The Influence of Sic Particle Size on the Thermal and Electrical Conductivities of Cu/Sic Composites.

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ABSTRACT.

The Potential demands for reliable materials in electronic industries are ever increasing. The main pronounced failure that occurs during microelectronic circuits' application involves thermal fatigue. Heat generated in electronic packages can be dissipated by developing suitable materials as heat sinks. Copper metal matrix composites reinforced with silicon carbide (SiC) proffer possibility of meeting these demands. Thus, the interest for appropriate coefficient of thermal expansion (CTE) of packaging materials in combination with a high thermal and electrical conductivity is inevitable in the design and selections of heat sink material. This research work entails producing copper matrix using silicon carbides (SiC) as reinforcement. This is aimed at getting a material with high thermal and electrical conductivities by non convectional liquid metallurgy. Copper silicon carbide composites were produced in 80%Cu-20%SiC, 70%Cu-30%SiC, 60% Cu-40% SiC, 50% Cu-50%SiC, 40%Cu-60%SiC ratios with an average grain size of 212µm, 425µm and 710µm respectively via liquid metallurgy method. The result revealed that increasing volume fraction and particle sizes of the particulate had significant effect on the thermal and electrical conductivity of the composites.

Keywords: Composite, particle size, volume fraction, thermal conductivity, electrical conductivity.

1. INTRODUCTION

Copper has been extensively used in electronic and thermal applications because of its high thermal and electrical conductivity, plasticity, high melting point and good corrosion resistance. Copper is second to Silver in electrical conductivity ranking of copper [1-4]. High

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temperature mechanical property can be improved with the inclusion of ceramic particulate reinforcement without severe deterioration of electrical and thermal conductivity of the matrix. Therefore, these types of materials are considered to be potential candidates for required mechanical property and high conductivity applications [4].

Composite materials are emerging mainly in response to exceptional demands from technology because of rapid advancing activities in automotive, aircrafts, aerospace industries and electronic devices. These materials have low density that makes their properties particularly superior in modulus and strength in comparison with many metals. The intensive studies into the essential nature of the composite [5-9] and enhanced understanding of their property relationship [10, 12, 14], has made it imperative to develop new composite materials with improved mechanical and physical properties.

Metal matrix composites (MMCs) are materials with great potential due to combinations of unique properties that can be achieved. These include: low thermal expansion (CTE), better electrical conductivity and superior thermal conductivity. MMCs proffer the opportunity to modify the properties of a metal (Cu) by adding a suitable reinforcement phase (SiC) to meet the demands for high thermal conductivities in thermal management applications [11, 17]. An important consideration in MMC manufacture is the nature of the interface between the reinforcement and matrix. The incompatibility between the reinforcement and the matrix coefficient of thermal expansion (CTE) will give rise to high residual stress, which leads to low tensile ductility of the composite [7, 9, 13, 15, 16]. This often depends on the processing methodological process, and since this occurs at high temperature, it is more chemical in nature than mechanical.

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This study investigates the mechanism controlling thermal conductivity of Cu-SiC particulate composite produced by liquid metallurgy method. Furthermore, the relationship and impact between particle sizes, volume fraction and processing parameters are evaluated for high thermal and electrical conductivity.

2. MATERIALS AND METHOD

Commercial pure copper wire C10200 (98.8% Cu) used for the experimentation was obtained from Cable Metal Nigeria Limited. The chemical composition, as well as the density, thermal expansion, thermal conductivity and electrical conductivity of the copper wire C10200 are

presented in Table 1 and 2.

Table 1: Chemical composition of Copper wire C10200.

Element	% Composition	Element	% Composition	Element	% Composition
Cu	98.80	Si	0.032	Cr	0.043
Pb	0.490	Mn	0.013	Sb	0.012
Zn	0.073	Fe	0.450	Mg	0.0005

Table 2: Density, thermal expansion, thermal conductivity and electrical conductivity of copper wire C10200.

Variable	Units	Values
Density	Kg/m^3	8940
Thermal Conductivity	W/mK	380
Electrical Conductivity	S / m	5.18×10^7
Thermal expansion	/K	17.6×10^{-6}

Table 3: Density and thermal conductivity of silicon carbide (SiC).

Variable	Units	Values
Density	$Kg.m^3$	3180
Thermal conductivity	W/mK	120

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The alloys were produced in 80% Cu-20% SiC, 70% Cu-30%SiC, 60%Cu-40%SiC, 50% Cu-50%SiC, 60% Cu-40%SiC from pure copper wire (C10200) with variation in SiC particle grain sizes of 212µm, 425µm and 710µm. The materials were synthesized by liquid metallurgy process in an oil fired pit furnace. The copper wires were properly cleaned prior to melting so as to eliminate any surface impurities and superheated to 1090°C. The addition of SiC particulates to the molten copper was done at the tail end of the melting. The mixture was continuously stirred before casting. The casting of the melt was done in a metal mould of diameter of 1.45cm x 14.5cm. 15 samples of the resulting Cu-SiC metal matrix composite were later heat treated in a muffle furnace to 490°C for 8 hours for homogeneous distribution.

Resistivity test was conducted on DV power micro-ohmmeter RM 0600 at 10 amperes and 20 amperes respectively. For each of the sample, tests were carried out 3 times, and the observed values were the average of all the samples taken. Thermal conductivity was conducted using

thermal transport sample station (TTO) P670. The value of resistivity of a wire can be evaluated from the expression below:

$$\text{Resistivity, } \rho = R\frac{A}{L} \quad (1)$$

ρ - Resistivity in Ohm-meter (Ωm); R - Resistance of materials in Ohms; A - Cross sectional area in m^2; L - Length in meter.

While the value of electrical conductivity (σ) in per ohm per meter was derived from the relationship

$$\sigma = \frac{1}{\rho} \text{ Siemens per metre } (Sm^{-1}) \quad (2)$$

$\rho =$ Resistivity in Ohm-meter (Ω m).

3. RESULTS AND DISCUSSION

The results of the different investigations carried out in respect of the study are shown in the Figures 1, 2, 3 and 4. In Figure 1, the thermal conductivity value of particle size 710µm was well above the other values of 212µm and 425µm respectively; 425µm performed slightly above 212µm. As a result of interfacial thermal resistance between copper and silicon carbide, the thermal conductivity decreases with a decrease in particles of SiC. Therefore, it can be inferred that thermal conductivity reduction varies in relation to decreasing particle size [16]. Furthermore validation of the result shows that there exist polynomial relationships between the thermal conductivity and the % volume fraction of the Cu/Sicp composites in relation to the particle sizes; i.e. R^2 shows 0.7, 0.81 and 0.93 respectively for 212µm, 710µm and 425µm. The larger the cross sectional area of the conductor, the more electrons per unit length is available to carry or dissipate the current as a result the particle size was above the others.

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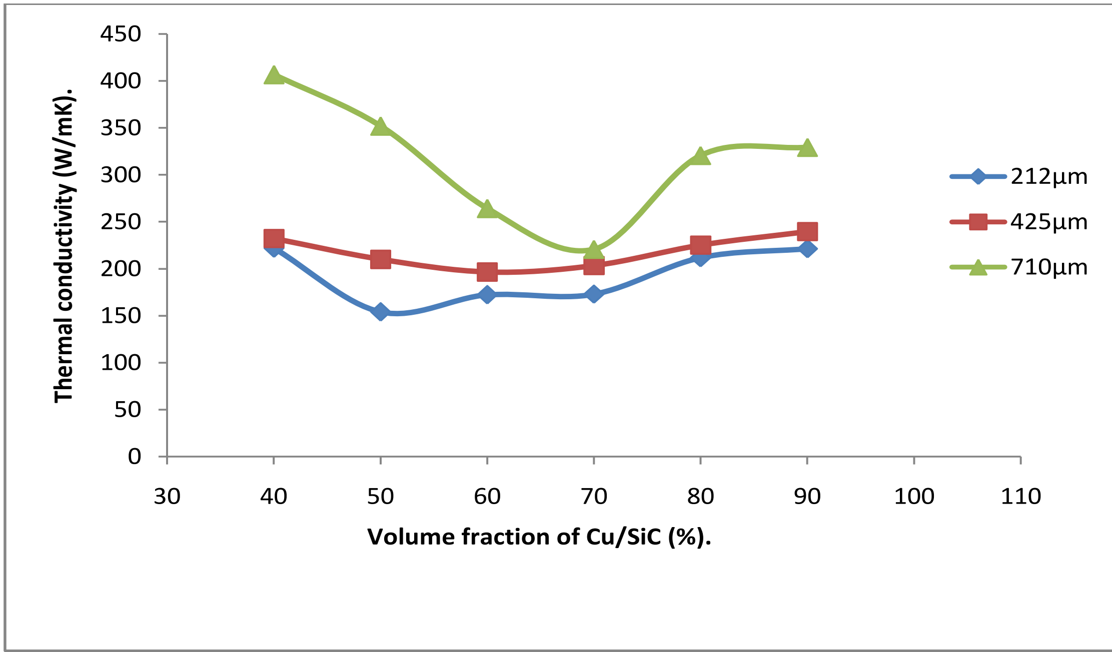

Figure 1a: Thermal conductivity of Cu/SiCp composites

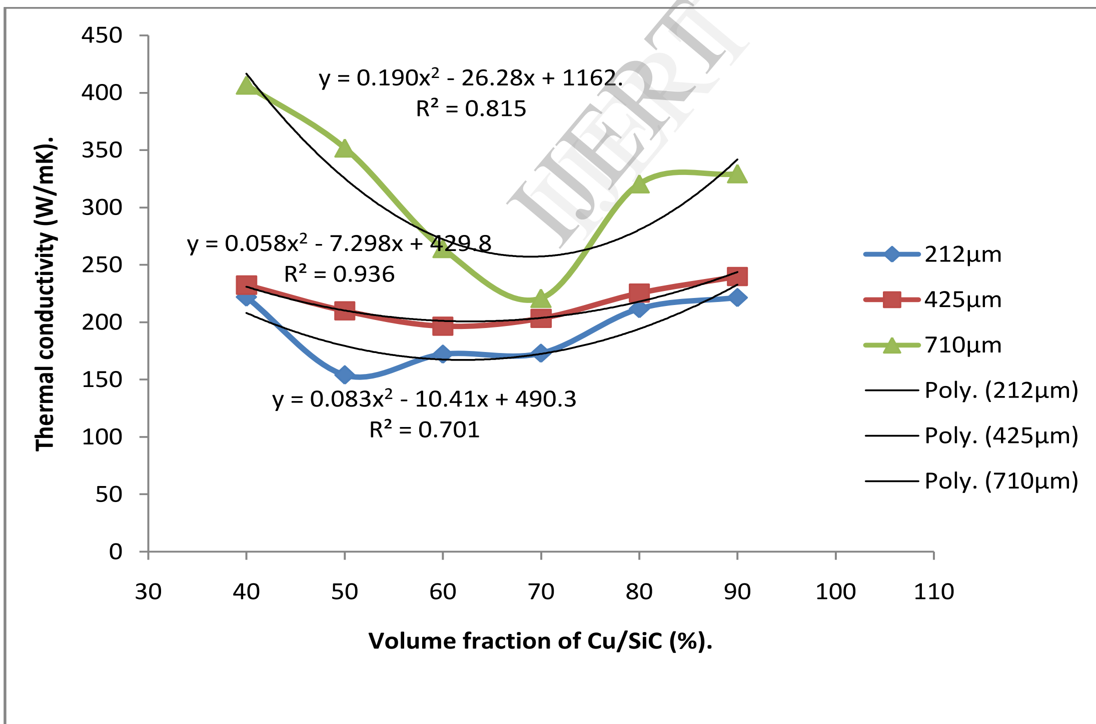

Figure 1b: Thermal conductivity of Cu/SiCp composites (Polynomial regression)

The heat treated Cu/SiCp composite in Figure 2 indicates that increase in volume fraction of SiC leads to decrease in thermal conductivity until 70/30 volume fraction when it rose sharply with an increase in thermal conductivity for particle size 710μm. Increase in volume fraction of Particle sizes 212μm and 425μm lead to decrease in thermal conductivity and further decrease from 70/30 to 50/50 volume fraction with a steady rise at 40/60 Cu/SiC volume fraction. These values are slightly lower than the untreated composites but also decreased with a decrease in particle sizes.

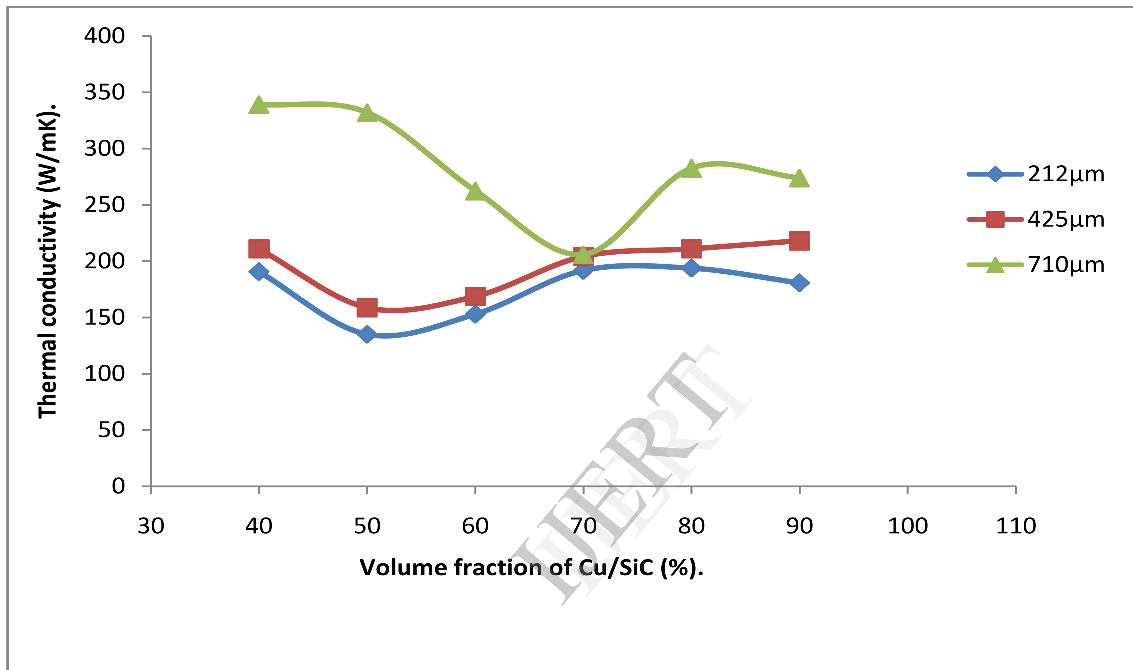

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Figure 2a: Thermal conductivity of Heat-treated Cu/SiCp composites.

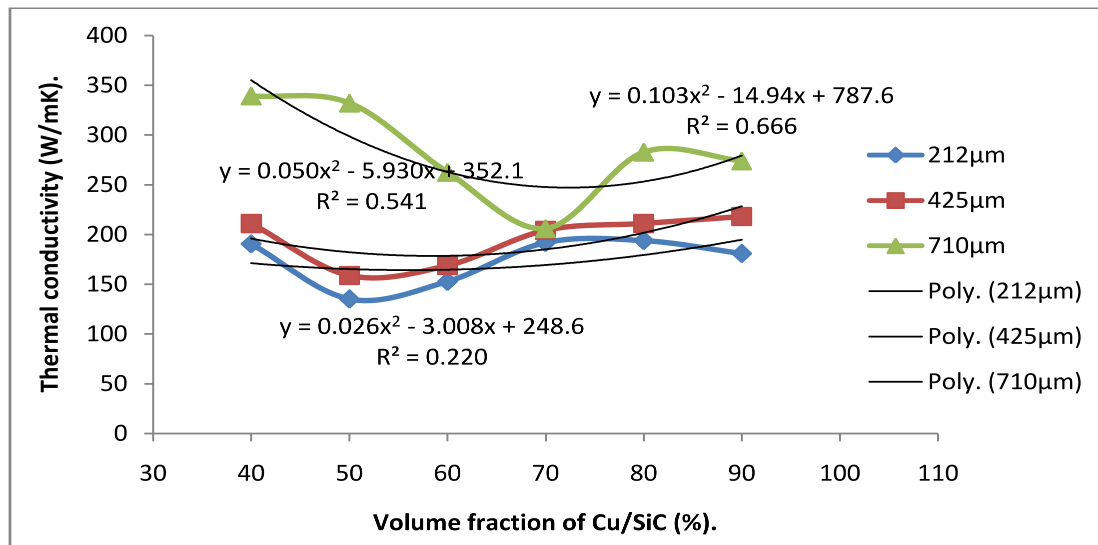

Figure 2b: Thermal conductivity of Heat-treated Cu/SiCp composites (Polynomial regression).

In Figure 3, the electrical conductivity of 212µm, 425µm and 710µm particle sizes of SiC decreased with increased volume fractions of SiC but increased with increasing particle sizes of SiC [15]. 710µm particle size showed a projectile decrease in value till 50/50 and rose slightly at 40/60 volume fraction. The electrical conductivity decreased slightly with particle size 425µm and rose slightly at 50/50 before decreasing again. 212µm particle size gave a sharp decrease in values of electrical conductivity till 40/60 volume fraction. The heat treated electrical conductivity values were lower than that of untreated values of Cu/SiC composites. Validation of the result also showed polynomial relationships between the thermal conductivity and the % volume fraction of the Cu/SiCp composites in relation to the particle sizes; i.e. R^2 shows 0.905, 0.9365 and 0.958 respectively for 710µm, 425µm and 212 µm.

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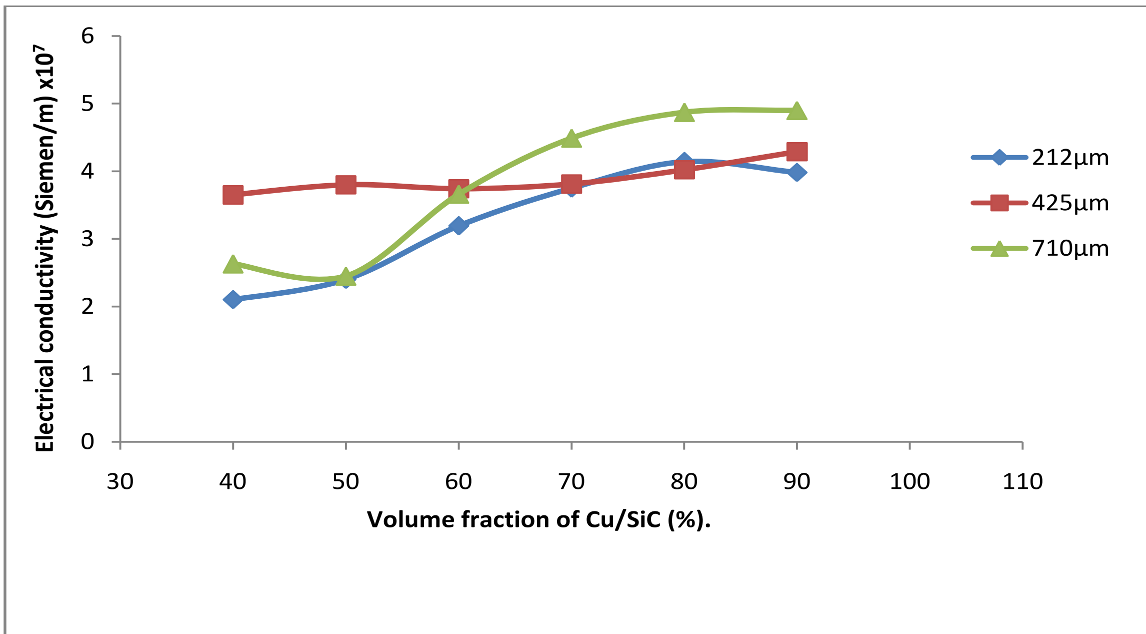

Figure 3a: Electrical conductivity of Cu/SiCp composites

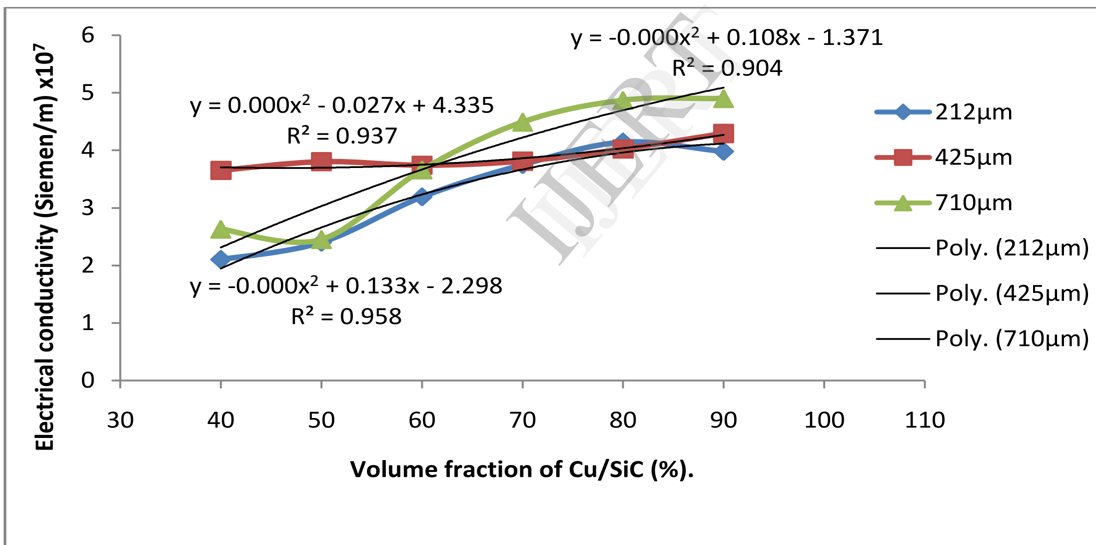

Figure 3b: Electrical conductivity of Cu/SiCp composites (Polynomial regression).

Figure 4 shows that electrical conductivity of heat-treated samples decreased with increasing volume fraction of SiC but increased with increasing particle sizes of SiC. 710µm particle size indicated a sharp decrease in values till 70/30-volume fraction followed by a slight decrease till 40/60 volume fraction. 425µm particle size showed a slight decrease till 70/30 and became steady but later decreased sharply at 60/40 volume fraction while 212µm showed a sharp

decrease till 40/60 volume fraction. Validation of the result also showed polynomial relationships between the electrical conductivity and the % volume fraction of the Heat-treated Cu/Sicp composites in relation to the particle sizes; i.e. R^2 shows 0.89, 0.918 and 0.994 respectively for 425µm, 212µm and 710 µm.

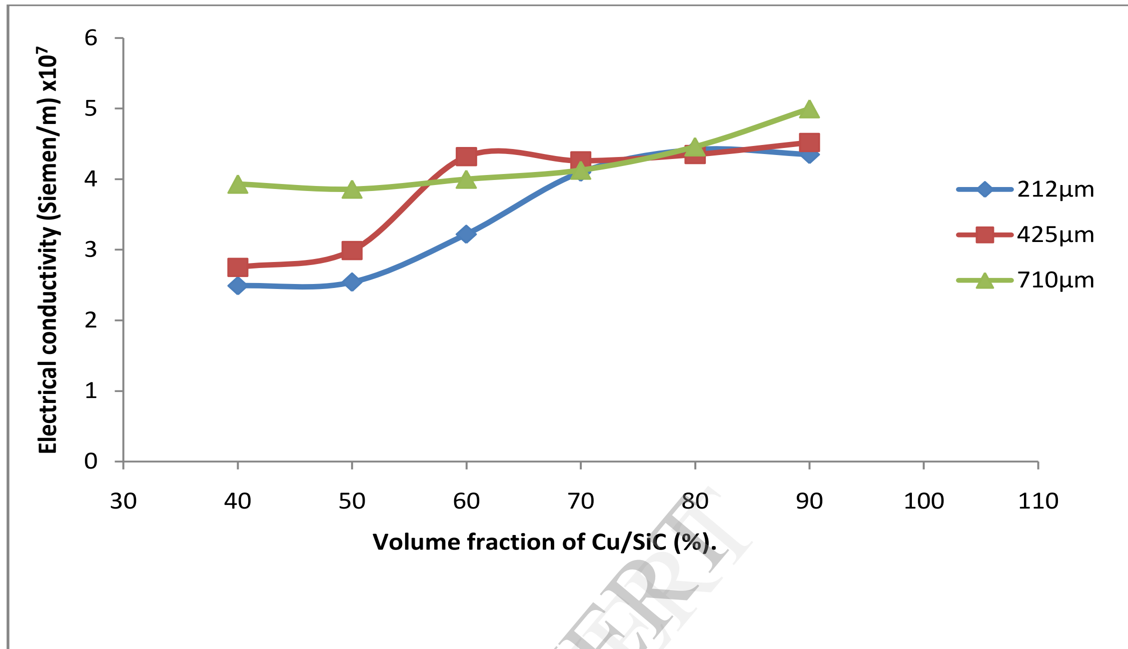

Figure 4a: Electrical conductivity of Heat treated Cu/SiCp composites

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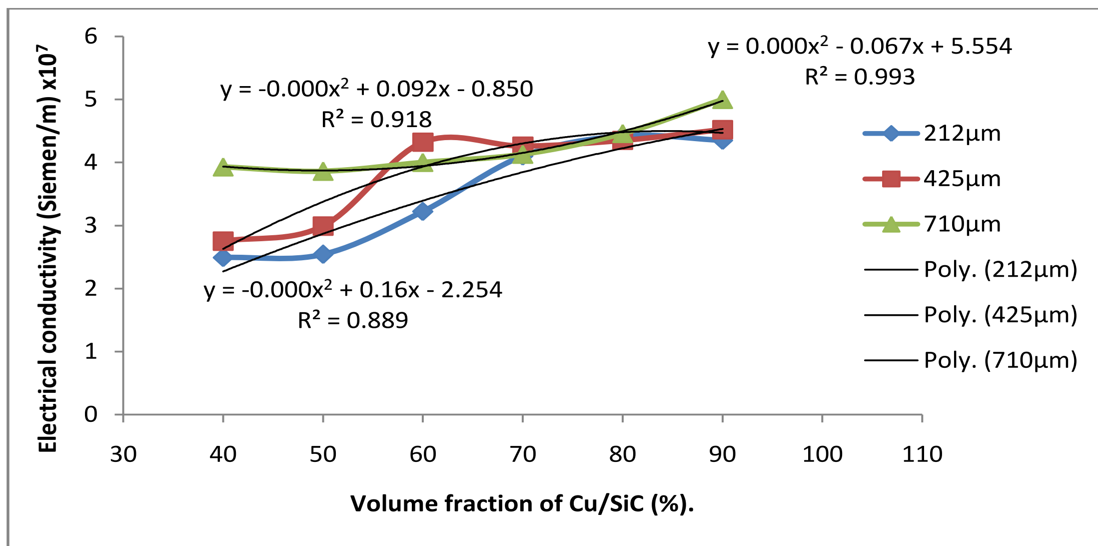

Figure 4b: Electrical conductivity of Heat treated Cu/SiCp composites (Polynomial regression).

4. CONCLUSIONS.

The mechanism controlling thermal conductivity of Cu-SiC particulate composite produced by liquid metallurgy was investigated with further emphasis on the evaluation of the relationship and impact between particle sizes, volume fraction and processing parameters for high thermal and electrical conductivity. Deduction from this study has shown that:

- The electrical conductivity increases with increase particle sizes but decreases with increasing volume fraction of SiC in the copper matrix. Also, with decrease grain sizes, thermal conductivity decreases but increases with increasing particle sizes i.e. the larger the cross sectional area of the particle size (conductor), the more electrons per unit length is available to carry or dissipate the current.

- The strengthening of the C10200 alloy with the particulate SiC shows to an appreciable extent the influence of the volume fraction and particle sizes on the electrical conductivity and thermal conductivity which was also validated by the regression analysis carried out.

- This will be found useful in sectors where high thermal conductivity, low resistivity and high electrical conductivity, as well as low thermal expansion (CTE) are required such as aerospace, defence technology and electronic industries.

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5. REFERENCES.

[1] Y.N. Liang, Effect of particle size on the wear behaviour of SiC particulate reinforced Copper alloy composite, J. Mater. Sci., **14** (1995) 115.

[2] A.K. Kuruvilla and Y.R. Mahagan, Effect of different reinforcements on composite-strengthening in Copper, Bull Mater. Sci., **12** (1989) 495.

[3] D.Z. Yang, S.I. Dong and J.F. Mao, High conductivity copper for electrical engineering, Compos. Sci. Technol., **35** (1989) 160.

[4] R. Zang, Effect of operating temperature on particle size of Cu/SiCp, J. Mater. Sci., **40** (2005) 223.

[5] D. Huda, M.A. Elbaradie and M.J.S. Hashni, Metal Matrix Composites, J. Mater. Process. Technol., **37** (1993) 528.

[6] J. Hashim, L. Looney and M.S.J. Hashni, Particle distribution in cast metal matrix composites, J. Mater. Process. Technol., **123** (2002) 251.

[7] H.J. Rack, Metal matrix composites, Adv. Mater. Process., **137** (1990) 37.

[8] A.K. Dhingra, Metal replacement by composite, J. Miner. Met. Mater. Soc., **38** (1996) 7.

[9] J. Doychak, Metal and intermediate matrix composites for aerospace propulsion and power system, J. Miner. Met. Mater. Soc., **44** (1992) 46.

[10] F. Margaret, Aerospace Composites, J. Met. Eng., **108** (1991) 27.

[11] W.D. Callister and D.G Rethwisch, Fundamentals of material science and engineering: An Introduction, Wiley (2008).

[12] http// www.wikipedia.org/wiki/copper.

[13] R. Zhang, L. Gao and J. Guo, Preparation and characterization of coated nanoscale Cu/SiCp, Ceram. Int., **30** (2004) 401.

[14] Y. Zhan and G. Zhang, Particle size effect on the elevated temperature wear behaviour of SiCp/Cu composites, Mater. Lett., **57** (2003) 4583.

[15] G. Celebi Efee, I. Altinsoy, M. Ipek, S. Zeytin and C. Bindal, The effect of SiC particle size on the properties of Cu-SiC composites, Acta phys. Pol., **121** (2012) 251.

[16] G. Wu, G. Chen, D. Zhu, Q. Zhang and L. Jiang, Effect of particle size on the thermo-physical properties of SiCp/Cu composites fabricated by squeeze casting, Trans nonferrous Metall. Soc., **15**(2) (2005) 217.

[17] Th. Schubert, A. Brendel, K. Schmid, Th. Koeck and T. Ciupinski, Interfacial design of Cu/SiC composites prepared by powder metallurgy for heat sink applications, Appl. Sci. Manuf., **38** (2007) 2.

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