Analytical Assessment of Effect of Heat Absorbed and Remitted By Copper Present In Molten Pb-Sb-Cu Alloy System on the Electrical Properties of the Solidified Alloy

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Abstract: The effect of heat absorbed and remitted by copper present in molten Pb-Sb-Cu alloy system on the electrical properties of its solidified form was studied and assessed following casting of the alloys (furnace cooled) and computing the quantities of heat absorbed and remitted to the alloy as a result of copper addition. Electric current flow through the solid Pb-Sb-Cu alloy was measured and other electrical properties; electrical resistance, resistivity, conductivity and power dissipation calculated using appropriate equations. The results of the investigation indicate that current flow, power dissipation and electrical conductivity increases with increase in the quantity of heat remitted to the Pb-Sb-Cu alloy. It was also found that the electrical resistance and resistivity of the alloy decreases with increase in the heat remittance to the alloy. This is attributed to the fact that the minimum additional energy (energy gap) which a bonding electron must acquire to leave the bond in the valence band and move into the conduction band hence becoming free to conduct electricity, decreases with decrease in the electrical resistance, resistivity and with increase in the heat content of the alloy (due to heat absorbed). Increased copper addition (up to a maximum of 45g) to the base alloy (Pb-Sb) was discovered to have increased correspondingly the current flow, power dissipation, electrical conductivity and decreased correspondingly the electrical resistance and resistivity of Pb-Sb-Cu alloy so produced. This is attributed to the increased absorption of heat by the alloy as a result of increased impurity atoms in the alloys in the form of copper. The correlation coefficients between heat absorbed by the Pb-Sb-Cu alloy and its electrical properties are all above 0.97 indicating a good system parameter interaction and connection. [Researcher 2010;2(4):38-43]. (ISSN: 1553-9865).

Keywords: Effect, Heat Absorbed and Remitted, Electrical Properties, Pb-Sb-Cu Alloy.

1. Introduction

Geiss and Peretti (1962) reported that addition of indium to Pb-Sb alloy increases the corrosion resistance of the alloy. Indium is added to the Pb-Sb alloy by ionic exchange through electrolytic process where indium is the anode and Pb-Sb, the cathode.

Past studies by Ezenwa (1987) and Weaver (1935) on lead-antimony alloy involving addition of Sn to improve its mechanical properties and corrosion resistance indicate that addition of Sn to the Pb-Sb matrix increases both the tensile strength, hardness and corrosion resistance of the alloy. This makes Pb-Sb-Sn alloy suitable for coating tanks and pipes.

Sodacha and Kerr (1972) reported that arsenic addition to Pb-Sb-Sn alloy increases the corrosion resistance of the alloy due to its ability to reduce oxidation during service by formation of oxide film on the matrix

Researches (Blumenthal, 1944. Rollason and Hysel, 1940; Nwoye, 2000) have been carried out to improve the electrical conductivity of Pb-Sb alloy used as wet cell battery heads. Blumenthal, (1944) discovered that addition of cadmium enhances the electrical conductivity of Pb-Sb alloy tremendously. It was however, stated that the alloy cannot find application in battery heads and plates because Cd is very radioactive and causes a volatile and explosive reaction when in contact with sulphuric acid for a long time.

Rollason and Hysel, (1940) reported that addition of silver to Pb-Sb alloy increases very significantly the electrical conductivity of the alloy. It was however, stated that this increase does not give a stable value due to impurities in the Ag. It was stated that these impurities are Au, As, Sn, Cu and S. He further posited that these impurities create an unstable electrical field in the alloy of Pb-Sb-Ag. It is believed that this short coming has made the use of this alloy for battery heads and plates impossible since it obscures the precise electromotive force of the electrolyte in the battery.

Research results (Nwoye, 2000) have shown that addition of copper powder by dispersion to Pb-Sb alloy improves the electrical conductivity of alloy greatly. It is believed that this breakthrough was possible because Cu used, had high purity level (99.8%).

Ijomah (1992) reported that the higher the temperature applied to metals and alloys, the greater the bonds broken, and the higher the level of conductivity attained. The same report indicates that the resistivity of engineering materials such as metals and alloys is dependent on the temperature at which the material is exposed. The report (Ijomah, 1992) concluded that increase in temperature of materials reduces its resistivity. Ijomah (1992) reported that the energy gap; minimum additional energy which a bonding electron must acquire to leave the bond and, hence become free to conduct electricity decreases with increasing temperature and impurity content. The report also revealed that the resistivity increases with increase in the energy gap.

The aim of this research work is to assess the effect of heat absorbed and remitted by copper present in Pb-Sb-Cu alloy system on the electrical properties of the solidified alloy.

2. Materials and methods

ALLOY PREPARATION:

The materials used are antimonial lead scraps and electrolytic copper powder of grain size < 425µm. They antimonial lead collected were melted together in order to obtain a fairly uniform composition of lead antimonial alloy, in case of any variation in antimony content. The melting operation was carried out at the forge, followed by casting of the alloys in sand mould and cutting to various sizes for use in the actual alloying. They melting crucible was of 260mm long, 200mm wide mild steel of about 100mm breadth with handle for carriage.

MOULD PREPARATION:

The preparation of the mould was done by first sieving the sand for aeration and mixing 6% moisture to give good green strength. The mould box of dimension 300mm wide, 100mm breadth and 500mm long was made from cast metal frame. A long hollow cylindrical pipe of 85mm long and 9mm diameter was used as the pattern for the cast. The mould was allowed to dry.

CASTING TECHNIQUES:

A weighed quantity of lead antimony alloy (500g) was placed on the crucible and then placed inside the furnace. The technique used involved simultaneous addition of Cu powder and pouring of the molten Pb-Sb (heated to a temperature of 425^0C) into the mould. The Control alloys were cast by just pouring only the molten Pb-Sb into the mould (Conventional Technique). All cast alloys were furnace cooled.

HEAT TREATMENT:

They cast alloys were cut to lengths:0.075m before being heat treated at a temperature of 180^0C to relieve stresses incurred during solidification of the alloys. The heat treatment was also carried out to homogenize the microstructure of the alloys prior to the impact testing process.

ELECTRICAL MEASUREMENTS:

Following the heat treatment process, electric current, I flowing through the alloy measured and other electrical properties associated with current flow calculated using appropriate equations. The electromotive force from the dry battery equals 2.9V, being voltage supply to the alloys. Current was allowed to flow through the alloys for five minutes, and the power dissipated during the process calculated for all alloys produced using three techniques. This is to ascertain the power dissipating capacity of the alloys. The tested specimen were thereafter melted and their temperatures recorded correspondingly against their respective values of electric current, resistance, resistivity, conductivity and power dissipation.

CALCULATION OF ELECTRICAL PARAMETERS

According to Ohm's law

$$R = V/I \quad \text{(Okeke,1987)} \qquad (1)$$

Where

R = Resistance of the alloy (Ω)

V = Voltage supply to the alloy (V)

I = Current flowing through the alloy (A)

The resistance of the alloy was calculated using equation (1). Also, the resistivity of the alloy was calculated using the equation;

$$\rho = RA/L \quad \text{(Okeke,1987)} \qquad (2)$$

Where

ρ = Resistivity of the alloy (Ωm)

L= Length of the alloy material (m)

A = Cross sectional area of the alloy (m^2)

The cross sectional area of the alloy material was calculated using the equation;

$$A = \Pi D^2/4 \qquad (3)$$

Where

Π = 22/7 Substituting these values into

D = 0.9cm; (Diameter of cross- section of the sample)

Substituting these values into equation (3)

$$A = 6.364 \times 10^{-5} m^2$$

Also, the conductivity of the alloy was calculated as the reciprocal of the resistivity;

$$\alpha = (\rho)^{-1} \quad \text{(Okeke,1987)} \qquad (4)$$

$$\alpha = (RA/L)^{-1} \qquad (5)$$

Where

α = Conductivity of the alloy $(\Omega m)^{-1}$

Power dissipated as current flow through the alloy was calculated using the equation;

$$P = IVt \quad \text{(Okeke,1987)} \qquad (6)$$

Where

P = Power dissipated by the alloy (W)

t = Time elapse within which power was dissipated (s)

On heating the crucible containing the antimonial lead and copper powder, it iis believed that Cu present in the molten Pb-Sb-Cu alloy system gained or absorbed heat based on its own specific heat capacity and temperature exposed. Since the Cu added to the Pb-Sb alloy forms an alloy system Pb-Sb-Cu, it is strongly conceived and believed that the heat absorbed by the Cu is remitted to the alloy system formed ensuring uniformity of temperature gradient within the alloy matrix. This agrees with past report (Okeke, 1987).

Based on the foregoing,

Heat absorbed and remitted by copper in the molten Pb-Sb-Cu alloy system is given by the equation;

$$Q = MC\Delta T \quad \text{(Okeke, 1987)} \qquad (7)$$

Where

Q = Quantity of absorbed and remitted by copper present in the Pb-Sb-Cu alloy (KJ)

M = Mass of copper powder added (g)

C = (0.385); Specific heat capacity of copper (J/g/K).

ΔT= Change in temperature (between the initial and final temperature to which copper is exposed) (K).

The correlation coefficient R, for assessing the level of the system parameter interaction and connection between the electrical properties of the Pb-Sb-Cu alloy and the heat absorbed & remitted to it, is given by the equation;

$$R = \sqrt{R^2} \qquad (8)$$

3. Results and discussion

Results of chemical analysis carried out on the materials used (as shown in Table 1) indicate that antimonial lead contains about 3.3% Cu in addition to Pb and Sb present. The percentage composition of the powdered Cu used is as received.

Table 1:Chemical composition of materials used

Material	Pb (%)	Sb (%)	Cu (%)
Antimonial Lead	92	4.7	3.3
Copper powder	-	-	99.80

Effect of heat absorbed and remitted on the flow of electric current through Pb-Sb-Cu alloy

The results of investigation as shown in Figure 1 show that current flow through these alloys increases with increase in the quantity of heat absorbed and remitted to the alloys. The relationship was found to give a correlation coefficient of 0.9715 (using equation (8)), indicating a good system parameter interaction.

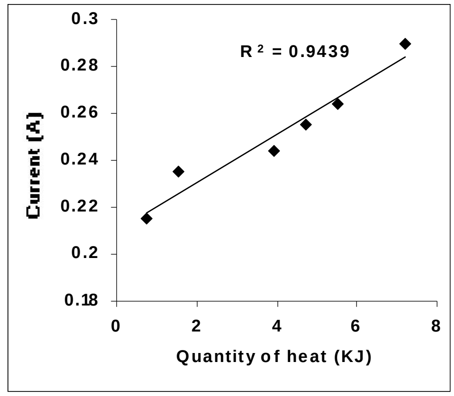

Figure 1: Effect of heat absorbed and remitted by copper on the current flow through Pb-Sb-Cu alloy

Considering Figure 1, Figure 6 and Table 3, it is believed that current flow through the Pb-Sb-Cu alloys increases with increase in the heat absorbed and remitted to the alloys as a result of increased Cu addition and distribution (up to 45g) within the Pb-Sb matrix. This implies that increased absorption and remittance to the alloy is as a result of increased Cu addition and distribution within the base alloy (Figure 6). Moreso, increasing the temperature of alloys through increased heat input on them reduces their respective resistivities (Ijomah, 1992). Therefore, substituting eqn. (1) into eqn. (2) gives $\rho = V A/L I$ which shows an inverse relationship between current I, and resistivity, ρ. This indicates that decrease in the resistivity of the alloys results to increase in the current flowing through the alloy. This is sequel to the fact that increase in the temperature of metals and alloys excites the electron and increases the number bonds broken resulting to increased flow of electron (through increased vibrational motion) into the conduction band (Ijomah, 1992). Furthermore Cu added to the base alloy (Pb-Sb) behaves like impurity atoms which have been reported (Ijomah, 1992) to reduce the electrical resistivity of the alloys involved. It is therefore expected that increased Cu addition into the base alloy will also result to much reduction in the resistivity of the alloy and hence much increase in the current flow.

Effect of heat absorbed and remitted on the electrical resistance of Pb-Sb-Cu alloy

Figure 2 shows that the electrical resistance of the alloy decreases with increase in the quantity of heat absorbed and remitted to the alloy, giving a correlation coefficient of 0.9713 as calculated using equation (8). This is because increase in the heat input to the alloy decreases its electrical resistivity indicating a good system parameter interaction. This agrees with past findings (Ijomah, 1992).

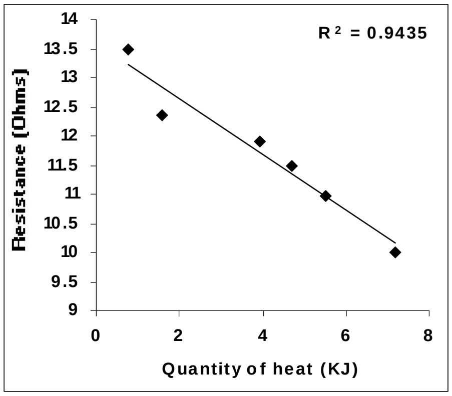

Figure 2: Effect of heat absorbed and remitted by copper on the electrical resistance of Pb-Sb-Cu alloy

Equation (2) shows a direct relationship between resistance R, and resistivity ρ. This indicates that decrease in the resistivity of the alloy decreases the resistance. Table 3 indicates that increase in Cu addition to the base alloy decrease its resistance. This is because increased Cu addition to the base alloy increases the quantity heat absorbed and remitted to the alloy (as in Figure 6) which invariably decreases the resistivty. This decrease in the resistivity in turn results to decrease in the resistance.

Effect of heat absorbed and remitted on the electrical resistivity of Pb-Sb-Cu alloy

Figure 3 giving a correlation coefficient of 0.9775 (as calculated using equation (8)) shows that the resistivity of Pb-Sb-Cu alloy decreases with increase in the quantity of heat absorbed and remitted to the alloy. This is in agreement with report by Ijomah (1992). Comparison of Figure 6 (having a correlation coefficient of 0.9998 as calculated using equation (8)) and Table 3 shows that increase in the heat absorbed and remitted to the alloy resulted from increase in the Cu added to the base alloy as impurity atoms. Table 3 shows that increased addition of the impurity atoms (Cu) to the alloy reduced its resistivity in agreement with past findings (Ijomah,1992).

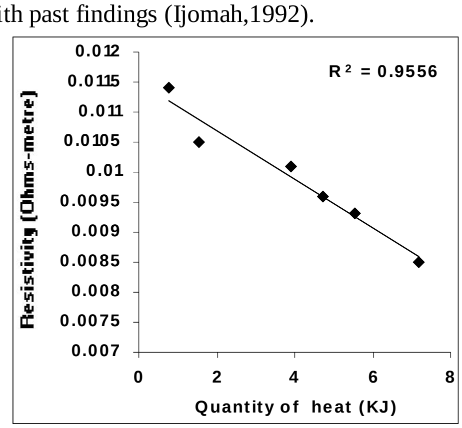

Figure 3: Effect of heat absorbed and remitted by copper on the electrical resistivity of Pb-Sb-Cu alloy

Effect of heat absorbed and remitted on the electrical conductivity of Pb-Sb-Cu alloy

Figure 4 shows that the electrical conductivity of the Pb-Sb-Cu alloy increases with the quantity of heat absorbed and remitted to the alloy. The correlation coefficient obtained (using equation (8)) is 0.9754 indicating a good system parameter interaction. Equations (4) and (5) show an inverse relationship between electrical conductivity α and resistivty ρ. This implies that the electrical conductivity of the Pb-Sb-Cu alloy increases with decrease in the resistivity of the alloy.

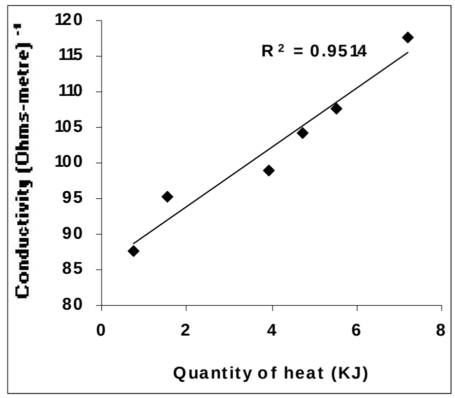

Figure 4: Effect of heat absorbed and remitted by copper on the electrical conductivity of Pb-Sb-Cu alloy

Figure 3 shows that the resistivity of the decreases with increase in the quantity of heat absorbed and remitted to the alloy, implying increase in conductivity as the heat input to the alloy increases (Equations (4), (5) and Figure 4). This is in accordance with past report (Ijomah, 1992). A comparison of Figure 6 and Table 3 indicates that decrease in the resistivity of the alloy as a result of increase in the quantity of heat absorbed and remitted to it, resulted from increased Cu addition (which acts as impurity atoms) to the base alloy.

Effect of heat absorbed and remitted on the power dissipated by Pb-Sb-Cu alloy

Equation (6) shows a direct relationship between electrical current and power dissipated by Pb-Sb-Cu alloy. This indicates that increase in the current flowing through the alloy results to increase in the power dissipated by the alloy following such current flow. Figure 5 shows an R^2 value of 0.9439 and its substitution into equation (8) gives a correlation coefficient of 0.9715 which is quite a good system parameter interaction factor. Comparison of the relationship between Figures 1 and 5 agrees with equation (6). Equation (6) indicates that if the current flowing through the alloy increases with increase in the quantity of heat absorbed and remitted to the alloy, then the power dissipated during the flow of the current is also expected to increase with the heat input to the alloy (Figure 5).

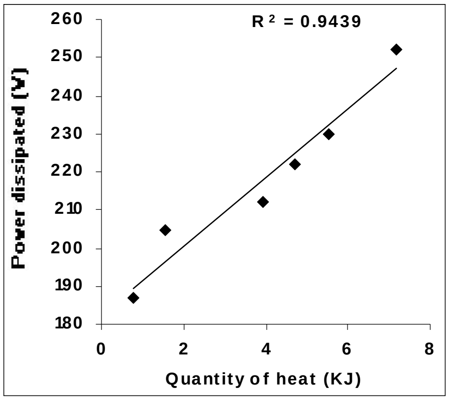

Figure 5: Effect of heat absorbed and remitted by copper on the power dissipated through Pb-Sb-Cu

Comparison of Figure 6 and Table 3 shows that increase in Cu addition to the base alloy increases the heat absorption and remittance to the alloy which invariably decreases the electrical resistance and resistivity of the alloy. This condition favours increased flow of current and invariably increases power dissipation.

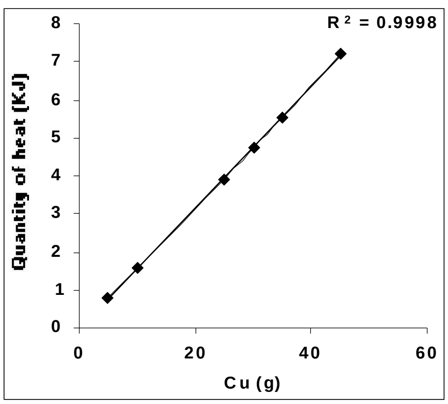

Figure 6: Effect of copper addition (to Pb-Sb matrix) on its resultant heat absorption and remittance to the of Pb-Sb-Cu alloy formed

Effect of copper addition (to Pb-Sb alloy) on the electric current flow, resistance, resistivity, conductivity and power dissipation through the Pb-Sb-Cu alloy.

Table 3 shows that increased addition of Cu (up to a maximum of 45g) to the primary alloying material (Pb-Sb alloy) to form Pb-Sb-Cu alloy increased correspondingly the current flow, power dissipated and electrical conductivity but decreased correspondingly the electrical resistance and resistivity. Comparison of Tables 2 and 3 show that addition of Cu to the Pb-Sb matrix (control) greatly improved the current flow, power dissipated and conductivity of the base alloy and also reduced greatly the resistance and resistivity of the alloy.

Table 2: Electrical properties of Pb-Sb alloy cooled in furnace (Alloy control of melting temperature 425^{0}C)

I (A)	R (Ω)	ρ(Ωm)	α $(\Omega m)^{-1}$	P (W)
0.212	13.68	0.0116	86.21	184.45

Table 3: Effect of copper addition (to Pb-Sb alloy) on the current flow, resistance, resistivity, conductivity and power dissipated through the Pb-Sb-Cu alloy formed.

Cu (g)	I (A)	R (Ω)	ρ(Ωm)	α$(\Omega m)^{-1}$	P(W)
5	0.215	13.49	0.0114	87.70	187.05
10	0.238	12.19	0.0103	97.09	207.06
25	0.242	11.98	0.0102	98.04	210.54
30	0.257	11.37	0.0096	104.17	223.59
35	0.264	10.98	0.0093	107.53	229.68
45	0.298	9.73	0.0083	121.10	259.26

Conclusion

The current flow, power dissipation and electrical conductivity of Pb-Sb-Cu alloy increased with increase in the quantity of heat absorbed and remitted to the alloy, while the electrical resistance and resistivity of the alloy decreases with increase in the heat input. Increased Cu addition (up to a maximum of 45g) to the base alloy (Pb-Sb alloy) increased correspondingly the current flow, power dissipated, conductivity but decreased correspondingly the resistance and resistivity of Pb-Sb-Cu alloy so produced.

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It is the intention of the author to publish this work culled from his M. Eng. Thesis in honour of Prof. Sylvanus I. Okeke of Nnamdi Azikiwe University, Awka as a memorial research piece credited to his numerous publications in recognition and appreciation of his unequalled supervisory role during this research work.

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