Influence of Physicochemical Property and Composition on Cermet Resistivity

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Abstract: **In this paper, the influence of physicochemical property and composition of clay on resistance behavior of copper-cermet was studied and it is revealed that metal filler and conducting grains diffused through the pores of the clay (porosity of 49%) at temperature greater than 400 ºC and duration above 120 minutes. Good performance of cermet was noticed for compositions below 20%. The porosity of clay in addition to annealing were able to activate the diffusion of conducting grains in the cermet in the form of electrons and holes in motion while the temperature coefficient of resistance remains positive within the temperature range. Metal composition increment also reduces the peak resistance attained as the temperature increases.**

Keywords: **Thermal diffusivity, Activation energy, Cermet, Colloid, Porosity.**

I. INTRODUCTION

Physicochemical interactions that occur simultaneously at soil-fluid interface are not well understood [1]. Complications arise in the sense that the changes in physicochemical properties at soil-liquid interface are pH, moisture content, and resistivity dependent. Application of direct current through a soil specimen induces three mechanisms including redox, water decomposition, and ion migration which can change the physicochemical properties at the soil-liquid interface and would alter the electrical properties of the soils [2]. Electrical conductivity in soils takes place through the moisture filled pores that occur between individual soils particles [3]. Resistivity of a soil depends on the surface conductivity of the colloids (i.e. clay or/and humus), presence of ions, moisture content, and temperature; and is determined using Ohm's law [4]. Need for appropriate properties such as high sheet resistance, low-temperature coefficient of resistance, and stability under ambient conditions has motivated investigations into electronic conduction mechanisms in a number of ceramal [5], [6] and alloy resistor systems [7], [8]. This makes development of composite materials one of the best choices [9].

Cermet (ceramic and metal) conductivity/resistivity is similar to that of composite. A challenge in the development of electrically conductive composites is the ability to determine the ideal filler concentrations. Insufficient concentrations result in an insulating material, while excess leads to the loss of mechanical properties [10]. The resistivity/conductivity of the metal-clay cermet resistors varied remarkably with conductive grain content [11]. The carrier concentration of composite films increases, while the mobility decreases with increasing metal doping ratio [12]. There is peak annealing duration and/or temperature that when exceeded, development of interfacial structures will result and lead to the formation of weak layers in the interfacial regions and damage the bonds [13] as they enhanced diffusion rate of conducting grains [14]. Study on the effect of production processing on resistivity of copper clad steel 'CCS' wires indicated that the resistivity of CCS wires was gradually decreased with annealing temperature rising with prolonging holding time. It was assumed that dislocations and other defects in CCS wires were eliminated after annealing treatment, resulting in the decrease of resistivity [15]. The average separation of the metal islands in Cu-MgF_2 composite thin films studied was observed to increase with decrease in copper metal content of the composite resistors [6].

This paper studies the influence of physicochemical property and composition on the resistance/resistivity nature of copper cermet.

1.1 Theoretical View

Electrical resistivity of a material is determined from Ohm's law, current density, and resistivity. Current is determined by charge in coulombs over a given period of time in seconds where current is represented as 'I', coulombs in 'q', and time 't'.

$$I = \frac{q}{t} \qquad ------ \quad (1)$$

Current density is the amount of current flowing through a particular area in which the current density is represented by 'J', and the area is represented with 'A'.

$$J = \frac{I}{A} \qquad ------ \quad (2)$$

Resistivity 'ρ' is the relation of resistance, area 'A', length 'L' and current 'I' and is written as:

$$R = \rho\frac{L}{A} \qquad ------ \quad (3)$$

For thermal diffusivity, where 'h' is the thermal diffusivity, 'K' is the thermal conductivity, 'ρ' is the density, 's' is specific heat.

$$h = \frac{k}{\rho s} \qquad ------ \quad (4)$$

By free election theory, the resistivity may be obtained in terms of the carrier mean free path such as (Ziman 1960):

$$\rho = \frac{(\frac{3}{8})^3 h}{q^2 n^{\frac{2}{3}} \lambda} \qquad ------ \quad (5)$$

II. MATERIALS AND METHODOLOGY

2.1 Materials

Imported copper powder with unique granules of less than 75 µm and 99% pure from Aldrich in United State and carefully selected white clay in ratios, using deionized water as binder were mechanically mixed together.

2.2 Method

The copper cermets were fabricated with clay compositions of 95%, 90%, 85%, 80% and 75% mass ratio respectively using volume displacement method. A unique diameter of 5mm and lengths 5mm to 25 mm in steps of 5 were fabricated with the aid of a designed mechanical hydraulic device. The pressure size applied was about 15 bars. The cermets were allowed to stay for 72 hours in a dust free environment at room temperature. Firing of the cermets at 200 ºC for one hour duration was done and resistances were taken for all the compositions with the aid of digital ohm-meter repeatedly. Subsequently, the furnace temperature was raised to 300 ºC – 500 ºC with hourly annealing for 5%, 15%, and 25% copper compositions to allow sintering. The resistance values were also taken after furnace cooling. Firing time and lengths of 5 mm, 10 mm, and 25 mm length for 10% and 20% copper at 300 ºC and 500 ºC respectively were evaluated with 30 minutes intervals.

2.3 Elemental and Physicochemical properties of clay

The elemental and physicochemical characterization of clay revealed the clay composition before pounding to a smaller particle size. Association of official analytical chemists methods (AOAC) using the flame system of the atomic absorption spectrophotometry (AAS), (Unicam 969 Solaar). Working standard solutions of Copper, Aluminium, Manganese, Magnesium, Zinc, Iron, Nickel and Calcium were prepared from stock standard solution (1000ppm), in 2M Nitric acid and absorbance was noted for standard solution of each element and samples using atomic absorption spectrophotometer AAS.

III. RESULTS AND DISCUSSION

3.1 Results

The analyses of clay sample and the experimental study of cermet gave the following result. The result reveals the metallic silicate components of the clay with the other impurities

Table 1: Elemental composition of clay

Component	mg/l (soil)	mg/l (water)
Mg	16.455	20.811
Ca	33.621	14.801
Na	7.664	6.481
K	3.89	3.641
Fe	2.653	0.945
Cu	1.892	0.648
Zn	2.441	1.411
HCO^{3-}	1.481	0.984
Cl	0.699	0.247
SO_4^{2-}	1.257	0.846
Pb	0.2193	
Cd	0.1973	
Al	0.1634	
Mn	3.165	1.094
Ni	1.2404	0.819

Table 2: Physicochemical properties of clay

Soil property	
Bulk density (g/cc)	0.678
True density (g/cc)	1.716
% porosity	49.29
Specific gravity (g/cc)	2.01
pH	6.89
% moisture content	8.65
Particle size (µm)	650

Table 3: Physicochemical properties of water for analysis

Water property	
pH	6.48
Cond (µs/cm)	268
TDS (g/l)	18.15
Bicarbonate (mg/l)	1.849
Chloride (mg/l)	0.948
Sulphate (mg/l)	8.65
Turbidity	0.16
Phosphate (mg/l)	0.125

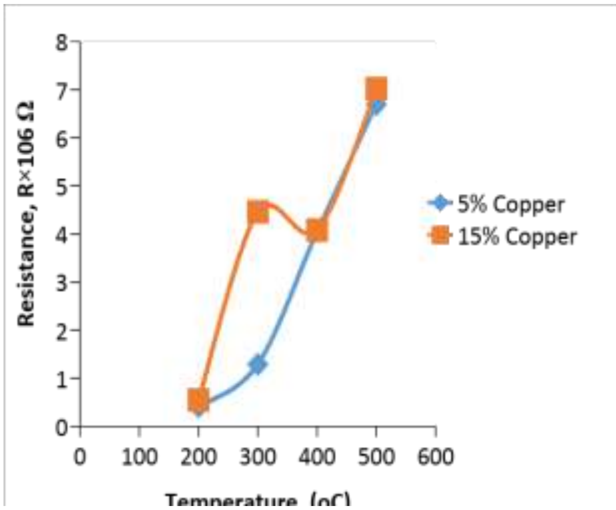

Fig. 1: Resistance against Temperature for 5 mm with one hour annealing.

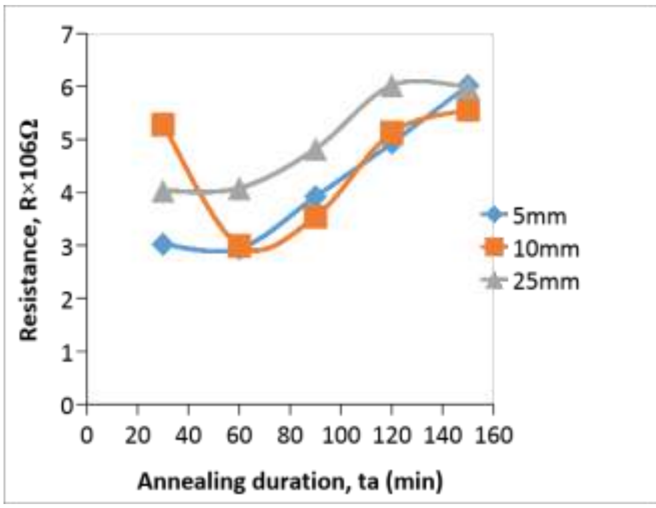

Fig. 2: Resistance against annealing duration for 10% Copper at 300 ºC.

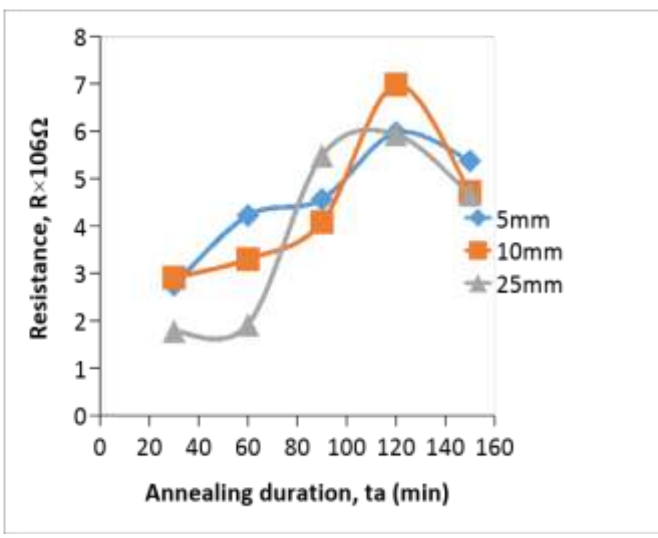

Fig. 3: Resistance against annealing duration for 20% Copper at 500 ºC

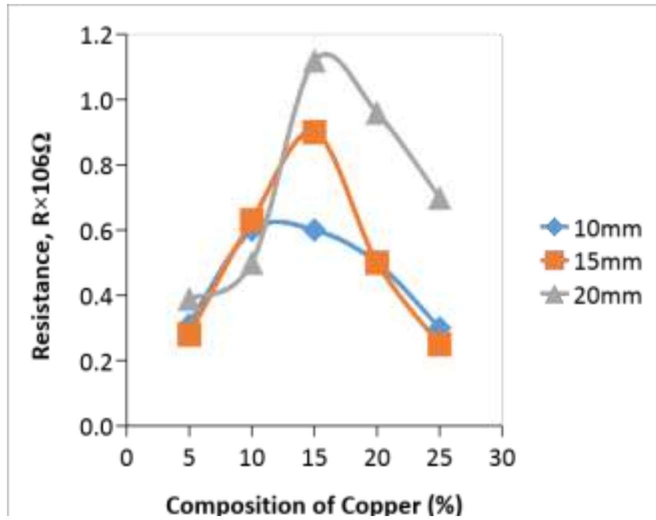

Fig. 4: Resistance against Copper composition (%) at 200 ºC.

3.2 Discussion

Firing of a cermet hardens the material and results to vibration of conducting grains due to excitation. Thus in fig. 1, the increase in temperature increases resistance property until the temperature is able to set in motion the conduction the atoms of the conducting grains due to higher activation energy. If the temperature is further increased to higher values, there is certainty of resistivity breakdown because of the plastic property of ceramic that will set in and enhanced easy migration of conducting ions. Temperature coefficient of resistance TCR is determined by the separate temperature coefficient of a particular cermet constituents. The decline of TCR 15% copper composition between 300 ºC and 400 ºC could be due to fabrication defect that results into clustered conducting grains.

Figs. 2 and 3 depict the peak resistance as a result of conductivity of the colloids (i.e. clay), metallic ions, moisture content, and temperature. Though the pH of the clay is neutral, the pores of the clay enables filling by the metal filler, which aids easy movement of the conducting electrons/holes of the metal matrix composition in addition to the conductivity of the clay at percolation as firing duration increases. This also conforms to Malthiessen rule in determining the total resistivity of a material.

$$\rho_{tot} = \rho_{therm} + \rho_{imp} + \rho_{dis}$$

ρ_{tot} = total resistivity, ρ_{therm} = thermal resistivity, ρ_{imp} = impurities resistiviy and ρ_{dis} = dislocation resistivity

Fig. 4 shows that cermet with good resistivity is expected to have less than 20% metal filler and this result also depicts earlier researchers’ statements because optimal resistance is gotten at this particular composition. This factor can be attributed to the recrystallization and interfacial diffusion of atoms

IV. CONCLUSION

Oxidation of the metal filler to copper I and copper II oxides combined with the reduction of clay to silicates, increases the resistance of the cermet at temperature below 400 ºC and oxidation state and quantity reduced the atomic/molecular collision rate. Clay composition (impurities and structural nature) which determine the strength and the kind of bond (ionic or covalent) that exist between layers and particles also affects the rate at which resistance increases with annealing duration and temperature. Annealing also results in recrystallization of particles as temperature and duration increase thus, at peak resistance, conducting grains were capable of diffusing as electrons and holes within the filled pores of the cermet. Impurities presence enable excitation to be attained quickly as thermal activation energy increases.

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