

Effect of Melting Temperature of Pb-Sb-Cu Alloy on Its Electrical Resistivity and Power Dissipation Capacity

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Abstract: The effect of melting temperature of sand cast Pb-Sb-Cu alloy (designed for production of battery heads and plates) on its electrical resistivity and power dissipation capacity was studied following determination of the electrical properties of the alloys (cast using three different techniques; Technique A, Technique B, Technique C and cooled in the furnace) and then heating of the alloy until melting occurred. Technique A, involves simultaneous addition of Cu powder and pouring of the molten Pb-Sb into the mould. Techniques B, involves addition of Cu powder intermittently as pouring of Pb-Sb into the mould was going on and Technique C involves pouring a stirred mixture of heated Pb-Sb alloy and powdered Cu into the mould. The results of the investigation indicate that the current flow, power dissipation and electrical conductivity increases with increase in the melting temperature of the Pb-Sb-Cu alloy. It was also found that the electrical resistance and resistivity of the alloy decrease with increase in the melting temperature. This is sequel 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 increasing temperature. Increased copper addition (up to a maximum of 8.26%) 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 melting temperature of the alloy as a result of increased impurity atoms in the alloys in the form of copper. [Academia Arena, 2010;2(6):67-71] (ISSN 1553-992X).

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1. Introduction

It has been reported (Geiss and Peretti, 1962) 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.

Several studies (Ezenwa, 1987; Weaver, 1935) have been carried out on lead-antimony alloy by addition of Sn to improve its mechanical properties and corrosion resistance. Results of the investigation 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.

Arsenic addition to Pb-Sb-Sn alloy has been found (Sodacha and Kerr, 1972) to increase the corrosion resistance of the alloy due to its ability to reduce oxidation during service by formation of oxide film on the matrix.

Several research works (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.

Nwoye (2000) found 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%).

It has been reported (Ijomah, 1992) 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 study the effect of melting temperature of Pb-Sb-Cu alloy (designated for production of battery heads and plates) on its electrical resistivity and power dissipation capacity. In this work, copper powder was added to the Pb-Sb melt by dispersion.

2. Materials and methods

ALLOY PREPARATION:

The materials used are antimonial lead scraps and electrolytic copper powder of grain size < 425 μm . 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. Techniques A, B and C were used to produce the first, second and third batch of the Pb-Sb-Cu alloys respectively. Technique A involved simultaneous addition of Cu powder and pouring of the molten Pb-Sb into the mould. Technique B involved addition of Cu powder intermittently as pouring of Pb-Sb into the mould was going on while Technique C involved pouring a stirred mixture of Cu powder and Pb-Sb alloy heated to 420°C, into the mould. The Control alloys were cast by just pouring only the molten Pb-Sb into the mould (Conventional Technique).

CAST ALLOYS COOLING:

Cast alloys from each of the techniques were cooled in the furnace.

HEAT TREATMENT:

They cast alloys were cut to lengths:0.075m before being heat treated at a temperature of 180°C 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

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

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;

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

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;

$$A = \pi D^2/4 \quad (3)$$

Where

π = 22/7 Substituting these values into

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

Substituting these values into equation (3)

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

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

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

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

Where

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

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

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

Where

$$P = \text{Power dissipated by the alloy (W)}$$

$$t = \text{Time elapse within which power was dissipated (s)}$$

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 melting temperature of Pb-Sb-Cu alloy on its electrical current flow ability

Results of measurement (Figure 1) of the current flowing through the Pb-Sb-Cu alloys (for all techniques used) and the melting temperature of the alloy show that current flow through these alloys increases with increase in the melting temperature of the alloys.

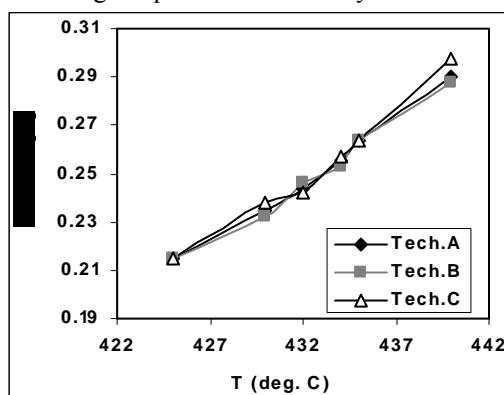


Figure 1: Effect of melting temperature of Pb-Sb-Cu alloy on the electrical current flow through it.

Considering Figure 1, Figure 2 and Table 3, it is believed that current flows through the Pb-Sb-Cu alloys increases with increase in the melting temperature of the alloys (up to 440°C) as a result of increased Cu addition and

distribution (up to 8.26%) within the Pb-Sb matrix. This implies that increased melting temperature of the alloy is as a result of increased Cu addition and distribution within the base alloy (Figure 6). Moreso, increasing the temperature of metals and alloys 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 result 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 melting temperature of Pb-Sb-Cu alloy on its electrical resistance

Figure 2 shows that the electrical resistance of the alloy decreases with increase in the melting temperature of the alloy. This is because increase in the melting temperature of the alloy decreases its electrical resistivity. This agrees with past findings (Ijomah, 1992).

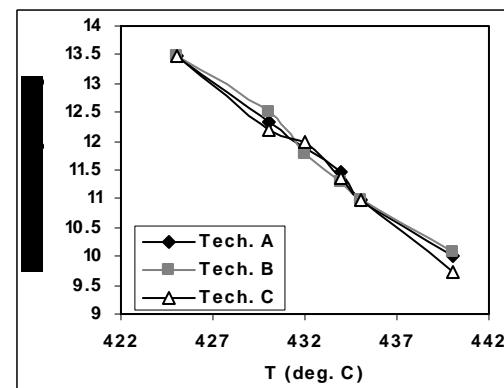


Figure 2: Effect of melting temperature of Pb-Sb-Cu alloy on its electrical resistance

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 its melting temperature (as in Figure 6) which invariably decreases the resistivity. This decrease in the resistivity in turn results to decrease in the resistance.

Effect of melting temperature of Pb-Sb-Cu alloy on its electrical resistivity

Figure 3 shows that the resistivity of Pb-Sb-Cu alloy decreases with increase in the melting temperature of the alloy. This is in agreement with report by Ijomah (1992). Comparison of Figure 6 and Table 3 shows that increase in the melting temperature of 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).

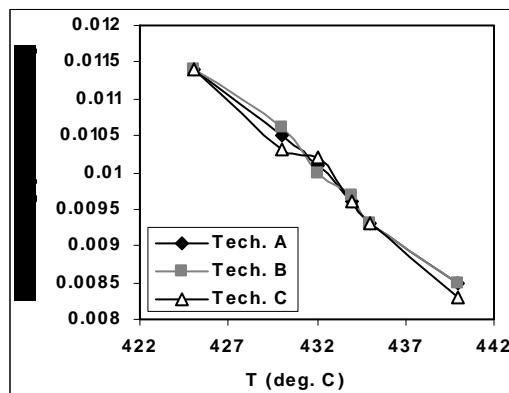


Figure 3: Effect of melting temperature of Pb-Sb-Cu alloy on its electrical resistivity

Effect of melting temperature of Pb-Sb-Cu alloy on its electrical conductivity

Figure 4 shows that the electrical conductivity of the Pb-Sb-Cu alloy increases with the melting temperature of the alloy. Equations (4) and (5) show an inverse relationship between conductivity α and resistivity ρ . This implies that the electrical conductivity of the Pb-Sb-Cu alloy increases with decrease in the resistivity of the alloy.

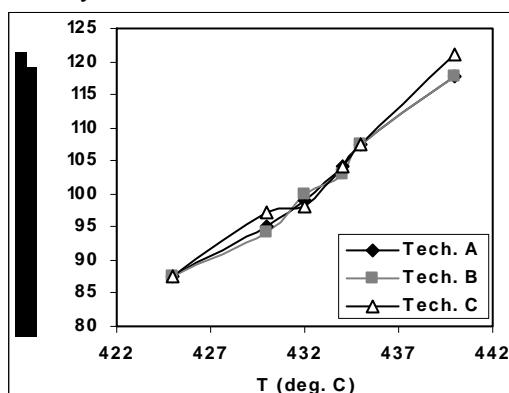


Figure 4: Effect of melting temperature of Pb-Sb-Cu alloy on its electrical conductivity

Figure 3 shows that the resistivity of the alloy decreases with increase in the melting temperature, implying increase in conductivity as the melting temperature increases (eqns.(4), (5) and Table 3). 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 melting temperature resulted from increased Cu addition (which acts as impurity atoms) to the base alloy. This agrees with report by Ijomah, (1992).

Effect of melting temperature of Pb-Sb-Cu alloy on power dissipation through it.

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.

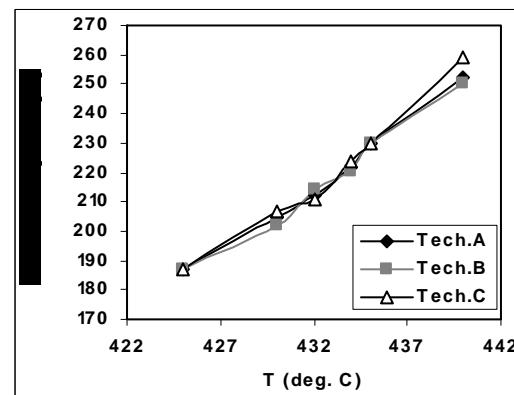


Figure 5: Effect of melting temperature of Pb-Sb-Cu alloy on power dissipation through it.

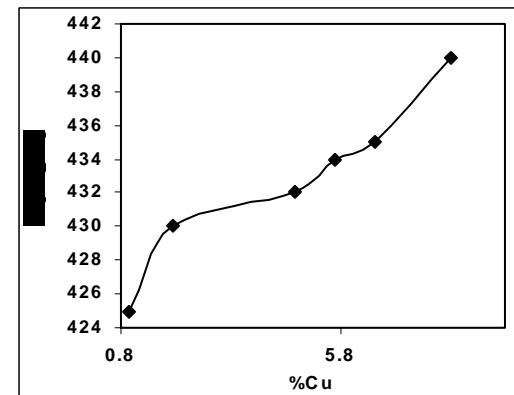


Figure 6: Effect of copper addition (to Pb-Sb matrix) on the melting temperature of Pb-Sb-Cu alloy system.

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 melting temperature of the alloy, then the power dissipated during the flow of the current is also

expected to increase with the melting temperature (as shown in Figure 5). Comparison of Figure 6 and Table 3 shows that increase in Cu addition to the base alloy increases the melting temperature of the alloy hence resulting to the decrease in the resistance and resistivity of the alloy. This condition favours increased flow of current which invariably increases power dissipation.

Effect of copper addition (to Pb-Sb alloy) on the 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 8.26%) 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°C)

I (A)	R (Ω)	$\rho(\Omega\text{m})$	$\alpha (\Omega\text{m})^{-1}$	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	I (A)	R (Ω)	$\rho(\Omega\text{m})$	$\alpha (\Omega\text{m})^{-1}$	P(W)
0.99	0.215	13.49	0.0114	87.70	187.05
1.96	0.238	12.19	0.0103	97.09	207.06
4.76	0.242	11.98	0.0102	98.04	210.54
5.66	0.257	11.37	0.0096	104.17	223.59
6.54	0.264	10.98	0.0093	107.53	229.68
8.26	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 melting temperature of the alloy, while the electrical resistance and resistivity of the alloy decreases with increase in the melting temperature. Increased Cu addition (up to a maximum of 8.26%) 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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