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Effect of Melting Temperature of Pb-Sb-Cu Alloy on its Hardness and Impact Strength

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Abstract

The effect of melting temperature of Pb-Sb-Cu alloy on its impact strength, energy absorbed and hardness was studied following melting of the sand cast alloy just after carrying out the mechanical tests. The casting process was carried out using three different techniques and then cooled in water, air and furnace to vary the microstructure of the alloys produced. Cu addition to the base alloy was by dispersion of the Cu powder within the Pb-Sb-Cu matrix using the three techniques. The results of the investigation indicate that impact strength, energy absorbed and hardness of the Pb-Sb-Cu alloy increased correspondingly with increased melting temperature of the alloy (up to 440^0C) as a result of corresponding increase in Cu addition and distribution (up to 8.26%) within the Pb-Sb matrix. Casting of Pb-Sb-Cu alloy using Technique A was found to impart higher and better impact strength, energy absorbed and hardness on the alloy (compared with the other techniques used). Furnace cooling was found to confer higher impact strength and energy absorbed on the Pb-Sb-Cu alloy compared with similar alloy cooled in water and air, irrespective of the casting technique used. Water cooling however, imparted greater hardness on Pb-Sb-Cu alloy compared with similar alloy cooled in air or furnace, irrespective of the casting technique used.

Keywords: Melting Temperature, Hardness, Impact Strength, Pb-Sb-Cu Alloy.

1. Introduction

The effect of tellurium(Te) on the mechanical properties of Pb-Sb alloy has been studied by Abrikosov (1969). The results of the investigation indicate that impact strength, tensile strength and hardness of the alloy is enhanced with addition of Te. He however, stated that the durability of the components made with this alloy cannot be guaranteed since Te is very radioactive. 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. Nwoye (2000) reported that dispersion of Cu powder in Pb-Sb melt increases the impact strength and hardness of the alloy when cooled. He stated that the higher values of these mechanical properties (relative to those of Pb-Sb alloy) obtained is believed to be jointly as a result of Cu dispersion in the Pb-Sb matrix and the high level of purity (99.8%) of the copper powder used. This is in accordance with studies (Gellach 1968) which show that impurities in metals and alloys affect negatively their mechanical properties. Effect of oxygen addition on Pb-Sb alloy has been reported (Gellach 1968) to be an improvement in the corrosion resistance of the alloy due to the formation of transient oxide film as oxygen diffuses into the alloy. However, the alloy does not find wide industrial application due to the low mechanical properties attributed to it which includes tensile strength, impact strength and hardness. 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. Addition of 0.7% Al and 0.23% Bi to Pb-Sb alloy was found to increase the hardness, tensile strength, ductility and corrosion resistance of the alloy (Kasten 1940).

Arsenic addition to Pb-Sb-Sn alloy has been found to increase the corrosion resistance of the alloy due

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to its ability to reduce oxidation during service by formation of oxide film on the matrix (Sodacha and Kerr 1972). However, this alloy has not found application in pipes and tanks because of its poisonous nature. Ackerrmann (1929) reported, following characterization of Pb-Sb-Sn-Ni alloy, that addition of 0.25% Ni imparts good casting properties to Pb-Sb-Sn alloy. He also found that presence of Ni in the alloy increases the tensile and impact strength of Pb-Sb-Sn particularly at high temperature. He further stated that the hardness and corrosion resistance of the alloy is tremendously improved with addition of 0.25% Ni. 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. He 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. He however, stated that this increase does not give a stable value due to impurities in the Ag. He 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 greatly. It is believed that this breakthrough was possible because Cu used, had high purity level (99.8%). It is widely accepted that the mechanical properties of cast alloys and metals depend significantly on the chemical compositions of the material, casting temperature, casting technique, mould material, cooling medium and cooling rate. Studies (Nwoye 2000 and 2008; Nwajagu 1994) have shown that amongst cooling media such as water, air and furnace, water gives the highest cooling rate followed by air and then furnace. They posited that furnace cooling imparts better impact strength, ductility and tensile strength to cast metals and alloys followed by air cooling and then water cooling. They however, stated that water cooling imparts greater hardness to these materials followed by air cooling and then furnace cooling.

The aim of this research work is to study the effect of melting temperature of sand cast Pb-Sb-Cu alloy on its impact strength and hardness. In this work, copper powder was added to the Pb-Sb melt by dispersion.

2. Materials and methods

The materials used are antimonial lead scraps and electrolytic copper powder (200 mesh to dust type). The 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. The melting crucible was of 260mm long, 200mm wide mild steel of about 100mm breadth with handle for carriage. 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 before use following its preparation. A weighed quantity of lead antimony alloy (500g) was placed on the crucible and then placed inside the furnace. At 420^0C, the melt was slagged (since the whole constituent of the crucible has melted) and a weighed quantity of Cu added and the whole constituent stirred and returned to the furnace. After 5 minutes, the crucible was brought out of the furnace and poured into the mould (Technique C). In another batch of the casting operation Cu was added simultaneously as pouring of the molten Pb-Sb into the mould was going on (Technique A). In the other batch, Cu was added intermittently as pouring of Pb-Sb into the mould was going on (Technique B). This invariably created several layers of Cu inside the alloy formed. Cast alloys from each of the techniques were cooled in water, air and furnace.

They cast alloys were 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 testing of their mechanical properties. Following the heat treatment process, impact strength and hardness test were carried out on the cast alloys (applying British standard procedures) using impact strength testing machine and Vickers hardness testing machine respectively from the Mechanical Engineering Workshop of University of Nigeria, Nsukka. The energy absorbed by the alloy before fracture was calculated from the values of the impact strength by considering the cross-sectional area of the alloy sample. The tested specimens were thereafter melted and their melting temperatures recorded correspondingly against their respective values of impact strength, energy absorbed and hardness.

The striking energy of the impact strength testing machine is given by the equation (Mc Graw 1982);

S_E = MgH ...1

where

S_E =Striking energy of the impact strength machine (Kg/Fm)

M = Mass of hammer from the machine (g) = 3941Kg

g = Acceleration due to gravity (m/s^2) = $10m/s^2$

H = Height of hammer (rad.) = 90^0 (Ð/2) (by conversion to radian) and Ð = 22/7

Substituting these values into equation (1) gives;

S_E = 619300J (61930 KgFm)

where 1Nm = 1J and 1KgF = 10N

Cross-sectional area, A (cm^2) of the alloy sample is given by the equation;

A = ÐD^2/4 ...2

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

Substituting the value of D into equation (2) gives:

A = $0.6364cm^2$

Energy absorbed at fracture, E_B (KgFm) is given by the equation (see Mc Graw 1982);

E_B = I_M x A ...3

where I_M = Impact strength of the alloy sample before fracture ($KgFm/cm^2$)

3.0 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	3.30
Copper powder	-	-	99.80

3.1 Effect of melting temperature of Pb-Sb-Cu alloy on its impact strength

The results of impact strength test (Figures1-3) carried out on Pb-Sb-Cu alloys show that irrespective of the casting technique and cooling medium used, the impact strength of the alloy increases with increase in its melting temperature (up to 440^0C).

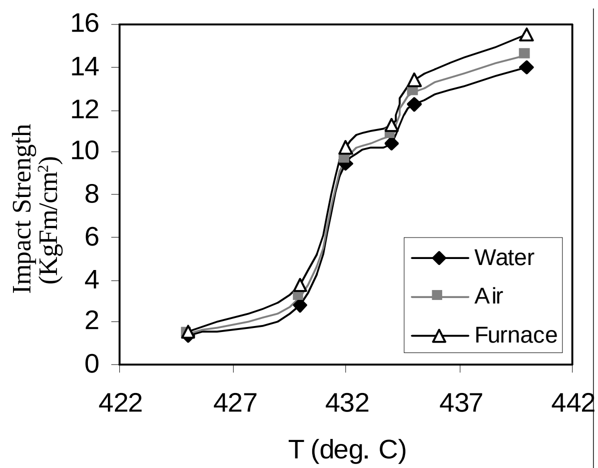

Figure 1: Effect of melting temperature of Pb-Sb-Cu alloy system on its impact strenght (For technique A)

Figure 10 indicates that increase in the Cu added to Pb-Sb matrix (up to 8.26%) increases the melting temperature of the Pb-Sb-Cu alloys formed.

It is therefore believed that increased impact strength of the Pb-Sb-Cu alloys resulted from increased melting temperature of the alloys as a result of increased Cu addition and distribution within the Pb-Sb matrix (See Figure 10 and Table 3). This implies that increased melting temperature of the alloys is due to increased percentage of Cu added and

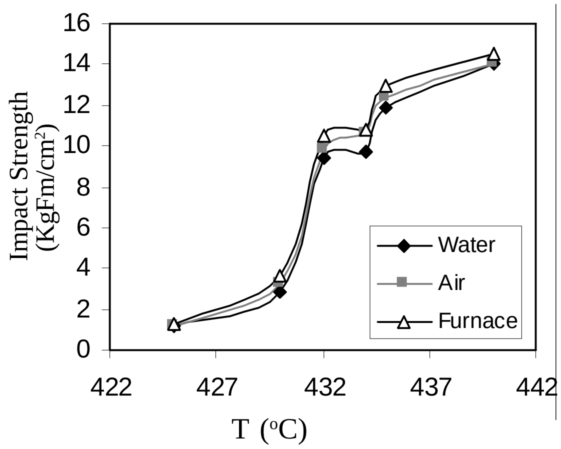

Figure 2: Effect of melting temperature of Pb-Sb-Cu alloy system on its impact strength (For Technique B)

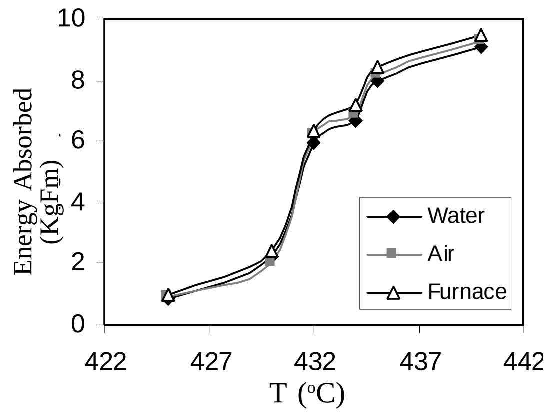

Figure 4: Effect of melting temperature of Pb-Sb-Cu alloy system on the energy absorbed prior to fracture (For Technique A)

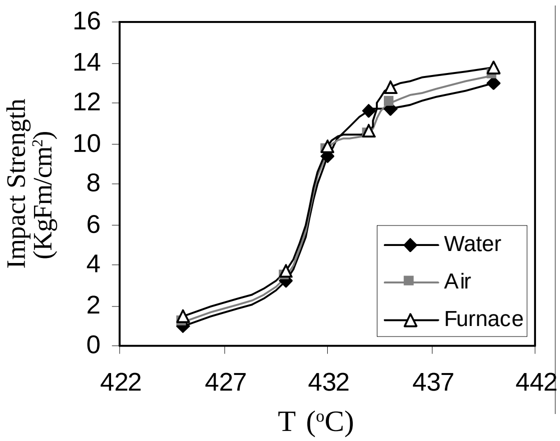

Figure 3: Effect of melting temperature of Pb-Sb-Cu alloy system on its impact strength (For Technique C)

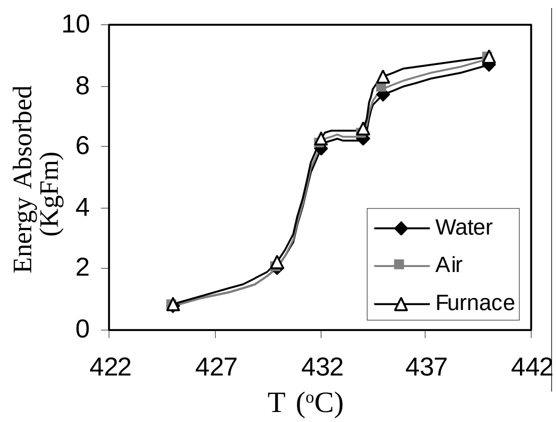

Figure 5: Effect of melting temperature of Pb-Sb-Cu alloy system on the energy absorbed prior to fracture (For Technique A)

distributed within the Pb-Sb matrix.

3.3 Effect of melting temperature of Pb-Sb-Cu alloy on the energy absorbed

Energy absorbed by Pb-Sb-Cu alloys prior to fracture was calculated from the values of the impact strength using equation (3) following the calculation of the cross-sectional area of the alloy sample using equation (2).

Figures 4-6 show that irrespective of the casting techniques and cooling medium used, energy absorbed by the alloy increases with increase in its melting temperature (up to 440^{0}C).

Comparing Figure 10 and Table 3, it is strongly believed that since energy absorbed by the alloys is a derivative of the impact strength, increased energy absorbed by the Pb-Sb-Cu alloys also resulted from increased melting temperature of the alloys as a result of increased Cu addition and distribution (up to 8.26%) within the Pb-Sb matrix.

3.4 Effect of melting temperature of Pb-Sb-Cu alloy on its hardness

The hardness of Pb-Sb-Cu alloy was also found to increase with increased melting temperature of the alloy (up to 440^{0}C) irrespective of the casting techniques and cooling medium used.

Comparison of Figures 7-9, 10 and Table 3 shows that increase in the hardness of the Pb-Sb-Cu alloys resulted from increased melting temperature of the alloys (up to 440^{0}C) as a result of increased Cu

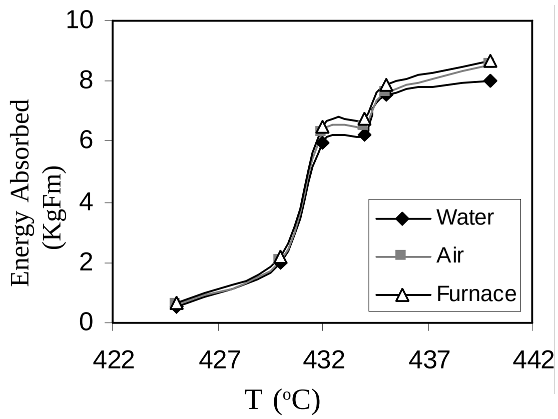

Figure 6: Effect of melting temperature of Pb-Sb-Cu alloy system on the energy absorbed prior to fracture (For Technique C)

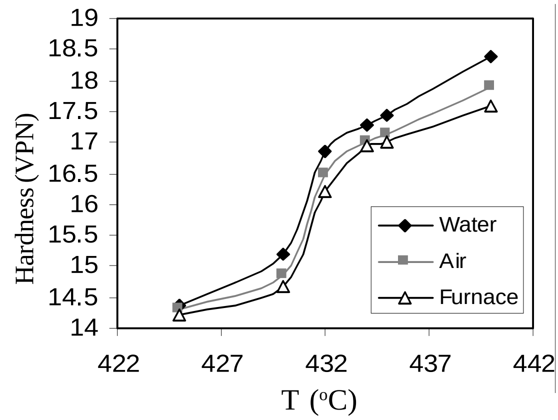

Figure 8: Effect of melting temperature of Pb-Sb-Cu alloy system on its hardness (For Technique B).

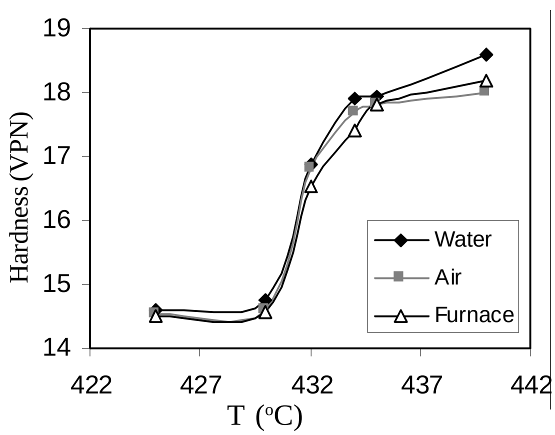

Figure 7: Effect of melting temperature of Pb-Sb-Cu alloy system on its hardness (For Technique A)

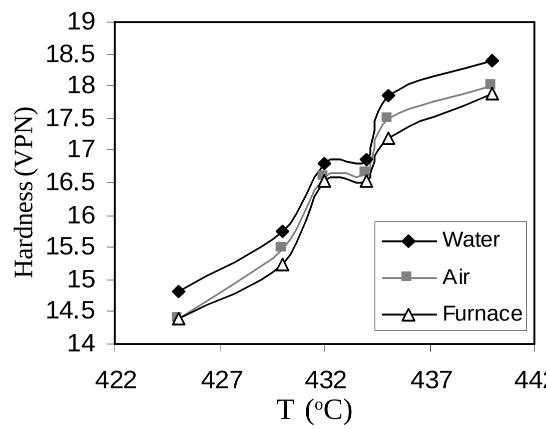

Figure 9: Effect of melting temperature of Pb-Sb-Cu alloy system on its hardness (For Technique C).

addition and distribution (up to 8.26%) within the Pb-Sb matrix.

This also implies that increased melting temperature of the alloys is due to increased percentage of Cu distributed within the Pb-Sb matrix.

3.5 Effect of copper addition on the impact strength, hardness and energy absorbed by cast Pb-Sb-Cu alloy

Comparison of Figures 1-9, 10, Tables 2 and 3 shows that increased addition of Cu (up to 8.26%) to the primary alloying material (Pb-Sb alloy, of melting temperature , 425^{0}C) to form Pb-Sb-Cu alloy increased its melting temperature and also correspondingly increased the impact strength, energy absorbed and hardness of the Pb-Sb-Cu alloy.

3.6 Effect of cooling medium and casting technique on the hardness, impact strength and energy absorbed by Pb-Sb-Cu alloy

Figures 1-9 show that furnace cooling imparted better impact strength and energy absorbed to the alloy (compared with water and air cooling) irrespective of the casting technique used. This is suspected to be due to the formation of equiaxed structure in the microstructure of the alloys as a result of slower cooling rate imposed by furnace cooling. This agrees with past report (Nwajagu 1994). This result implies that alloys cooled in the furnace can withstand greater stress or load (than water and air cooled alloys) before actually undergoing failure. This is in accordance with past reports (Nwoye 2000 and 2008; Nwajagu 1994). It was also found that

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

Technique A			
Mech. Property	Water	Air	Furnace
Impact strength	1.01	1.18	1.26
Energy absorbed	0.64	0.75	0.80
Hardness	14.45	14.26	14.40

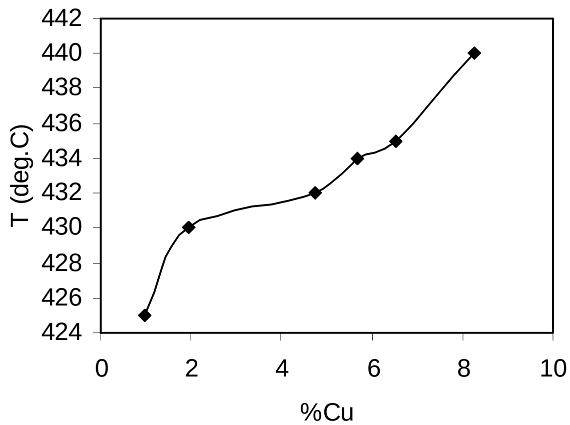

Figure 10: Effect of Copper addition (to Pb-Sb matrix) on the melting temperature of Pb-Sb-Cu alloy system.

Table 3: Effect of copper addition (to Pb-Sb matrix) on the impact strength, energy absorbed and hardness of Pb-Sb-Cu alloy (For Technique A alloys cooled in Furnace)

%Cu	Hardness (VPN)	Energy absorbed (KgFm)	Impact Strength (KgFm/cm^2)
0.99	14.49	0.96	1.50
1.96	14.56	2.40	3.80
4.76	16.53	6.35	10.20
5.66	17.40	7.20	11.30
6.54	17.80	8.40	13.40
8.26	18.20	9.45	15.50

water cooling the alloys imparted higher hardness (compared with furnace and air cooling) irrespective of the casting technique used. This is suspected to be as a result of the formation of coarse grain within the alloy structure imposed by rapid cooling of water. Coarse grains achieved in this way have been found to give greater hardness (Nwajagu 1994; Chapman 1972)

Comparison of Figures 1-9 shows clearly that Technique A imparts higher impact strength, energy absorbed and hardness to Pb-Sb-Cu alloys when used (compared to Technique B and C). This is attributed to the uniform distribution of Cu within the Pb-Sb matrix unlike in Techniques B an C where segregation between Cu and Pb-Sb matrix are expected in some parts of the Pb-Sb-Cu alloy system.

4.0 Conclusion

Impact strength, energy absorbed and hardness of sand cast Pb-Sb-Cu alloys increased with increased melting temperature of the alloys (up to 440^{0}C) as a result of increased Cu addition and distribution (up to 8.26%) within the Pb-Sb matrix. Casting of Pb-Sb-Cu alloys using Technique A imparts higher and better impact strength, energy absorbed, and hardness on the alloys. Furnace cooling confers higher impact strength and energy absorbed on cast Pb-Sb-Cu alloys compared with similar alloys cooled in water and air irrespective of the casting technique used. Water cooling however, imparts greater hardness on Pb-Sb-Cu alloys compared with similar alloys cooled in air or furnace, irrespective of the casting technique used.

5.0 Acknowledgement

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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