The Effect of Tin Contents on As-cast Microstructures and Hardness of Alpha/Beta Brasses

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Abstract
The purpose of this work is to study the effect of tin contents on as-cast microstructures and hardness of alpha/beta brass. Ternary alloys with Cu-Zn-Sn have been melted from pure elements by an electrical furnace. The chemical composition of each alloy has been analyzed by optical emission spectroscopy. Microstructures of the as-cast brass ingots have been reviewed by optical microscopy and scanning electron microscopy including the respective chemical analysis of the phase determined by X-ray energy dispersive spectroscopy (EDS). It could be concluded that, the higher tin contents result in the enhancing of hardness due to changing microstructures. The higher tin contents reveal in the increasing of γ1 phase resulted to increase the hardness.

Keywords: Brass / Microstructure / Heat Treatment / Alloying Element

1. Introduction

Brasses are a rather large family of copper-zinc alloys that are widely used in plumbing and bearing application. Brasses with as much as 35% zinc will be a single phase solid solution from normal casting. Single phase solid solution brass has excellent ductility and cold formability. The zinc contents between 35-40 wt% are a dual phase alpha/beta (α/β) or alpha/beta prime (α/β′) microstructure forms. The alpha is FCC. On the other hand the beta phase is BCC and the β′ phase is an order CsCl-type (CI2) structure [1-3].

The ternary alloys comprised of the copper-zinc-tin are interested since tin can improve strength, corrosion resistance and dezincification in sea water. The common copper alloy, admiralty brass, contains 29 wt%Zn, 1wt%Sn and balance with copper. The rate of diffusion of copper and tin into each other is much lower than it is with copper and zinc leading to a high degree of coring during solidification process. The solubility of tin in α- and β-phases, of copper-zinc system, is a function of zinc content. High tin contents are responsible for the eutectoid structure with the formation of a hard phase, γ1, as a sequence of the reaction β↔α+γ1 [4]. The isothermal sections of the copper-zinc-tin phase equilibrium have been constructed by several authors [5-6]. However, there is a lack of the experimental information about the effect of tin contents in 60 wt%Cu-40 wt%Zn brass on microstructures and hardness. Thus, the experimental investigations are carried out in this study to determine the effect of tin contents about nominal 1-4 wt%Sn on the brass used in the present work containing 39-40 wt%Zn and remaining Cu, which falls under a dual phase with the metallic mould casting.

2. Experimental Procedures

Alloys were prepared by melting high purity copper, zinc and tin (≥99.5 purity) in an electrical furnace with a graphite crucible at the temperature of 1050°C. The molten alloys were poured into a steel mold with a dimension of an ingot being 40 mm width by 100 mm length and 10 mm thickness. The steel mold was preheated at 550 °C. The casting was allowed to cool in the mould for 5 minutes, and then the ingot was exposed to the air cooling.

The analyzed chemical compositions of the as-cast ternary the copper-zinc-tin alloys determined by an optical emission spectrometer model Baird-DV6S were given in table 1. Accuracy of the determinations was ± 0.5% for all elements. All traces elements were detected less than 0.1 wt%. The specimens were mechanically polished and etched with the solution of 5 g. $FeCl_3$ + 5 ml. HCl + 100 ml. H_2O.

Table 1 Analyzed chemical compositions of Cu-Zn-Sn alloys.

Alloy Number	Analyzed Compositions (wt%)			
	%Cu	%Zn	%Sn	Traces
1	Remaining	40.1	0.8	<0.1
2	Remaining	39.6	1.9	<0.1
3	Remaining	39.0	2.4	<0.1
4	Remaining	39.1	3.8	<0.1

The characteristics of the microstructure of the as-cast brass ingots have been reviewed by optical microscopy and scanning electron microscopy (SEM) including the respective chemical analysis of the phase determined by X-ray energy dispersive spectroscopy (EDS).

Hardness of the as-cast ingots were measured by the standard test methods for Rockwell hardness scale B method (ASTM E18-03) with the GALILEO machine model COMP 25 RS. The hardness values were calculated by averaging 5 impressions.

3. Results and Discussion

3.1 Microstructures

The microstructures of the present alloys mainly consist of alpha and beta phase according to the copper-zinc binary equilibrium phase diagram illustrated in fig. 1. The alpha and beta phases are solid solution.

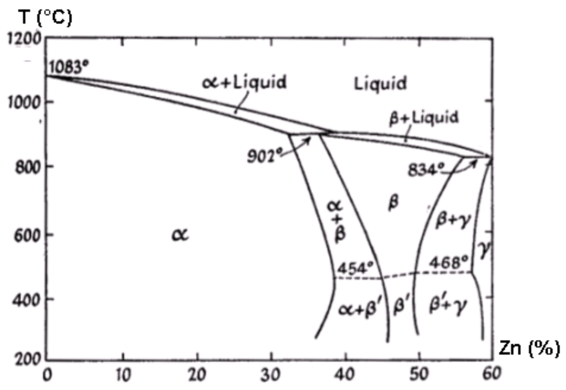
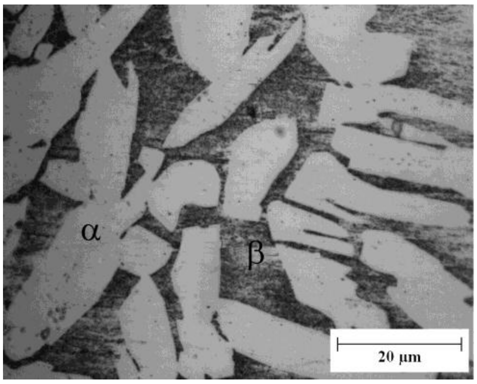
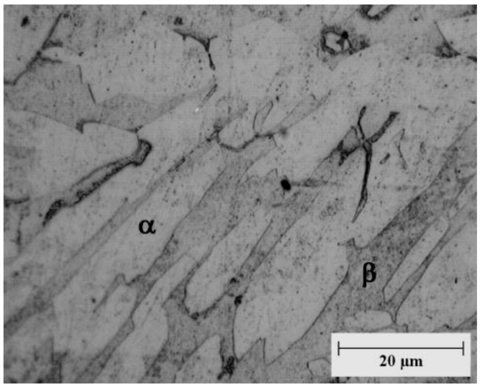


Fig. 1 The Cu-Zn binary equilibrium phase diagram.

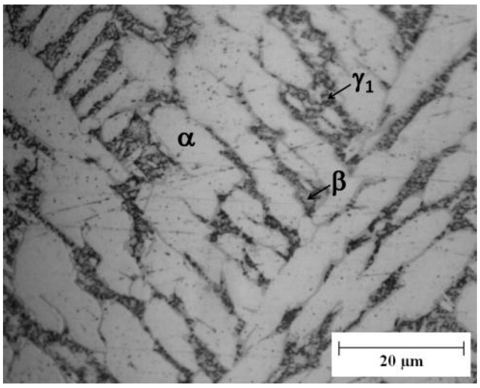
The optical microstructures of all as-cast alloys are shown in fig.2. Tin additions to copper-zinc alloys take part in raising the volume fraction of beta phases in the dual structures, leading to develop the γ1 phase and get the smaller dendrite structure [4].



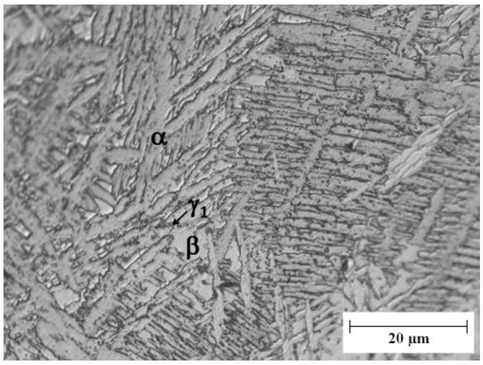
(a) Alloy 1



(b) Alloy 2



(c) Alloy 3



(d) Alloy 4

Fig. 2 Optical micrographs of the as-cast samples.

A small amount of the γ1 phase presents in alloys are hardly observed by an optical microscope. In contrast, SEM micrographs of all as-cast samples show in fig. 3. With higher magnification in SEM micrographs of alloys 3 and 4, it can be obviously revealed the fine round precipitates in the beta phase. The result is in accordance with the previous work. Higher tin contents are responsible for the eutectoid structure with the formation of hard phase, γ1, at the interdendritic dendrite of the beta phase [4].

The chemical analysis of the phase was determined by EDS at the specific three sites on alloy 4 (fig. 3d) as shown in table 2. Three spectrums of the compositions in specific three sites show in fig.4.

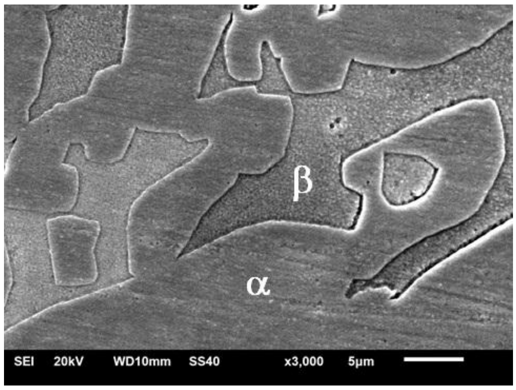
Table 2 The phase chemical analysis by EDS.

Spectrum	Element (wt%)			
	Cu	Zn	Sn	Total
Spectrum 1, α phase	63.6	35.4	1.0	100.0
Spectrum 2, β phase	56.3	40.9	2.8	100.0
Spectrum3, γ1 phase	55.0	36.9	8.1	100.0

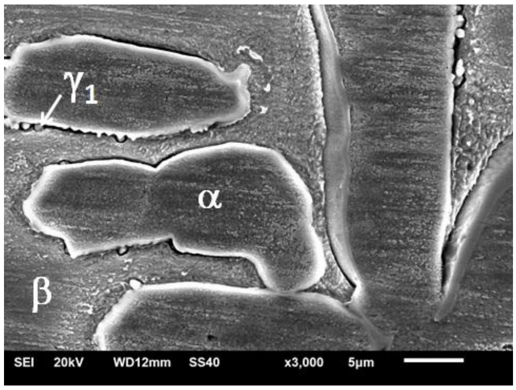
From the chemical analysis, it can be seen that there are three elements of copper, zinc and tin in each site but there are different in the contents. Spectrum 1 is the solid solution alpha phase which is the first solidified containing of the 63.6wt%Cu-35.4wt%Zn-1.0wt%Sn.

Spectrum 2 is analyzed on a very fine round intermetallic phase containing the composition of 55.0wt%Cu-36.9wt%Zn-8.1wt%Sn, which is likely to be the γ1 phase. Due to the tiny nearly round precipitates of γ1 phase (about 2-3 micron width), the chemical composition is normally to be interfered with the matrix. Tin content in the γ1 phase is higher than those in both of the alpha and beta phases. However, this result is in agreement with the other previous work which reveals the tin content in the γ1 phase containing of 51.3wt%Cu-36.6wt%Zn-12.1wt%Sn and play a role in refining the dendrite structure [6].

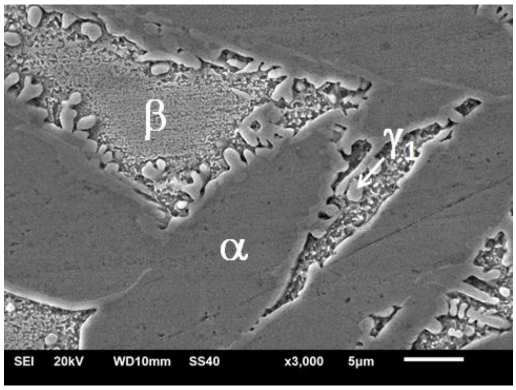
Spectrum 3 is the solid solution beta phase containing the composition of 56.3wt%Cu-40.9wt%Zn-2.8wt%Sn. It shows that a small amount of tin can be completely soluble in copper and form solid solution with copper.



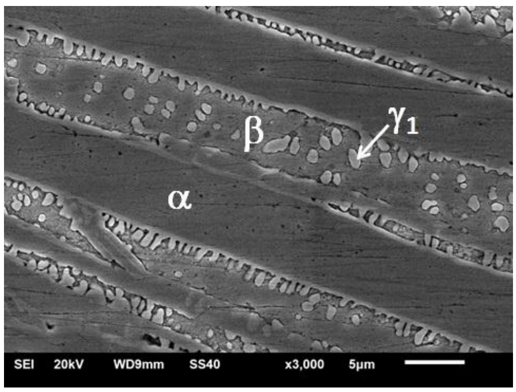
(a) Alloy 1



(b) Alloy2

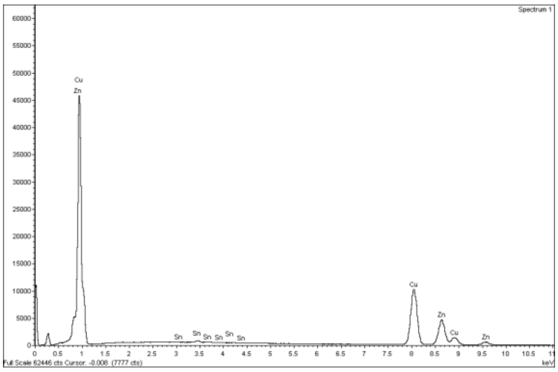


(c) Alloy 3

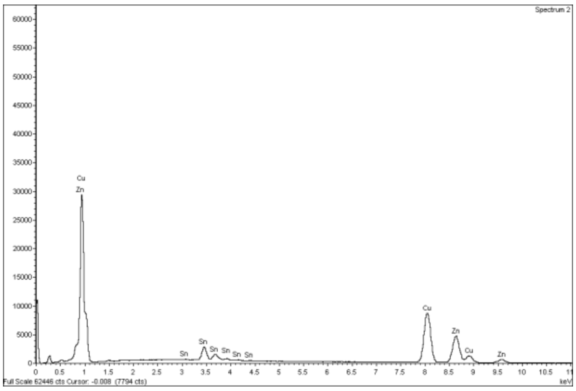


(d) Alloy 4

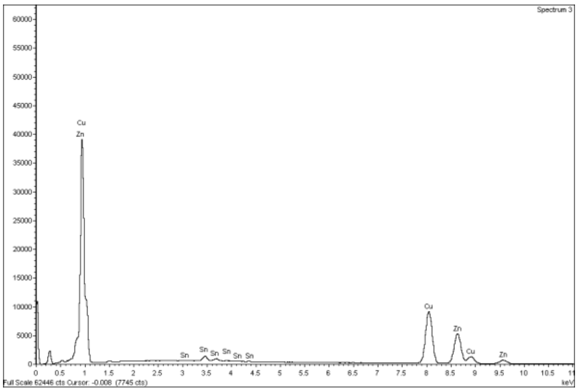
Fig. 3 SEM micrographs of the as-cast samples.



(a) Spectrum 1, alpha phase



(b) Spectrum 2, γ1 phase



(c) Spectrum 3, beta phase

Fig. 4 EDS analysis on three sites.

Moreover, the element distribution not only depends on its composition variation but also cooling rate of casting. In the present work, the metallic permanent mold was used to cast ingots, so the cooling rate was definitely different from equilibrium. Therefore, the cooling rates, at which the alloy is solidified, control the microstructures of the cast products.

The binary equilibrium phase diagram of the copper-tin binary alloys shows in fig.5 [3]. At the room temperature, it should be found the alpha + epsilon (α+ε) phase, but in these experimental results the ε phase is not being observed. The epsilon phase is orthorhombic corresponds to the formula Cu_3Sn. It is formed under equilibrium conditions at 350°C by the slow eutectoid transformation of delta (δ) phase, to alpha + epsilon [3, 6]. Therefore, this is the reason to describe that this experimental result cannot be found epsilon phase.

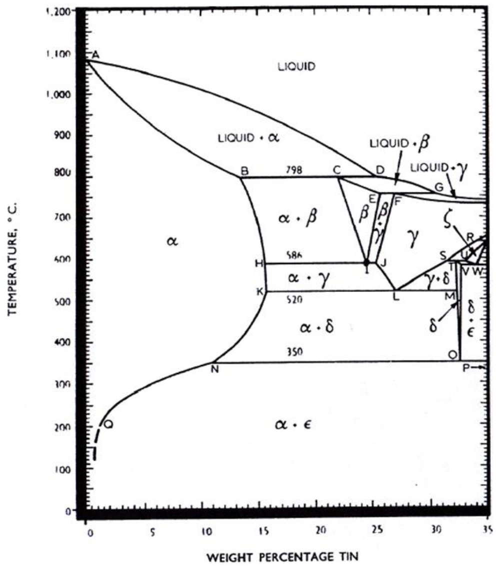


Fig. 5 The binary equilibrium phase diagram of the Cu-Sn binary alloys [3].

The copper-zinc binary alloys equilibrium diagrams are modified when other elements are added. Vilarinho et al [6] revealed the isothermal section at various temperatures. Concerning the chemical composition of the beta phase, it strongly changes with temperature, both of tin and zinc contents. In this literature, the existence of the ternary phases (α, β and γ1) was published by isothermal section at 350ºC calculated by statistical treatment of the results obtained in homogenization experiments including point out the present studied compositions for four alloys as shown in fig. 6 [6].

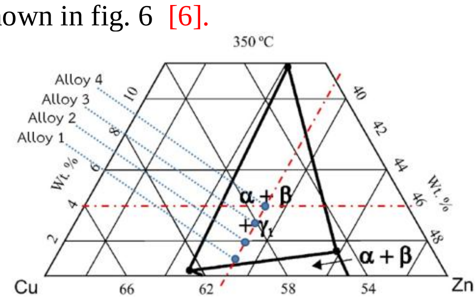


Fig. 6 Isothermal section of copper-zinc-tin system at 350ºC [6].

This result could be confirmed that the ternary phases were observed at room temperature for alloys containing tin content of 2-

4 wt%. Unfortunately, isothermal section at the room temperature could not be published. However, the alloy containing tin 1 wt% shows only alpha and beta phases.

3.2 Hardness

The hardness of the as-cast samples shows in table 3. It is to be noted that the higher tin contents result in the enhancing of hardness due to changing microstructures. Solid solution strengthening mechanism and distribution of fine intermetallic compounds are involved to promote the hardness. Theoretically, tin is reasonably large atom and fills the entire available at the boundary of the beta phase resulting to encourage the longer dendrite and well refine [7-9]. The higher tin contents reveal in the increasing of γ1 phase, result to increase the hardness.

Table 3 Hardness of the as-cast samples.

Alloy Number	Averaged Hardness (HR_B)
1	46.2
2	61.3
3	76.5
4	88.2

However, very small voids could be found in some area of the as-cast samples as shown in fig 7. It is a general defect in atmosphere casting. So, the mechanical properties have not been measured yet. Degasing process may be more carefully concerned to remove the small voids in the cast samples. Thus, the further study on mechanical property of samples with no defects will be investigated.

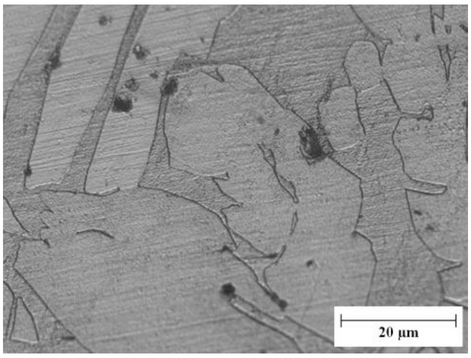


Fig. 7 Optical micrograph of voids in some area of the as cast sample.

4. Conclusions

The results in this work enabled to indicate the effect of tin contents on the as-cast microstructures and hardness of alpha/beta brass. The higher tin contents result in the enhancing of hardness due to changing microstructures. The higher tin content reveals in the increasing of γ1 phase resulted to increase the hardness.

5. Acknowledgement

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6. References

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