# Effect of Heat Absorbed and Remitted by Copper Present In Molten Pb-Sb-Cu Alloy System on the Impact Strength and Hardness 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 impact strength, energy absorbance and hardness of the solidified alloy was studied following casting and cooling of the alloys in the furnace as well as computation of the heat absorbed and remitted by copper. The results of the investigation indicate that the impact strength, energy absorbance, and hardness of the sand cast Pb-Sb-Cu alloys increased with increase in the quantity of heat absorbed and remitted into molten Pb-Sb-Cu alloy system as result of increase in the weight (up to 45g) of copper added and distributed within the Pb-Sb alloy matrix. This was attributed to a wider temperature gradient believed to have been created (due to increased copper addition and distribution) during cooling of the alloy system as a result of the increased heat remittance into the system. This on one hand, increased the cooling time as desirably expected for increased energy absorbance and impact strength and on the other hand increased the temperature difference through which the cooling process desirably increased the hardness. It was found that increase in heat absorbance by the Pb-Sb-Cu alloy resulted from increased weight of copper added (up to 45g) and distributed within the Pb-Sb matrix. Furnace cooling conferred higher impact strength and energy absorbance on the Pb-Sb-Cu alloy compared with similar alloy cooled in water and air. Water cooling however, imparted greater hardness on Pb-Sb-Cu alloy compared with similar alloy cooled in air or furnace. [Nature and Science. 2009;7(7):1-7]. (ISSN: 1545-0740).

**Keywords: Effect, Heat Absorbance and Remittance, Hardness, Impact Strength, Pb-Sb-Cu Alloy.**

## 1. Introduction

The effect of tellurium on the mechanical properties of Pb-Sb alloy has been studied by Abrikosov [1]. 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.

It has been reported [14] that solid or liquid gains heat when introduced into a heated liquid or molten system, and then looses the heat to the system, to maintain temperature uniformity.

The aim of this research work is to study the effect of heat absorbed and remitted by copper present in molten Pb-Sb-Cu alloy system on the impact strength, energy absorbance and hardness of the solidified alloy. 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 (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 $420^0$C, the melt was slagged (since the whole constituent of the crucible have 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. HEAT TREATMENT

The cast alloys were heat treated at a temperature of $180^0$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 testing of their mechanical properties.

IMPACT STRENGTH AND HARDNESS TEST

Following the heat treatment process, impact strength 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. Heat absorbed by copper present in the molten Pb-Sb-Cu alloy was calculated considering the masses of copper added to the base alloy, the specific heat capacity of copper and the initial and final temperatures to which the copper was exposed.

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 [15];

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

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 = $90^0$ ($\Pi/2$) (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;

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

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 ($KgFm/cm^2$)

On heating the crucible containing antimonial lead and copper powder, it is 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 or gained by the Cu is remitted into the alloy system formed, ensuring uniformity of temperature gradient within the alloy matix. This agrees with past reports [14]

Based on the foregoing,

Heat absorbed and remitted by Cu in the molten Pb-Sb-Cu alloy system is given by the equation[14];

$$Q = M C \Delta T \qquad (4)$$

Where

Q = Quantity of heat 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) [14]
$\Delta T$ = Change in temperature (between the initial and final temperature to which copper was exposed (K)

**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 input resulting from copper addition (to Pb-Sb) on the impact strength of Pb-Sb-Cu alloy**

The result of impact strength test (Fig.1) carried out on Pb-Sb-Cu alloys shows that irrespective of the cooling medium used the impact strength of the alloy increases with increase in the quantity of heat absorbed and remitted by Cu to the molten Pb-Sb-Cu alloy system.

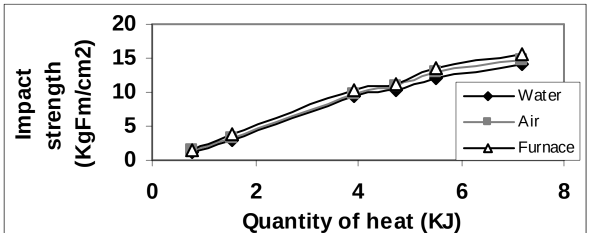


**Fig. 1 Effect of heat absorbed and remitted by copper on the impact strength of Pb-Sb-Cu alloy**

Fig. 4 indicates that increase in the quantity of Cu added to Pb-Sb matrix (up to 45g) increases the quantity of heat absorbed and remitted by it to the of Pb-Sb-Cu alloys formed. It is therefore believed that increased impact strength of the Pb-Sb-Cu alloys resulted from increased heat absorbed and remitted into the alloy system as a result of increased Cu addition and distribution within the Pb-Sb matrix (Fig. 4 and Table 3). This is true because increase in the heat absorbed and remitted by Cu into the Pb-Sb-Cu alloy system widens the temperature gradient prevailing during cooling of the system and increases the cooling time of the alloy which is considered ideal for better strength. This is in accordance with findings by Nwajagu [12]. This implies that increased heat absorbed by the Pb-Sb-Cu alloy is due to increased weight of Cu added and distributed within the Pb-Sb matrix.

**Effect of heat input resulting from copper addition (to Pb-Sb) on the energy absorbance of Pb-Sb-Cu alloy**

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). Fig. 2 shows that irrespective of the cooling medium used, energy absorbed by the alloy increases with increase in the quantity of heat absorbed and remitted by Cu present in the molten Pb-Sb-Cu alloy system.

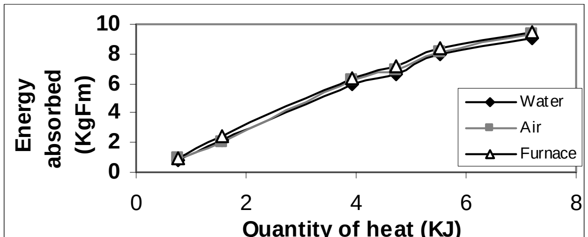


**Fig. 2 Effect of heat absorbed and remitted by copper on the energy absorbed by Pb-Sb-Cu alloy**

Comparing Fig. 4 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 increase in the heat absorbed and remitted into the alloy system as a result of increased Cu addition and distribution (up to 45g) within the Pb-Sb matrix. This is also true because increase in the heat absorbed and remitted by Cu into the Pb-Sb-Cu alloy system widens the temperature gradient prevailing during cooling of the system and increases the cooling time of the alloy which is considered ideal for better strength

**Effect of heat input resulting from copper addition (to Pb-Sb) on the hardness of Pb-Sb-Cu alloy**

The hardness of Pb-Sb-Cu alloy was also found to increase with increase in the quantity of heat absorbed and remitted by Cu into the molten Pb-Sb-Cu alloy system cooling medium used. Comparison of Figs.3, Fig. 4 and Table 3 shows that increase in the hardness of the Pb-Sb-Cu alloys resulted from increase in the heat absorbed and remitted into the alloy system as a result of increased Cu addition and distribution (up to

45g) within the Pb-Sb matrix. This also implies that increase in heat absorbed and remitted by the Cu into the alloy system is due to increased weight of Cu added and distributed within the Pb-Sb matrix.

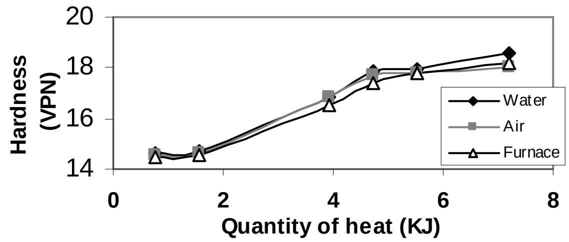


Fig. 3 Effect of heat absorbed and remitted by copper on the hardness of Pb-Sb-Cu alloy

This is believed to be so because increase in the heat absorbed and remitted into the Pb-Sb-Cu alloy system is likely to raise the temperature of the alloy system, widen the temperature gradient prevailing during cooling of the system and also increase the cooling time. The widening of the temperature gradient is believed to have increased the hardness the solidified Pb-Sb-Cu alloy especially when cooled in water. This is in agreement with past report [12]. However, increased cooling time imposed by increased heat absorption and remittance into the molten Pb-Sb-Cu alloy system imparted lower hardness on the alloys when they are cooled in the air and furnace. This is so because air and furnace cooling is associated with slower cooling rate which is not ideal for higher hardness. However, Fig. 3 indicates that the hardness of alloys cooled in air and furnace increases with increase in the quantity of heat absorbed and remitted into the molten alloy. This is a clear indication that the cooling rate increased with increase in the heat content of the molten alloy system. This is in accordance with the law guiding heat emission in solid bodies.

**Effect of copper addition (to Pb-Sb alloy) on the quantity of heat absorbed and remitted into Pb-Sb-Cu alloy**

Comparison of Figs.1-4, Tables 2 and 3 shows that increased addition of Cu (up to 45g) to the base alloy to form Pb-Sb-Cu alloy increased the quantity of heat absorbed and remitted into Pb-Sb-Cu alloy system. This invariable resulted to corresponding increase in the impact strength, energy absorbance and hardness of the Pb-Sb-Cu alloy due to increased cooling time and widened

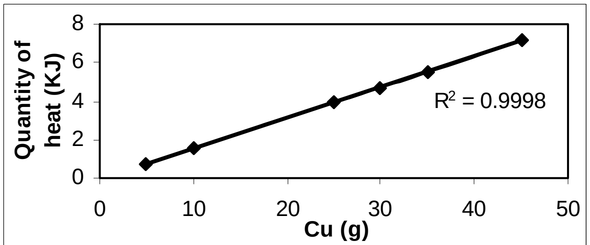


Fig. 4 Effect of copper addition (to Pb-Sb alloy) on its resultant heat absorption and remittance to the Pb-Sb-Cu alloy formed

temperature incurred. An evaluation of the correlation coefficient, R between the Cu added to the base alloy (Pb-Sb alloy) and heat absorbed and remitted to the formed Pb-Sb-Cu alloy (as in Fig.4) using the equation;

$$R = \sqrt{R} \quad (5)$$

gives R = 0.9999 which is approximately unity. This represents a very ideal and desirable relationship between the experimental process parameters.

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

| 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 |

**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 (g) | Hardness (VPN) | Energy absorbance (KgFm) | Impact Strength (KgFm/cm$^2$) |
|---|---|---|---|
| 5 | 14.49 | 0.96 | 1.50 |
| 10 | 14.56 | 2.40 | 3.80 |
| 25 | 16.53 | 6.35 | 10.20 |
| 30 | 17.40 | 7.20 | 11.30 |
| 35 | 17.80 | 8.40 | 13.40 |
| 45 | 18.20 | 9.45 | 15.50 |

**Effect of cooling medium on the hardness, impact strength and energy absorbance of Pb-Sb-Cu alloy.**
Figs. 1-3 show that furnace cooling imparted better impact strength and energy absorbance to the alloy (compared with water and air cooling) in agreement with previous work [16,17]. 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 [12]. 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 [4, 12,13]. It was also found that water cooling the alloys imparted higher hardness to the alloy (compared with furnace and air cooling). 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 [12,18].

## Conclusion

Impact strength, energy absorbance and hardness of sand cast Pb-Sb-Cu alloys increased with increase in the quantity of heat absorbed and remitted into the molten Pb-Sb-Cu alloy system as a result of wider temperature gradient prevailing during cooling of the system and also increase in the cooling time. Furnace cooling confers higher impact strength and energy absorbance on cast Pb-Sb-Cu alloys compared with similar alloys cooled in water and air. Water cooling however, imparts greater hardness on Pb-Sb-Cu alloys compared with similar alloys cooled in air or furnace.

## Acknowledgement

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