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# Effect of Replacement of Lead by Tin on The Properties of Yellow Brass (Cu-Zn) alloy

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## Abstract

Brass alloys are widely used as industrial material because of their excellent characteristics such as high corrosion resistance, excellent electrical and thermal conductivities, and good machinability. In particular, machinable brass is obtained by adding lead. It is, however, necessary to reduce the use of lead from a view point from the hazardous effects on the environment and humans. The effect of replacement of toxic lead (Pb) in conventional brass alloy, with tin (Sn) has been investigated. Two brass alloys with copper content (~59) wt% were laboratory made, chemical compositions, microstructure of surfaces were characterized by optical microscope. Hardness, machinability, and compression test have also been studied. The experimental studies provided that high tin contents are responsible for eutectoid structure with the formation of a hard phase $\gamma$ (Sn) improves hardness to the maximum and rise up elastic modulus and maximum stress than leaded brass. Fine crumbles and spiral chips swarf produced during machinability of leaded and tin brasses respectively.

**Keywords:** Brass Alloys, Thermal conductivities, Machinability, Optical microscope, Hardness.

## 1. Introduction

Copper and copper alloys constitute one of the major groups of commercial metals. They are widely used because of their excellent electrical and thermal conductivities, outstanding resistance to corrosion, ease of fabrication, and good strength and fatigue resistance. They are generally nonmagnetic. They can be readily soldered and brazed [1].

Small percentage of alloying elements can be added to brass alloys to improve certain characteristics such as strength (*e.g.* Mn, Al, Si, Ni, Fe), machinability (*e.g.* Pb, Te, S, Zn), corrosion resistance (*e.g.* Al, As, Sn) and color (*e.g.* Zn, Ni, Sn) [2].

Lead is frequently added to copper alloys to increase brass machinability and pressure tightness. The solubility of lead in copper alloys is very low and for that reason it is found in microstructure as dispersed globules all over the material. It act as a lubricant decreasing the friction coefficient between tool and the material, creating discontinuities that promote chips fragmentation, reducing the cutting force and tool wear.

In fact, as a consequence of its high toxicity and unhealthy effects for humans, high toxicity of lead caused a strong tendency to eliminate lead from all products being in contact with humans, especially plumbing fittings [3].

Tin added to brass makes rise in strength and corrosion resistance than conventional brass alloys. Also reduces susceptibility of selective leaching of zinc from the brass leaving a porous copper structure, dezincification. To some extent, it does not change machinability, in spite of color improving [4].

## 2. Experimental work

The selected copper material was electrolytic tough pitch high conductive copper, and its chemical composition was 99.99 wt % Cu. High grade zinc ingots with purity 99.99 wt % Zn, high purity lead metal with 99.99 wt % Pb, and commercial grade Tin with 99.99 wt% Tin were used.

In the present study; two brass alloys with different chemical composition were laboratory made, coded (B0, B1) brass alloy. Copper content that represent the main part of all investigated alloys was varying from (59- 59.5) wt %. Different amounts from lead and iron were added to conventional brass alloy (B0) and tin added to other alloy (B1).

Eight samples were cast in the form of cylindrical shape for each alloy for tensile test with dimensions (height 185 mm and diameter 14 mm), half of them to be tested in as-cast condition and the other half in heat treated condition (annealing). Two bars with rectangular cross section shape with dimensions (length 210 mm, width 40 mm and thickness 30 mm) for other tests, *e.g.* chemical analysis, microstructure, hardness, machinability and compression test were cast. All investigated brass alloys were prepared in Central Metallurgical Research and Development Institute (CMRDI) Laboratories using conventional melting and casting techniques.

Each prepared alloy weights approximately 3000 g. Melting of high grade purity copper was done firstly in an electrical wire resistance furnace crucible type (Nabertherm, Germany), when copper was completely melted at 1300ºC. The calculated amount of zinc was added, and then the melt temperature was decrease to 1100ºC followed by adding the other elements. When the melt composition was finished, the flux was spread over the melt surface before pouring by 10 minutes.

The chemical composition of alloys produced in this work determined by atomic absorption (Spectro max-x) apparatus in which produce the corresponding chemical analysis in wt%. Annealing heat treatment process was done in muffle furnace (Linne, Germany) with accuracy ±5 °C, by heating the samples to 850 °C for 2h and then furnace cool. Hardness values were determined by Vickers hardness tester (HBV-30A Huaying testing instrument Co. Ltd. Laizhou, China).

Microstructures of investigated brasses have been examined by optical microscope (OM) (Olympus BX41M, Japan). The surface preparation procedures of the test samples were grinding using emery papers (200, 400, 600 and 800) grit from Sic abrasive papers, successively, and then polishing them with alumina powder slurry with grain size (1 µm and 0.5µm) using a low speed polishing machine. And finally, Etching was occurred by immersing all brass alloys samples in solution of 25 ml HCl, 25 g $FeCl_3$ and 100 ml distilled water.

Machinability test was carried out using high speed precision Jessy champion lathe; model Cp 1550Vs, and compression test were conducted in Shimadzu universal testing machine.

## 3. Results and Discussion

### 3.1. Chemical analysis

The chemical analysis of investigated alloys was examined and performed at room temperature on atomic absorption (Spectromax- x). The average value of three sparks on each sample was taken. Precision of this apparatus was 0.15 wt% for Cu content and 0.004 wt% for other elements.

Table 1. Chemical composition of investigated brass alloys, in wt%.

| Alloy code* | Zn | Pb | Sn | Fe | Bi | Se | Al | Cu |
|---|---|---|---|---|---|---|---|---|
| B0 | 37.67 | 2.21 | 0.26 | 0.289 | 0.002 | 0.001 | 0.033 | Rem. |
| B1 | 37.50 | 0.09 | 3.30 | 0.003 | 0.001 | 0.001 | 0.096 | Rem. |

* Letter B denote to brass while the number signify to the alloy

B0-alloy is a conventional brass alloy which contains 2.2 wt% Pb and 0.289 wt% Fe. While B1-alloy is approximately Pb and Fe free, but contains higher Sn (3.3 wt %) and Al (0.096 wt %).

### 3.2. Microstructure study

3.2.1: Microstructure of as-cast brass alloys

The optical microstructure of (Cu-Zn) brass alloy samples were investigated at the central part of casting rods with Φ 25 mm using Olympus optical microscopes model BX 41 M.

The microstructure of as-cast brass alloys is presented in Fig.1 with two magnifications; the higher magnification (500 x) is to clarify the difference between the existing phases in each alloy.

The microstructure of B0-alloy consists mainly of white phase which is α (Cu), when zinc content was maintained 40 wt% and black phase which is β ′ when zinc- content increases more than 40 wt% and less than 60 wt%. Metallographic evaluation showed that the microstructure of the B0-brass alloy consisted of a mixture of (α + β′) phases as can be seen in Fig.1 (a and c).

The (α) phase, i.e., Cu-Zn phase is a solid solution with a face-centered cubic crystal lattice in which exhibits high cold workability. The presence of β′ ordered phase that transformed from random (β) phase at 454 ºC, improves hot workability of brass alloys and at the same time contributes to its quasi-static strength. More specifically, in binary Cu-Zn alloy systems, β ′-phase volume percentage is mainly controlled by Zn content and casting processing.

The brass alloy matrix is strengthened by addition of iron in B0 brass alloy and an increase in the area fraction of the hard beta phase making alloy is harder and more brittle [5].

In brass alloy B1 high tin content (3.3 wt%) is responsible for eutectoid structure with the formation of a hard phase γ (Sn) as detected in Fig.1(d).

### 3.2.2: Microstructure of heat- treated brass alloys (annealed at 850 $^{o}$C).

When the studied alloys were subjected to annealing at 850 $^{o}$C for 2h and furnace cooled, no big change take place for B0-alloy only α-Cu phase became coarser in width and smaller in length, i.e., attempted to decrease its surface energy, as can be seen from comparing Fig.1(a, and c) and Fig.2(a, and c).

In the B1-alloy, γ (Sn) phase precipitated in globules shape and uniformly distributed in the matrix after annealing and grain boundaries were approximately disappeared, see Fig. 1(b, and d) and Fig.2(b, and d) [6].

These changes in microstructure have big influence on hardness properties, machinability and in turn to compression as will be discussed later.

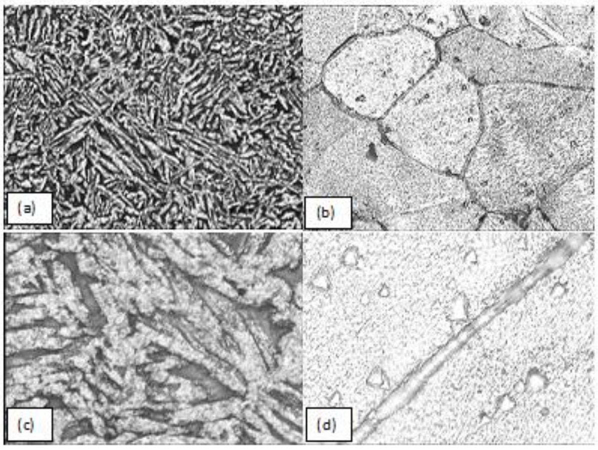

Fig.1. Microstructure of investigated as-cast brass alloys (a, c) B0-alloy, and (b, d) B1-alloy at mag. 100 x and 500x, respectively.

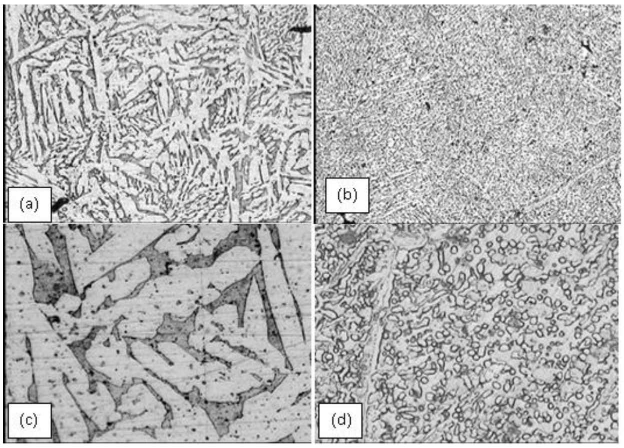

Fig. 2: Microstructure of studied heat- treated brass alloys: (a, and c) B0-alloy and (b, and d) B1-alloy at mag. 100x and 500 x), respectively.

### 3.3. Hardness test

The variation in hardness values of investigated alloys in as-cast and heat treated conditions is tabulated in Table 2. The increase in hardness value of B1-alloy than B0-alloy in as-cast condition is due to Sn addition. As well known from practice, all yellow brass (copper-zinc) alloys hardness lay between ranges in Vickers hardness (75-110 $HV_5$). Therefore, conventional cast brass alloy B0 code achieves hardness in range of Vickers 95 $HV_5$. But tin addition improves hardness to the maximum 175 $HV_5$, due to solid solution strengthening. Fig.3 shows how hardness was changed with the different investigated alloys. The maximum hardness increase of B1 alloy in as-cast condition reaches about 85% of initial hardness of B0-alloy.

Table 2: Hardness for the studied alloys in as-cast and heat treated conditions.

| Alloy code | Vickers hardness $Hv_5$, MPa | | |
|---|---|---|---|
| | As-cast | Heat treated | Deterioration, $-\Delta Hv_5$ |
| B0 | 95 | 86 | 9.5 |
| B1 | 175 | 165 | 5.7 |

Where: $Hardness\ deterioration\ (-\Delta Hv5) = \frac{Hv\ (as-cast\ alloys) - Hv\ (heat\ treated\ alloys)}{Hv\ (as-cast\ alloys)}\ x\ 100$

From Table 2, it is clear that all hardness values were decreased after heat treatment (annealing). These depressions can be attributed to the softening mechanism of as-cast alloys. At first, stress relief was taken place then at high temperature, the different phases become coarser. All these changes lead to decrease hardness. But the decrease of hardness percent (-Δ Hv) was variable according to alloy code, as can be seen in Table 2 and Fig. 3. The maximum hardness deterioration percent (-ΔHv%) value was observed for B1-alloy (approx..9.5%).

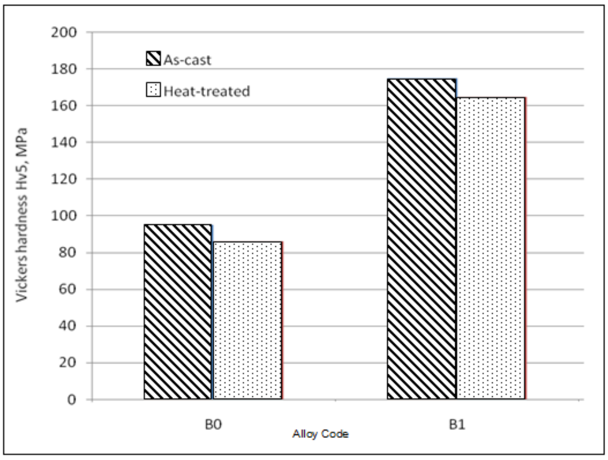

Fig.3. Hardness for the studied alloys in as-cast and heat-treated conditions.

### 3.4. Machinability test

From Fig 4, it was clear that during applying the same cutting conditions on lathe operation, the type of chips removed from alloy specimens were completely different. The specimens of B0-alloy gave very fine crumple chips. That are passable but difficult to clean, see Fig.4.a. Fig.4.b shows the spiral chips produced during machining of B1- alloy specimens, which has an optimum size, moderate tool wear, and easy to collect and remove from the machine.

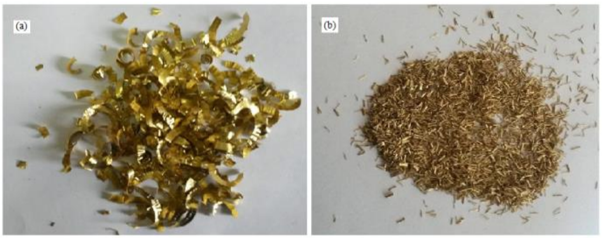

Fig.4: Different swarf types produced during machining of heat treated alloys at the same cutting conditions.

a) fine crumble chips of B0 alloy. b) spiral chips of B1-alloy

Table 3: Results of cold compression test of investigated heat treated brass alloy samples.

| Alloy code | Max. Stress, MPa | Max. Load, kN | Elastic modulus, MPa |
|---|---|---|---|
| B0 | 946.31 | 217.32 | 13031.3 |
| B1 | 1027.82 | 233.29 | 20288.4 |

### 3.5. Compression test

The compression test was done at room temperature on Shimadzu universal testing machine with 100 KN capacity. The specimens of investigated brass alloys in the heat treated condition were tested and the resulted values obtained from the computerized machine are summarized in Table 3. From this table, it is clear that commercial B0-alloy has the lowest maximum stress and elastic modulus.

Specimens of B1 alloy have the highest elastic modulus value. This means that this alloy more brittle than the others but still has higher max. stress than B0 alloy (≈ 9% higher). Finally it can be reported that the two alloys will behave the same behavior especially during upsetting. Therefore, these alloys must be deformed at high temperature (≈ 850 °C) to give the required configuration. Fig. 5 represents the investigated alloy samples after cold compression test.

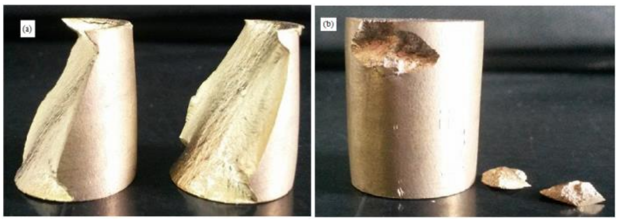

Fig.5. Samples shapes after fractures compression test at different loads and stress as presented in Table 3.

### Conclusions

Based on the results presented in this work on the effect of replacement of Pb by Sn on properties of yellow brasses,

The following conclusions may be drawn.

1- Sn can replace the toxic Pb

2- Addition of (3.3% Sn) gives eutectoid phase with good distribution of γ- Sn in microstructure.

3- Addition of Sn increase hardness by ~ 85% in as-cast condition and by ~92% after heat treatment in comparison with conventional brass.

4- Sn- brass improves Machinability rather than Pb- brass.

5- Sn- brass has ~1.6 elastic modulus (Young modulus) of Pb- brass.

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