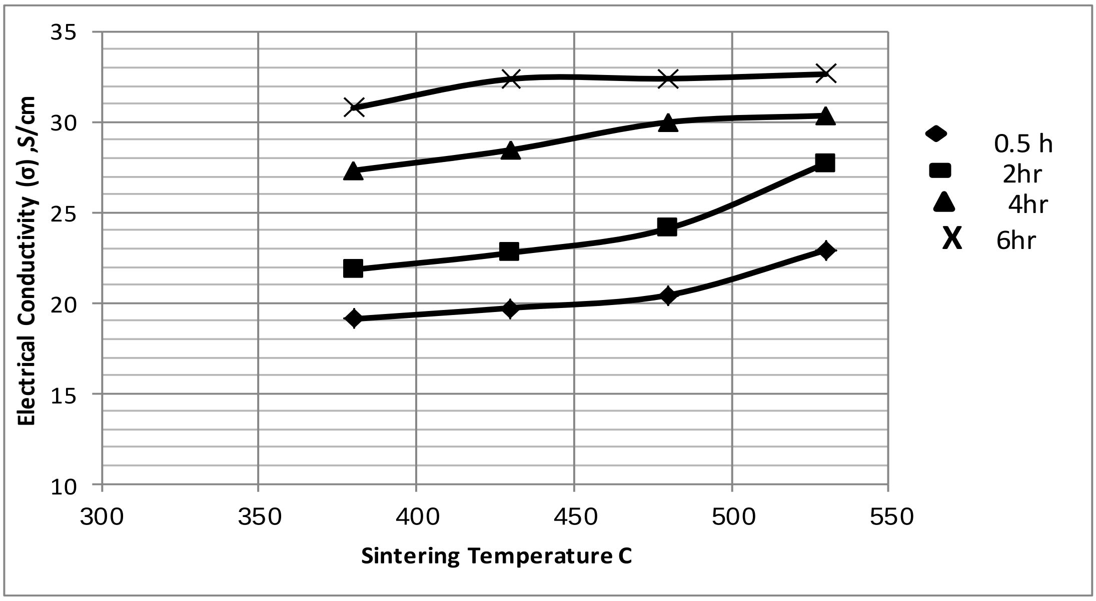

Fig.3: Electrical conductivity of Al-Al_2O_3 with different temperature and time.

2-Effect of porosity

The experimental results for investigating the relation between the electrical conductivity and porosity are shown in Figures (4and 5) and tables (3 and 4). From these figures, the electrical conductivity of the composite decreases by increasing the Al_2O_3 and SiC porosity. Also thermal conductivity is directly affected by the porosity; since the conductivity of a pore is zero so by increasing the pores decreases the electrical conductivity [7].

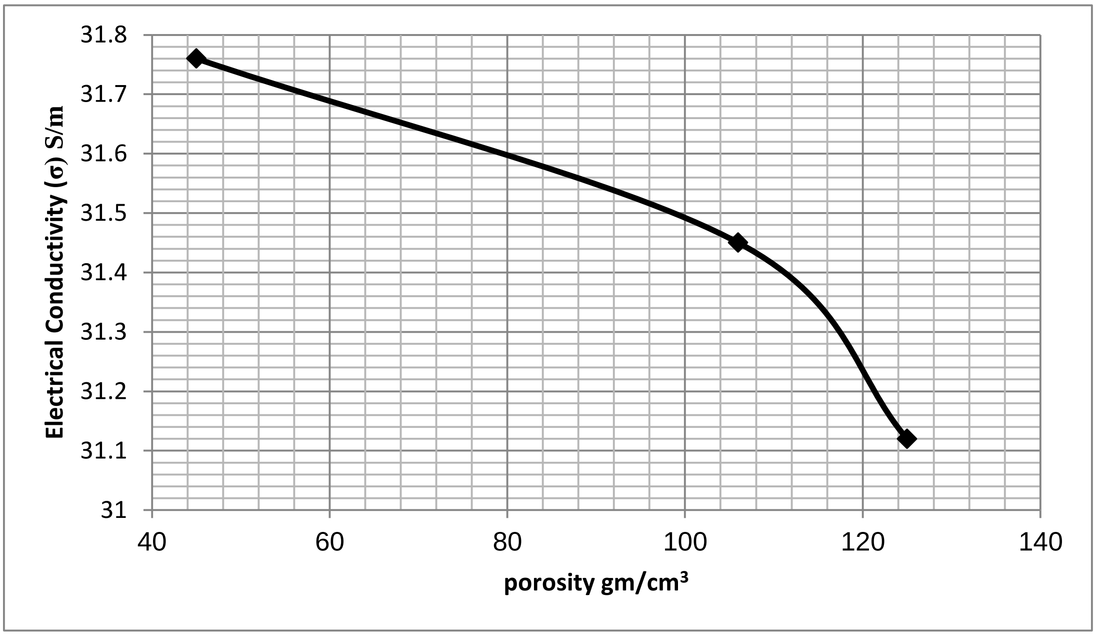

Fig4: Electrical conductivity at different porosities of Al-Al_2O_3 at 6 hours

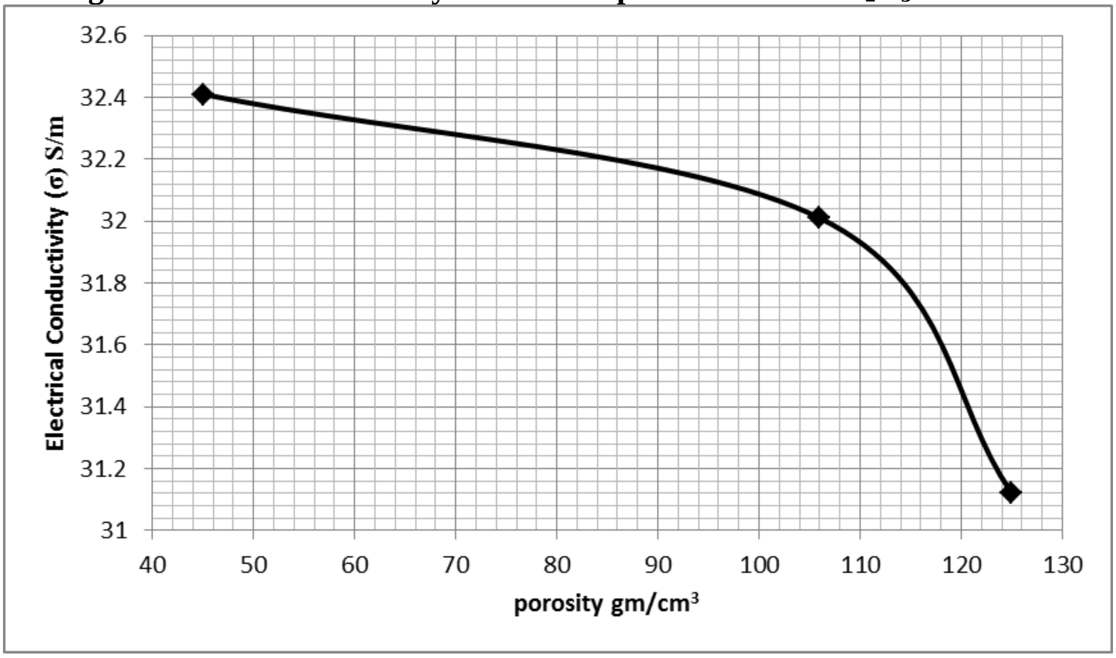

Fig5: Electrical conductivity at different porosities of Al-SiC at 6 hours

Conclusion

A) As sintering temperatures and time increases, electrical conductivity was decreased.

B) Electrical conductivity was decrease with increase of porosity

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Table 1: Electrical conductivity of $Al\text{-}Al_2O_3$ with different temperatures

σ (S/cm)				
Time, hr	**380 C°**	**430 C°**	**480 C°**	**530 C°**
0.5	18.21	19.43	20.57	22.38
2	21.24	22.70	23.43	26.52
4	25.63	27.44	28.94	29.37
6	28.83	31.52	31.69	31.76

Table 2: Electrical conductivity of Al –SiC with different temperatures

σ (S/cm)				
Time, hr	**380 C°**	**430 C°**	**480 C°**	**530 C°**
0.5	19.10	19.71	22,42	22.90
2	21.83	22.76	24.11	27.70
4	27.31	28.45	29.98	30.35
6	30.77	32.37	32.39	32.64

Table 3: Electrical conductivity at different porosities of $Al\text{-}Al_2O_3$ at 6 hours

samples	M_d, Gm	M_w, Gm	V, cm^3	ρs, gm\cm^3	ρ_B, gm\cm^3	P_0	(σ), S\cm
45 μm	1.62	1.67	0.785	2.063	0.970	0.529	31.76
106 μm	1.58	1.69	0.785	2.012	0.934	0.535	31.45
125 μm	1.55	1.72	0.785	1.974	0.901	0.543	31.12

Table 4: Electrical conductivity at different porosities of Al-SiC at 6 hours

samples	M_d, Gm	M_w, Gm	V, cm^3	ρs, gm\cm^3	ρ_B, gm\cm^3	P_0	(σ), S\cm
45 μm	1.62	1.67	0.785	2.063	0.970	0.529	32.41
106 μm	1.58	1.69	0.785	2.012	0.934	0.535	32.01
125 μm	1.55	1.72	0.785	1.974	0.901	0.543	31.89

دراسة تأثير التلبيد والمسامية على التوصيلية الكهربائية للمواد المتراكبة

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الخلاصة:

يهدف البحث الى دراسة تأثير التلبيد والمسامية على التوصيبية الكهربائية لمواد مركبة ذات اساس معدني. لقد تم تدعيم مسحوق الالمنيوم بواسطة دقائق سيراميكية الالومينا وكاربيد السيليكون باستخدام كسر وزني ثابت (10%) وحجوم حبيبية مختلفة. تم تحضير العينات باستخدام مكبس هيدروليكي وبعد ذلك تم حرق النماذج عند درجات تلبيد مختلفة.وقد بينت النتائج زيادة في التوصيلية الكهربائية مع زيادة درجة حرارة التلبيد والزمن حيث اعلى قيمة لها عند 500^0C وزمن ست ساعات لمتراكبات الالمنيوم وكاربيد السيليكون. بينما بينت الدراسة هناك نقصان في التوصيلية الكهربائية بزيادة المسامية للمواد السيراميكية حيث وجد ان اقل قيمة لها عند 125 مايكرون لدقائق الالومينا.