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Improvement of the Mechanical Properties of Pb-Sb Alloy System Through its Microstructural Modification by Copper Powder Dispersion during Casting

Chukwuka Ikechukwu Nwoye* and Sylvanus Ikechukwu Okeke
*Department of Materials and Metallurgical Engineering, Federal University of Technology, P.M.B 1526, Owerri. Nigeria.
Department of Materials and Metallurgical Engineering, Nnamdi Azikiwe University, P.M.B 5025, Awka. Nigeria.
chikeyn@yahoo.com

Abstract: An attempt has been made to improve the mechanical properties; impact strength, energy absorbance and hardness of Pb-Sb alloy system through its microstructural modification by copper powder dispersion during casting. The Pb-Sb-Cu alloy was formed through casting by simultaneous addition of Cu powder and pouring of the molten Pb-Sb into the mould. Results of this study show that impact strength, energy absorbance and hardness of the cast Pb-Sb-Cu alloy increased as a result of increase in Cu addition (up to 6.54%) due to decrease in the grain size of Pb-Sb-Cu alloy occasioned by increased uniform distribution of the Cu powder within the Pb-Sb matrix. [New York Science Journal. 2009;2(6):86-92]. (ISSN: 1554-0200).

Keywords: Improvement, Mechanical Properties, Pb-Sb-Cu Alloy, Microstructural Modification.

1. Introduction

Abrikosov [1] has studied the effect of tellurium on the mechanical properties of Pb-Sb alloy. 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 [2,3] 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 [4] 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 [5] which show that impurities in metals and alloys affect negatively their mechanical properties. It has been reported [5] that the effect of oxygen addition on Pb-Sb alloy is 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 [6] 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 [7]. 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 [8]. However, this alloy has not found application in pipes and tanks because of its poisonous nature. Ackerrmann [9] 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 [4,10,11] have been carried out to improve the electrical conductivity of Pb-Sb alloy used as wet cell battery heads. Blumenthal [10] 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 [11] 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 [4] 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 [4,12,13] 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. Nwajagu [12] found that cooling an alloy from a higher temperature widens the temperature gradient and hence increases the hardness in the case of water cooling. It was therefore concluded that increased cooling time increases the tensile and impact strength.

The aim of this research work is to improve the mechanical properties; impact strength, energy absorbance and hardness of Pb-Sb alloy system through its microstructural modification by copper powder dispersion during casting.

2. Materials and methods

ALLOY PREPARATION:

The materials used are antimonial lead scraps and electrolytic copper powder (200 mesh to dust type). 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 before use following its preparation.

CASTING TECHNIQUES:

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 have melted). Various quantities of Cu were added simultaneously with pouring of molten Pb-Sb into the mould.

HEAT TREATMENT

The 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.

IMPACT STRENGTH AND HARDNESS TEST

Following the heat treatment process, impact strength, energy absorbance and hardness tests 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. 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.

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 [14];

$$S_E = M \times g \times H \tag{1}$$

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 = $10 m/s^2$, H = 90^0 ($\Pi/2$) (by conversion to radian) and $\Pi = 22/7$. 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;

$$A = \Pi D^2/4 \tag{2}$$

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

Substituting the of D into equation (2)

$$A = 0.6364 cm^2$$

Energy absorbed at fracture, E_B (KgFm) is given by the equation [14];

$$E_B = I_M \times A \tag{3}$$

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

Effect of microstructural modification of Pb-Sb alloy system on the impact strength of Pb-Sb-Cu alloy formed

The result of impact strength tests (Tables 2 and 3) carried out on Pb-Sb-Cu alloys shows that the impact strength of the alloy increases with increase in the weight of Cu added (up to 6.54%) to the molten Pb-Sb alloy system. Micrographs in Figs. 1-8 show decrease in the grain size of the Pb-Sb-Cu alloy formed as the weight of Cu added increases. Figs.1-8 also shows increasing degree of uniform distribution of Cu as the weight of Cu added increases. It is therefore believed that increased uniform distribution of the Cu powder resulted to the decrease in the grain size of the Pb-Sb-Cu alloy formed. Comparison of Table 3 and Fig.8 shows that the highest impact strength ($13.4 KgFm/Cm^2$) is associated with the greatest weight-input of Cu powder (6.54%). Fig.8 also indicates the most uniform distribution of Cu within the Pb-Sb matrix. Based on the foregoing, impact strength increased as a result of increase in Cu addition due to decrease in the grain size of Pb-Sb-Cu alloy formed occasioned by increased uniform distribution of the Cu powder within the Pb-Sb matrix. This agrees with past studies [12] where decrease in the grain size of alloys resulted to increased tensile strength, impact strength and hardness.

Effect of microstructural modification of Pb-Sb alloy system on energy absorbance of Pb-Sb-Cu alloy formed

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). Comparison of Tables 2 and 3 show that energy absorbance increases with increase in the weight of Cu added (up to 6.54%) to the molten Pb-Sb alloy system. 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 increase in Cu addition (up to 6.54%) due to decrease in the grain size of Pb-Sb-Cu alloy formed occasioned by increased uniform distribution of the Cu powder within the Pb-Sb matrix. Table 3 and Fig. 8 show that the highest value of energy absorbed by the Pb-Sb-Cu alloy (8.40KgFm) is associated with the greatest weight-input (up to 6.54%) of the Cu powder.

Effect of microstructural modification of Pb-Sb alloy system on the hardness of Pb-Sb-Cu alloy formed

Comparison of Tables 2 and 3 show that the hardness of Pb-Sb-Cu alloy was also found to increase with the weight of Cu added (up to 6.54%) to the molten Pb-Sb alloy system. Figs. 1-8 show decrease in the grain size of the Pb-Sb-Cu alloy formed as the weight of Cu added increases with Fig.8 depicting the smallest grain size. Comparison of Figs.1-8 also shows increasing degree of uniform distribution of Cu as the weight of Cu added with Fig. 8 depicting the most uniform distribution of Cu in the Pb-Sb matrix. It is therefore believed that increased uniform distribution of the Cu powder resulted to the decrease in the grain size of the Pb-Sb-Cu alloy formed. Fig.8 and Table 3 is also associated with the highest hardness value (17.80VPN) resulting from the greatest weight-input of Cu powder (6.54%). It is therefore also believed that the hardness of Pb-Sb-Cu alloy increased as a result of increase in Cu addition due to decrease in the grain size of Pb-Sb-Cu alloy formed occasioned by increased uniform distribution of the Cu powder within the Pb-Sb matrix. This also agrees with past studies [12] where decrease in the grain size of alloys resulted to increased tensile strength, impact strength and hardness.

Conclusion

Based on the foregoing, impact strength, energy absorbance and hardness of Pb-Sb-Cu alloy increased as a result of increase in Cu addition due to decrease in the grain size of Pb-Sb-Cu alloy occasioned by increased uniform distribution of the Cu powder within the Pb-Sb matrix.

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

Mechanical Property	Values
Impact strength	1.26 KgFm/Cm^2
Energy absorbed	0.80 KgFm
Hardness	14.40 VPN

Table 3: Effect of copper addition (to Pb-Sb matrix) on the impact strength, energy absorbance and hardness of Pb-Sb-Cu alloy cooled in furnace

Cu (%)	Hardness (VPN)	Energy absorbance (KgFm)	Impact Strength (KgFm/cm^2)
0.99	14.49	0.96	1.50
1.96	14.56	2.40	3.80
2.91	15.20	3.40	5.74
3.85	15.60	4.84	8.20
4.76	16.53	6.35	10.20
5.66	17.40	7.20	11.30
6.54	17.80	8.40	13.40

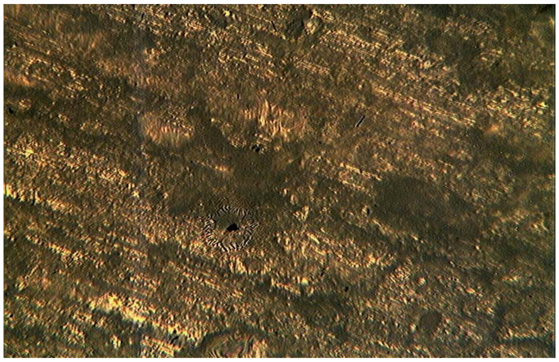

Fig.1-Microstructure of Pb-Sb matrix (Control) x400

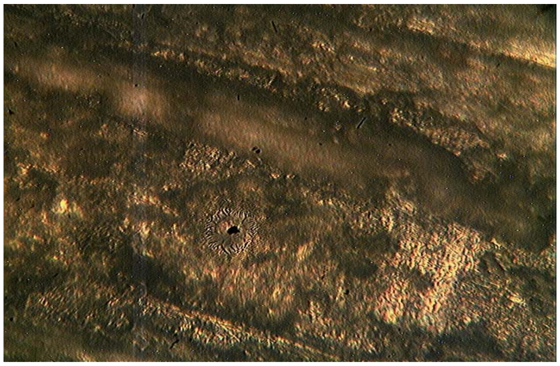

Fig.2-Microstructure of Pb-Sb matrix, 0.99%Cu x400

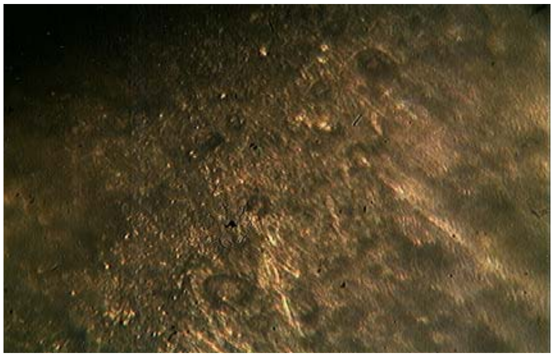

Fig.3-Microstructure of Pb-Sb matrix,1.96%Cu x400

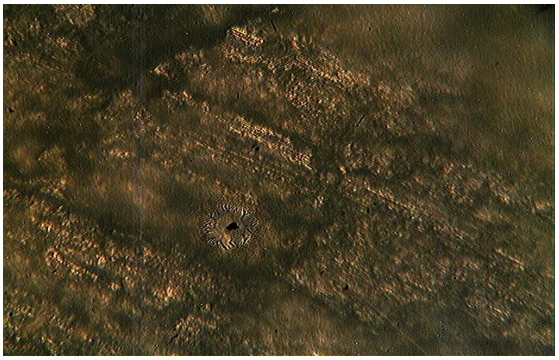

Fig.4-Microstructure of Pb-Sb matrix, 2.91%Cu x400

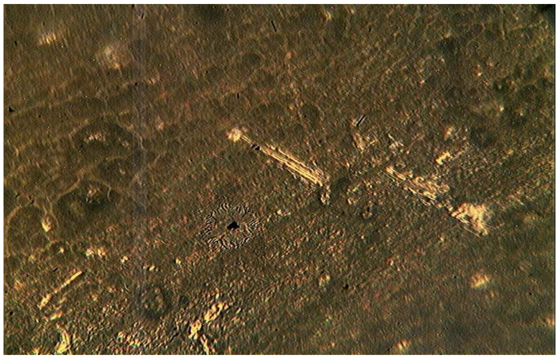

Fig.5-Microstructure of Pb-Sb matrix,3.85%Cu x400

Fig.6-Microstructure of Pb-Sb matrix, 4.76%Cu x400

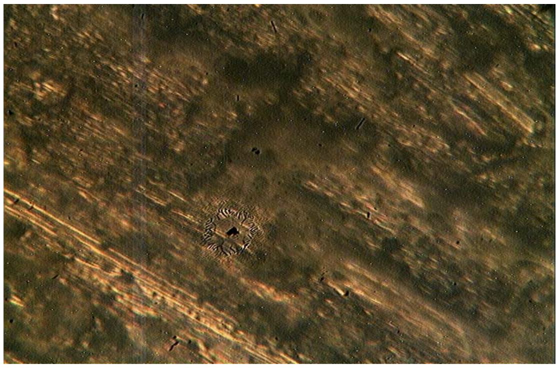

Fig.7-Microstructure of Pb-Sb matrix,5.66%Cu x400

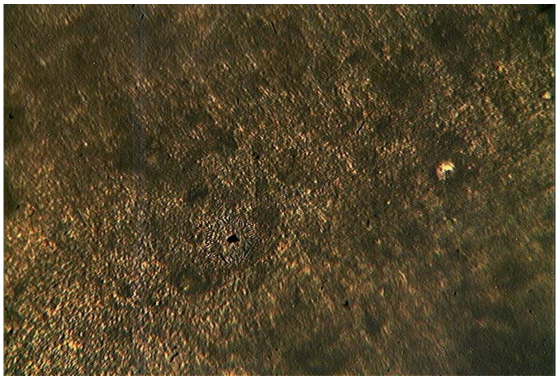

Fig.8-Microstructure of Pb-Sb matrix, 6.54%Cu x400

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References

[1]Abrikosov, N. K., (1969). Effects of Tellurium on the strength of Lead Antimony Alloy, Neorg Materially, USSR, p5.
[2]Ezenwa, Z.O., (1987). Equilibrium Studies of Lead-Tin-Antimony Alloys, B.Eng. Project Report, Enugu State University of Science & Technology, Enugu, p17-22.
[3]Weaver, F. D., (1935). Characterization of Lead-Antimony-Tin Alloy, J. Inst. Metals, New York, p56.
[4]Nwoye, C. I., (2000). Effect of Copper Powder Dispersion on the Electrical Conductivity of Lead-Antimony Alloy, M. Eng. Thesis, Nnamdi Azikiwe University, Awka.
[5]Gellach, J., (1968). Effects of Oxygen on the Mechanical Properties of Lead-Antimony Alloy, Metall. USSR, p22.
[6]Geiss, D. R., and Perrtti, E. A., (1962). Effects of Indium on the Corrosion Properties of Lead-Antimony Alloy, J. Less-Common Metals, Italy, p4.
[7]Kasten, G. W., (1940). Effects of Aluminum and Bismuth on the Mechanical Properties of Lead-Antimony Alloy, Siemen Werke, Japan, p50.
[8]Sodacha, J. P., and Kerr, H. W., (1972). Effects of Arsenic on the Corrosion Properties of Lead-Antimony-Tin Alloy, J. Inst. Metals. Japan, p100.
[9]Ackermann, C. L., (1929). Characterization of Nickel-Lead-Antimony-Tin Alloy, Z. Metallkunde, New York, p21.
[10]Blumenthal, B., (1944). Effects of Silver on the Electrical Conductivity of Lead-Antimony Alloy, Trans. Amer. Inst. Min. Met, England, p156.
[11]Rollason, E. C., and Hysel, V. B., (1940). Effect of Cadmium on the Electrical Conductivity of Lead-Antimony Alloy, J. Inst. Metals, London, p66.
[12]Nwajagu, C. O. (1994). Foundry Theory and Practice, A B C Publishers p209-259.
[13]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):35-38

[14]Mc Graw, H., (1982). Encyclopaedia of Science and Technology, Vol. 3, 5th edition, Mc Graw Hill.

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