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Effect of melting temperature on the energy absorbance of Pb-Sb-Cu alloy at fracture resulting from impact load

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Abstract

The effect of melting temperature on the energy absorbance of Pb-Sb-Cu alloy at fracture, resulting from impact load has been studied. The casting process was carried out using three different techniques; Technique A, involving simultaneous addition of Cu powder and pouring of the molten Pb-Sb into the mould. Techniques B, involving addition of Cu powder intermittently as pouring of Pb-Sb into the mould was going on and Technique C involving pouring a stirred mixture of heated Pb-Sb alloy and powdered Cu into the mould. The cast alloys were cooled in water, air and furnace. Impact test to determine the energy absorbance was carried out prior to melting of the alloys. Copper was added to the base alloy by dispersion using the three casting techniques. The results of the investigation showed that prior to fracture, energy absorbance of the Pb-Sb-Cu alloy increased correspondingly with increased melting temperature of the alloy (up to 440^{0}C) as a result of corresponding increase in Cu addition and distribution (up to 8.26%) within the Pb-Sb matrix. Technique A imparted higher impact strength and energy absorbance on the alloy (compared with the other techniques used). Furnace cooling also conferred higher impact strength and energy absorbance on the Pb-Sb-Cu alloy compared with similar alloy cooled in water and air, irrespective of the casting technique used.

Keywords: Effect; Melting temperature; Energy absorbance; Pb-Sb-Cu alloy

1. Introduction

The effect of tellurium 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. It was 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. It was 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 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 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. It was also found that presence of Ni in the alloy increases the tensile and impact strength of Pb-Sb-Sn particularly at high temperature. It was 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. 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 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; 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 on the energy absorbance of Pb-Sb-Cu alloy at fracture, resulting from impact load. In this work, copper powder was added to the Pb-Sb melt by dispersion. This is expected to give an idea about the extent to which the alloys can withstand impact loading through energy absorbance prior to failure.

2. Materials and methods

2.1. 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.

2.2. 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.

2.3. 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 420^0C, into the mould. The Control alloys were cast by just pouring only the molten Pb-Sb into the mould (Conventional Technique).

2.4. Cast alloys cooling

Cast alloys from each of the techniques were cooled in water, air and furnace.

2.5. Heat treatment

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 impact testing process.

2.6. Impact strength test

Following the heat treatment process, impact strength tests was carried out on the cast alloys (applying British standard procedures) using impact strength testing machine from the Mechanical Engineering Workshop of University of Nigeria, Nsukka. They 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 and energy absorbance.

2.7. Calculation of impact strength and energy absorbance of Pb-Sb-Cu alloys

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

$$S_E = M \times g \times H \qquad (1)$$

where

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

M = Mass of hammer from the machine (g)

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

H = Height of hammer (rad.)

M = 3941Kg, g = 10m/s^2, H = 90^0 (Π/2) (by conversion to radian) and Π = 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;

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

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

Substituting the of D into equation (2)

A = 0.6364cm^2

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

$$E_B = I_M \times A \qquad (3)$$

where

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

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

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

The impact strength test results (Figs.1-3) show that prior to fracture, 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^{0}C).

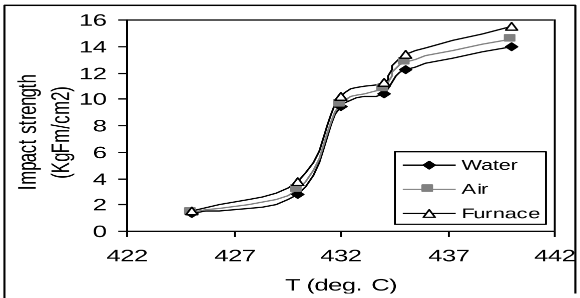

Fig. 1. Effect of melting temperature of Pb-Sb-Cu alloy system on its impact strength (for Technique A)

It was found (Fig. 7) 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.

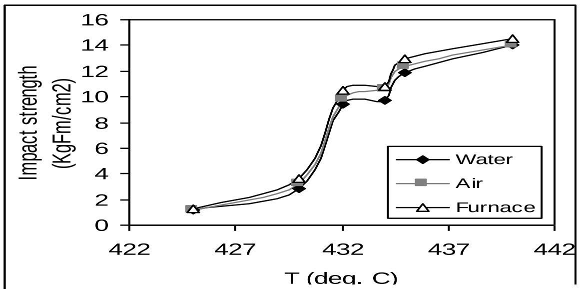

Fig. 2. Effect of melting temperature of Pb-Sb-Cu alloy system on its impact strength (for Technique B)

It is therefore believed that increased impact strength of the Pb-Sb-Cu alloys prior to fracture resulted from increased melting temperature of the alloys as a result of increased Cu addition and distribution within the Pb-Sb matrix (Fig. 7 and Table 3). This implies that increased melting temperature of the alloys is due to increased percentage of Cu added and distributed within the Pb-Sb matrix.

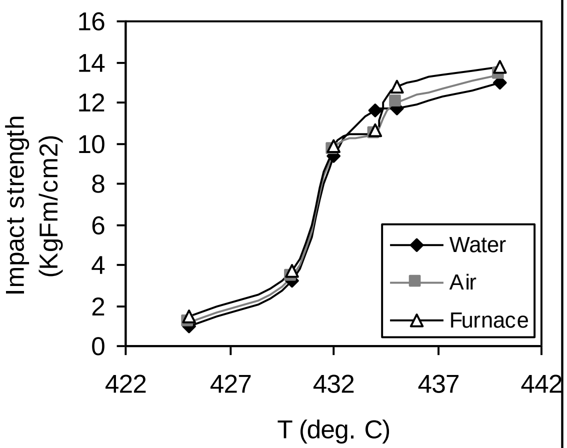

Fig. 3. Effect of melting temperature of Pb-Sb-Cu alloy system on its impact strength (for Technique A)

3.2. Effect of melting temperature of Pb-Sb-Cu alloy on energy absorbance

Energy absorbance of 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).

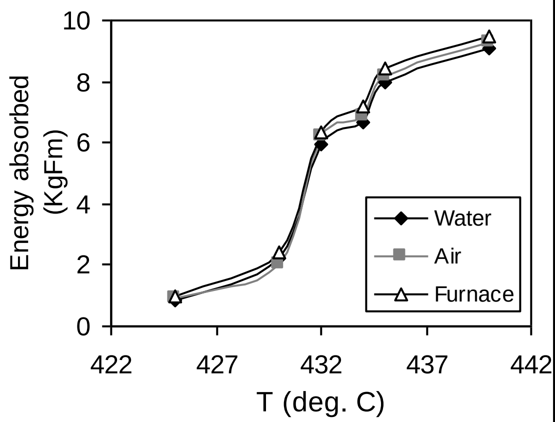

Fig. 4. Effect of melting temperature of Pb-Sb-Cu alloy system on the energy absorbed prior to fracture (for Technique A)

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

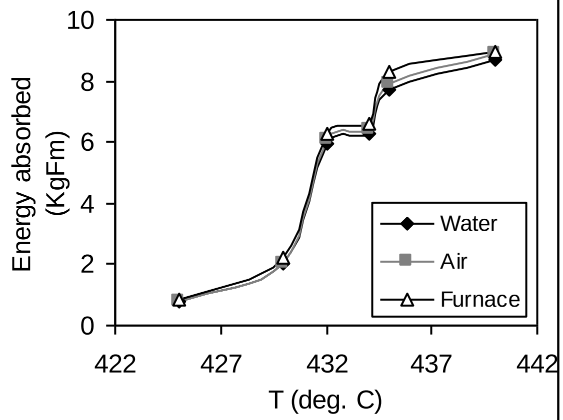

Fig. 5. Effect of Melting temperature of Pb-Sb-Cu alloy system on the energy absorbed prior to fracture (for Technique B)

Comparing Fig. 7 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.

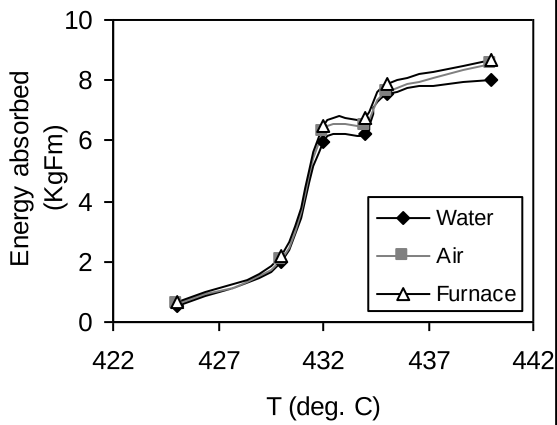

Fig. 6. Effect of Melting temperature of Pb-Sb-Cu alloy system on the energy absorbed prior to fracture (for Technique C)

3.3. Effect of copper addition on the impact strength and energy absorbance of cast Pb-Sb-Cu alloy

Comparison of Figs. 1-6, Fig. 7, 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 inturn correspondingly increased the impact strength and energy absorbance the Pb-Sb-Cu alloys prior to fracture.

Table 2
Results of impact test 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 absorbance	0.64	0.75	0.80

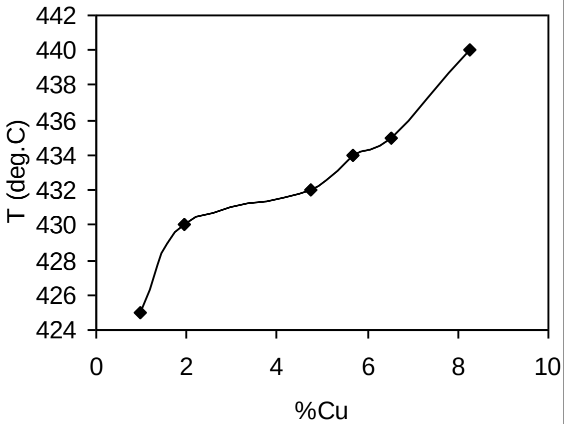

Fig. 7. effect of copper addition (to Pb-Sb matrix) on the melting temperature of Pb-Sb-Cu alloy system

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

%Cu	*Energy absorbed (KgFm)*	*Impact Strength (KgFm/cm^2)*
0.99	0.96	1.50
1.96	2.40	3.80
4.76	6.35	10.20
5.66	7.20	11.30
6.54	8.40	13.40
8.26	9.45	15.50

3.4. Effect of cooling medium and casting technique on the impact strength and energy absorbance of Pb-Sb-Cu alloy.

Results (Figs. 1-6) show that furnace cooling imparted better impact strength and energy absorbance to the alloys (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.,2008., Nwajagu, 1994). However, water cooling the alloys is expected to impart 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 Figs. 1-6 shows clearly that Technique A imparts higher impact strength and energy absorbance to the 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 and C where segregation between Cu and Pb-Sb matrix are expected in some parts of the Pb-Sb-Cu alloy system.

4. Conclusion

Prior to fracture, impact strength and energy absorbance 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 and energy absorbance on the alloys. Furnace cooling conferred higher impact strength and energy absorbance on cast Pb-Sb-Cu alloys compared with similar alloys cooled in water and air irrespective of the casting technique used.

5. 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.

References

Abrikosov, N. K., 1969. Effects of tellurium on the strength of lead antimony alloy. Neorg Materially, USSR, p5.

Ackermann, C. L., 1929. Characterization of nickel-lead-antimony-tin Alloy. Z. Metallkunde, New York, p21.

Blumenthal, B., 1944. Effects of silver on the electrical conductivity of lead-antimony alloy, Trans. Amer. Inst. Min. Met, England, p156.

Chapman, W. A. P., 1972. Workshop Technology, part 1. 5th edition, Edward Arnold, London, 31-51.

Ezenwa, Z.O., 1987. Equilibrium Studies of Lead-Tin-Antimony Alloys. B.Eng. Project Report, Enugu State University of Science and Technology, Enugu, p17-22.

Geiss, D. R., Perrtti, E. A., 1962. Effects of indium on the corrosion properties of lead-antimony alloy, J. Less-Common Metals, Italy, p4.

Gellach, J., 1968. Effects of Oxygen on the mechanical properties of lead-antimony Alloy. Metall. USSR, p22.

Kasten, G. W., 1940. Effects of Aluminum and Bismuth on the Mechanical Properties of Lead-Antimony Alloy. Siemen Werke, Japan, p50.

Mc Graw, H., 1982. Encyclopedia of Science and Technology, Vol. 3, 5th edition, Mc Graw Hill, New York.

Nwajagu, C. O. 1994. Foundry Theory and Practice, A B C Publishers p209-259.

Nwoye, C. I., 2000. Effect of Copper Powder Dispersion on the Electrical Conductivity of Lead-Antimony Alloy. M.Eng. Thesis, Nnamdi Azikiwe University, Awka.

Nwoye, C. I., 2008. Comparative Studies of the cooling ability of hydrocarbon based media and their effects on the hardness of heat affected zone (HAZ) in weldments. JMME , 3, 1.

Rollason, E. C., Hysel, V. B., 1940. Effect of cadmium on the electrical conductivity of lead-antimony alloy, J. Inst. Metals, London, p66.

Sodacha, J. P., Kerr, H. W., 1972. Effects of arsenic on the corrosion properties of lead-antimony-tin alloy, J. Inst. Metals. Japan, p100.

Weaver, F. D., 1935. Characterization of lead-antimony-tin alloy, J. Inst. Metals, New York, p56.