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# Research of Aluminium Influence on Tin Bronzes

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## Abstract

During the research a group of copper and tin alloys was investigated. The influence of variable additions of aluminium within the range of 0.3 – 1.4 wt % was analysed on tin bronze CuSn10 with the aim of obtaining durable bronzes, from outside the normalized copper alloy groups.
Melts were conducted in order to obtain alloy samples for testing the chosen properties. Metallographic and SEM-EDS tests were carried out to determine the microstructure changes caused by introducing Al addition to CuSn10 alloy. Also, chosen mechanical properties were tested for the alloys investigated.
The results showed considerable changes in the microstructure as well as significant hardening of the Cu-Sn alloys as the result of aluminium addition. The thermal and dilatometric analysis confirmed the presence of phase changes, also their parameters were assessed depending on the share of aluminium addition in the CuSn10.
The aluminium additive applied within the range of 0.3-1.4 wt% to CuSn10 bronze clearly impacted the microstructure and the strength properties analysed, causing the increase in strength and hardness with simultaneous insignificant decrease of elongation of the CuSn10Al alloys.

**Keywords**: Durable alloys, Tin bronzes, Mechanical properties, Metallography, Microstructure

## 1. Introduction

Within a numerous group of copper alloys used for manufacturing of machine parts for the industry sector, an important subgroup consists of copper and tin alloys, so called tin bronzes. In technical copper alloys, the content of tin varies from 2% to over 20%. The percentage of tin in tin bronzes mainly influences their strength, technological properties and usability, but also, because of high prices of the main alloying element (tin), the possibilities of this alloy application for machine parts. The optimal strength and technological properties characterise CuSn alloy, having been used for a long time. That is the reason why, in order to increase the chosen properties of this group of alloys, other alloying additives are introduced, such as zinc, lead, phosphor, nickel, iron and others. Important issues described in scientific literature and applied in the process of running casts of copper alloys is purifying and refining them [1--10], which ensures obtaining high and repeatable mechanical properties and faultless casts. Tin bronzes are characterised by good castability and machinability, resistance to significant static and dynamic load, corrosion, abrasion and the possibility to work in raised temperatures up to 280 $^{o}$C. Apart from these favourable properties, tin bronzes show a broad range of solidifying temperatures, which is connected with their propensity for dendritic segregation [11, 12].

Advanced studies on the influence of alloying additives on the properties and microstructure of copper and copper alloys (tin bronzes included), have been conducted for many years at the *Foundry* Department of *Non-Ferrous Metals at the Foundry. Faculty* of *AGH*, the University of Science and Technology, in *Krakow*. Alloys of Cu-Sn, and even more Cu-Sn-Al ones, show complex microstructure with many phase changes in solid state [6-7, 13, 14]. The results obtained so far point to the beneficial influence of insignificant additions of aluminium in copper and tin alloys, especially in CuSn10 and CuSn15 [14]. A heightened tensile strength and hardness have been achieved with an insignificant lowering of plasticity. An addition of 5 wt % of aluminium causes lowering of the high mechanical properties. The research of CuSn alloys with aluminium conducted so far requires further analysis, especially with the help of X-ray microanalsis, thermal and thermodynamic analysis as well as assessing technological, e.i. casting properties, from the perspective of strengthening mechanisms and optimization of aluminium additions, and also of the possibility of broadening the applicability of CuSnAl alloys in modern engineering.

## 2. Scope and methodology of research

As part of the research the normalised CuSn10 alloy conforming to PN-91/H87026 (EN 1982) was analysed, containing from 9-11% of tin and up to 0.5% of lead. To the base alloy, on the grounds of the previous research, experimentally determined varied amounts of aluminium were added, in the subsequent experimental melts: 0.3% (No 3), 0.8% (No 4), 1.0 % (No 5), 1.4% (No 6).

The charge material were CuSn10 copper ingots and aluminium AR1 (PN-EN 573-3). The melts were conducted in an induction electric furnace, of medium frequency, in a chamotte-graphite crucible. During the melt a protective layer of charcoal was used. During the melt samples were taken for the research. The alloy was cast into metal moulds preheated up to 200÷250$^{o}$C.

For the obtained alloys, control tests of chemical composition, microstructure and mechanical properties were made, as well as a thermal analysis. Their chemical composition was tested with the help of spectroscopy. The microstructure was analysed using light and scanning microscopy, the chemical composition in microareas was also tested. The hardness was tested using Brinell method, also the strength was measured. Additionally, for the samples coming from the successive melts, the thermal and dilatometric analyses were made. The tests were conducted in line with casting practice and the required norms.

## 3. Chemical composition and microstructure analysis

The chemical composition of the obtained alloys (tab.1) was determined with the help of spectrometry and X-ray fluorescence (XRF). The analyses confirmed the correctness of the melts and the correspondence of the obtained alloys to the experiment plan.

Table 1.
Chemical composition of the researched Cu-Sn-Al alloys (wt.%)

| Alloy | No 0 | No 3 | No 4 | No 5 | No 6 |
|---|---|---|---|---|---|
| Cu | 89.0 | 88.61 | 88.54 | 88.24 | 87.85 |
| Sn | 9.95 | 9.93 | 9.87 | 9.91 | 9.85 |
| Al | 0.00 | 0.30 | 0.80 | 1.00 | 1.40 |
| Zn | 0.24 | 0.21 | 0.14 | 0.20 | 0.16 |
| Pb | 0.49 | 0.48 | 0.48 | 0.49 | 0.46 |
| Ni | 0.12 | 0.03 | 0.04 | 0.05 | 0.05 |
| Others | 0.20 | 0.20 | 0.10 | 0.20 | 0.20 |

The research of tin bronze microstructures allowed to observe the change in size and layout of the microsctucture components, which happened as the consequence of aluminium additions to the CuSn10 alloy. The results of metallographic tests are presented in figs. 1 - 6. The samples were etched with Mi15Cu reagent, according to the atlas [15].

The images of microstructures presented in figure xx show clearly developed dendrites of solid solution α. In the interdendritic spaces there are precipitates of α + ε eutectoid mixture. The grain boundaries show themselves distinctly by changing the direction of the main dendrite axes in individual areas.

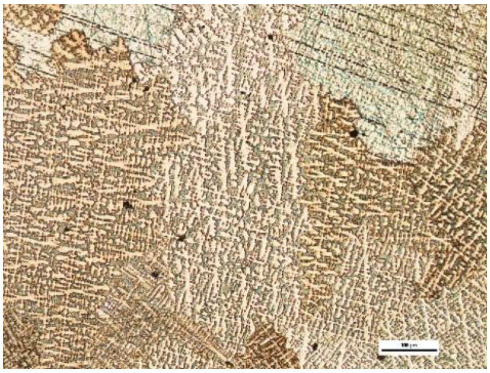


Fig. 1. CuSn10 (No 0) microstructure, 50x

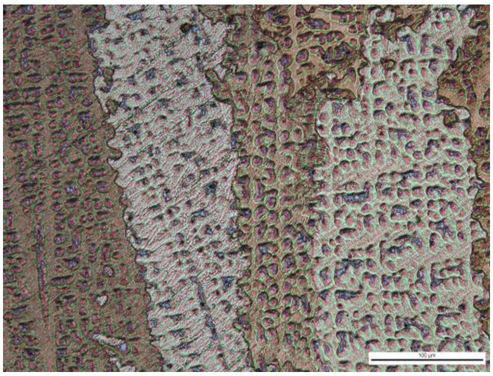


Fig. 2. CuSn10Al0.3 (No 3) microstructure, 200x

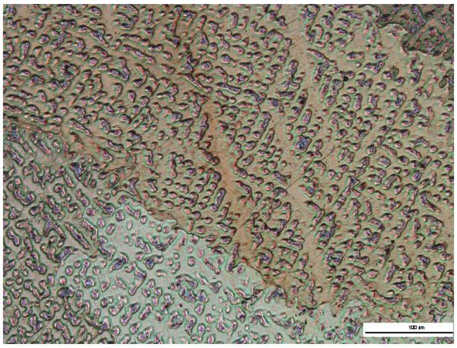


Fig. 3. CuSn10Al0.8 (No 4) microstructure, 200x

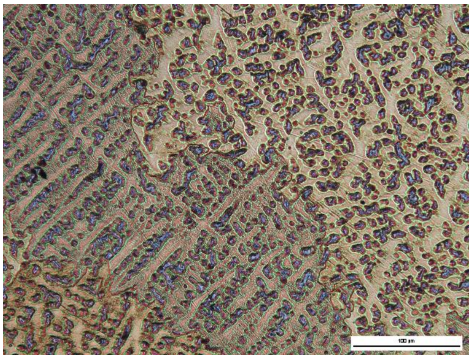


Fig. 4. CuSn10Al1.0 (No 5) microstructure, 200x

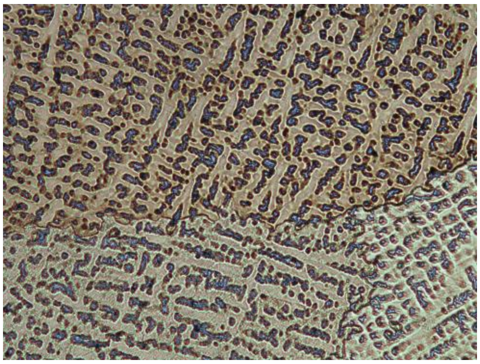


Fig. 5. CuSn10Al1.4 (No 6) microstructure, 200x

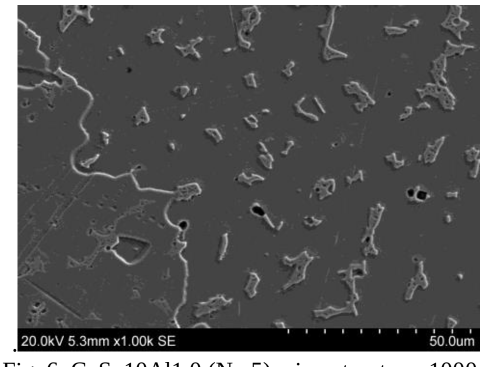



Fig. 6. CuSn10Al1.0 (No 5) microstructure, 1000x

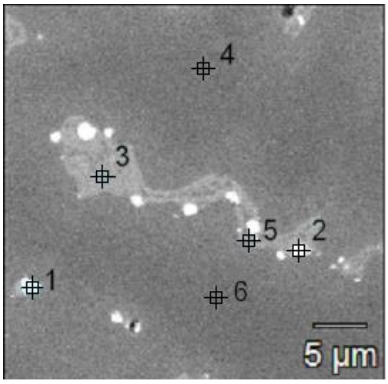
The microstructure of CuSn10 alloy with the addition of aluminium shows a characteristic dendritic structure. The grain outline is visible at the direction change of the main dendritic axes. In the alloy microstructure, there can be observed the tin solid solution in copper (α), and eutectoid mixture (α+ ε).

Clear changes of microstucture resulting from introducing into the alloy the aluminium additives become clearly visible above 0.8 wt %, this is only with the samples containing 1.0 and 1.4 wt % of aluminium. With a higher content of aluminium, clear grain boundaries disappear in the alloy, which can point to an increasing grain size or smaller content of dendritic precipitates of solid solution α.

The content of dendrites in the analysed group of alloys clearly diminishes in step with the increased amount of aluminium; instead there is greater share of intermetallic precipitates and eutectoid mixture. It is clear that the changes visible in the microstructure of the analysed CuSn alloy group with variable Al additions lead to the change of mechanical properties of the bronzes under investigation.

# 4. Scanning microscopy analysis

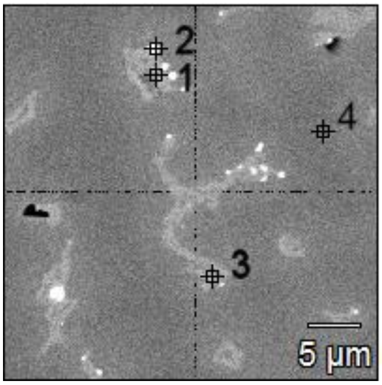
Testing the chemical content in microareas was conducted with the help of SEM scanninig microscope with the analysing EDS unit. The results of the tests conducted are presented in the figures 7-10.




| pt | Al | Cu | Sn | Pb |
|---|---|---|---|---|
| 1 | 0.26 | 41.37 | 8.65 | 49.73 |
| 2 | | 13.79 | | 86.21 |
| 3 | | 68.55 | 31.45 | |
| 4 | 0.69 | 94.85 | 4.46 | |
| 5 | | 81.76 | 18.24 | |
| 6 | 0.76 | 95.29 | 3.95 | |

Fig. 7. SEM-EDS of the CuSn10Al0.3 alloy (No 3), 3500x (wt.%)

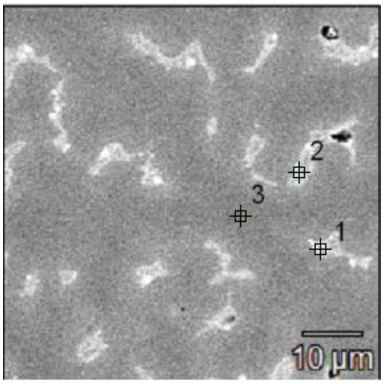
In the CuSn10Al0.3 microstructure (No. 3, fig. 7), in the dendrite axes there is the highest copper concentration (94.85-95.29%), with small contribution of tin (3.95-4.46%). In the solution there are small amounts of aluminium present (0.69-0.76%). In the interdendritic spaces there are eutectoid precipitates type α (Cu)+ε($Cu_3Sn$). Against the microstructure there are visible characteristic spherical, white precipitates of lead.




| pt | Al | Cu | Sn | Pb |
|---|---|---|---|---|
| 1 | 0.30 | 68.71 | 30.99 | |
| 2 | 0.34 | 42.30 | 18.05 | 39.31 |
| 3 | 0.41 | 74.75 | 23.64 | 1.20 |
| 4 | 1.28 | 93.33 | 5.38 | |

Fig. 8. SEM-EDS of the CuSn10Al0.8 (No 4) alloy, 3500x (wt.%)

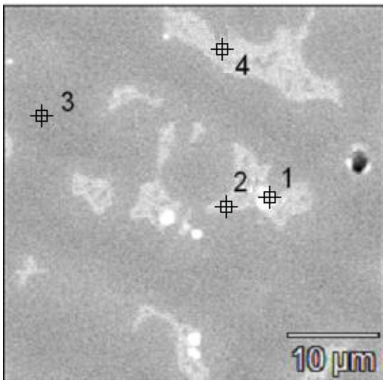
In the CuSn10Al0.8 sample, (No4, fig. 8) the highest share of copper was found in the dendrite axis of the solid solution (3.33%), with smaller share of tin (5.38%). The share of aluminium in the solution is 1.28%. In the interdendritic spaces there are eutectoid precipitates α (Cu)+ε($Cu_3Sn$) present, with a small concentration of Al, between 0.3 – 0.4%.




| pt | Al | Cu | Sn | Pb |
|---|---|---|---|---|
| pt1 | | 74.73 | 25.27 | |
| pt2 | 0.29 | 33.11 | 13.05 | 53.55 |
| pt3 | 1.78 | 94.56 | 3.66 | |

Fig. 9. SEM-EDS of the CuSn10Al1.0 (No 5) alloy, 3000x (wt.%)

In the CuSn10Al1.0 alloy microstructure (No5, fig. 9), the Al addition at the level of 1.78% is part of the tin solid solution (3.66%) in copper (94.56%). The α(Cu)+ε($Cu_3Sn$) precipitates in the interdendritic spaces show a small share of Al (0.29%). There are also lead precipitates visible.




| | Al | Cu | Sn | Pb |
|---|---|---|---|---|
| pt1 | | 9.55 | | 90.45 |
| pt2 | 1.34 | 86.53 | 12.13 | |
| pt3 | 2.33 | 94.08 | 3.59 | |
| pt4 | 0.65 | 73.36 | 25.99 | |

Fig. 10. SEM-EDS of the CuSn10Al1.4 (No 6) alloy, 3000x (wt.%)

The concentration of copper in solid solution is 94.08%, with the tin content at the level of 3.59% and aluminium at 2.33% (No 6, fig. 10). In the interdendritic spaces the presipitates of α (Cu)+ε($Cu_3Sn$) type contain an addition of Al between 0.65 to 1.34%.

Also, characteristic precipitates of lead are visible in the alloy microstructure.

# 5. Mechanical tests of Cu-Sn alloys

The alloys were subjected to further tests in order to assess the changes in the basic mechanical properties, this is HB hardness, $A_5$ elongation and $R_m$ tensile strength, in accordance with normalized methodology. The results of the conducted tests are presented in table 2 and graphically in figs. 11-12.

Table 2.
Results of mechanical tests of CuSnAl alloys

| No | Alloy | $R_m$ [MPa] | $A_5$ [%] | HB |
|---|---|---|---|---|
| No 0 | CuSn10 | 230 | 14 | 105 |
| No 3 | CuSn10Al0,3 | 326 | 20 | 107 |
| No 4 | CuSn10Al0,8 | 320 | 18 | 113 |
| No 5 | CuSn10Al1,0 | 323 | 15 | 128 |
| No 6 | CuSn10Al1,4 | 342 | 12 | 118 |

The obtained results point to the beneficial influence of small aluminum additions in the analyzed group of copper with tin alloys. Primarily, a significant increase of tensile strength and hardness were obtained.

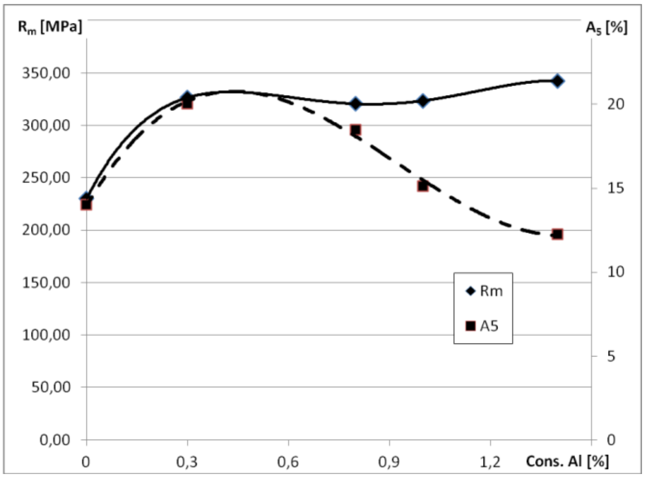



Fig. 11. Plot of $A_5$, $R_m$ mechanical properties

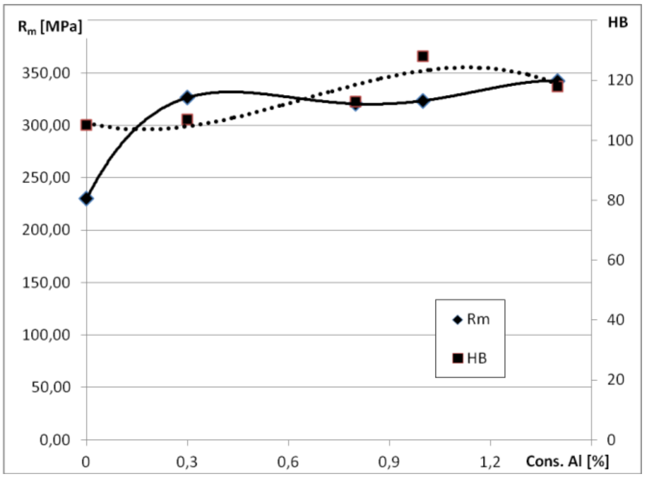



Fig. 12. Plot of HB, $R_m$ mechanical properties

# 6. Thermal tests

In order to analyse the kinetics of phase changes, which is accompanied by sudden changes of physical properties, thermal and dilatometric analyses were conducted.

The recorded results show phase transitions in the form of peaks in the DSC/T chart.

Owing to the tests it is possible to evidence slight structural changes in the material, depending on the temperature. An exemplary DSC/T curve for the CuSn10Al1 together with transition temperatures is shown in fig. 13.

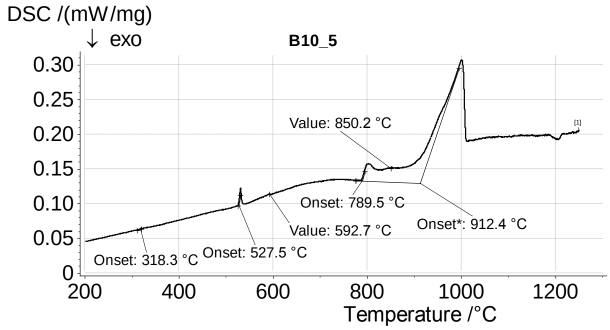



Fig. 13. DSC/T curve for the CuSn10Al1

# 7. Conclusions

The aluminium addition applied in the CuSn allys is a very active element. It can cause both deoxidation, as well as, in larger amounts, it influences microstructure changes, and at the same time, the properties. The obtained results show that introducing even small amounts of aluminium into CuSn10 alloy, causes grain size reduction. The 0.3 – 1.4 wt% of aluminium introduced into the CuSn10 bronze locates itself both in the solid solution α crystallites and in interdendritic precipitates. With the addition of aluminium above 1%, in the microstructure of the analysed alloys, a decrease of solid solution α dendrites and an increase of α (Cu)+ε($Cu_3Sn$) eutectoid mixture and intermetallic phases in interdendritic spaces can be clearly observed.

The aluminium addition influences the mechanical properties of the CuSnAl alloys analysed.

The results show that small aluminium additions cause grain size reduction and, thereby, they strengthen the alloy increasing its tensile strength.

Aluminium additions from 0.8 wt% increase hardness, lower elongation with a simultaneous slight increase of the $R_m$ strength. Dilatometric analysis accompanying the research confirm the presence of many phase transitions in solid solution and encourage the authors to perform further, more detailed analysis of CuSnAl alloys.

Obtaining a casting alloy with optimal properties demands continuation of the research and assessing such properties as castability, tendency for hot cracking, shrinkage porosity, impurities content and other properties, which will be the subject of further work and publications.

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