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# MICROSTRUCTURAL AND MECHANICAL CHARACTERIZATIONS OF THE BRONZE ALLOY CUSN8ZN4PB1 COMMONLY USED IN BEARINGS

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**Abstract.** *The microstructural and mechanical analyses of the CuSn8Zn4Pb1 alloy contribute to the current parameters for using the material, paving the way for new applications with the economic and environmental feasibility of this alloy, also known as SAE620. This material is widely used in the metal-mechanical segment due to characteristics related to wear resistance and corrosion resistance provided by adding tin to strategic content from a metallurgical point of view. Also known as "tin bronze", this alloy is commonly used as high-loaded bearings. With the development of this study, value and knowledge are added to the low-lead copper alloy. Based on this context, microstructural and hardness mechanical test characterizations of the alloy were carried out to assess its initial condition, promoting the discussion of possible responses in service. Analysis was carried out given the chemical composition, optical microscopy, and hardness tests, allowing the investigation of the microstructural characteristics, grain size, inclusions and phases, and Brinell hardness. In addition, the composition of the material was evaluated using the method of OES and X-ray fluorescence spectrometer. The results allow the use of the material in future tribological systems tests, presenting important definitions for the stages of the manufacturing process.*

**Keywords:** *Copper, Microstructural characterization, Tin bronze, failure analysis, copper alloys.*

## 1. INTRODUCTION

Bronze is a copper alloy whose historical importance, due to its relatively low melting point, meant that man could build clay molds early on (Finley, 1970). With the development of the technique, new components were created, from small decorative pieces to war components (glaive and shield covers). Bronze over the years went from being used only in ornamental and war pieces to having a wide application in mechanical components.

The addition of lead to copper alloys is intended to increase machinability. Lead does not combine with copper, zinc, or any secondary alloying element. It is present in these alloys in the form of globules that are randomly distributed within the brass microstructure.

The decision to select the CuSn8Zn4Pb1 alloy with low lead content, despite the wide recognition of lead toxicity (Pb) and its progressive ban on metal alloys, requires a sound technical and contextual analysis. It is common to find alloys with a higher lead content in traditional dry contact applications, but choosing to research a low-lead alloy has important implications for industry and the environment, Brass has several attributes that make it almost indispensable in industrial production (Hutchinson, 2016). Typically, alloys with high lead content are preferred in applications due to their self-lubricating properties (Molian et al., 1991). However, research on low-lead alloys, such as CuSn8Zn4Pb1, is crucial for several reasons. First, it paves the way for more sustainable alternatives, aligned with growing environmental concerns and restrictive regulations (Thomson et al., 2010). This choice demonstrates a commitment to environmental responsibility. In addition, CuSn8Zn4Pb1, with its low lead content, often finds applications in environments using lubricant oil. This alloy can withstand challenging conditions, providing exceptional mechanical properties (Equey et al., 2011).

Conducting an approach focused on the strength and good mechanical qualities of this alloy is relevant to assessing its viability in wider applications. By adopting a research approach that includes tribological dry contact tests sequential to this study, we are exploring the potential application of CuSn8Zn4Pb1 in situations where conventional lubrication is limited. This can represent a significant breakthrough for sectors seeking greener and more effective solutions. Choosing to investigate CuSn8Zn4Pb1, with its low lead content, not only contributes to the understanding of low-lead alloys but also sheds light on promising and ethical prospects for the future, where more sustainable alloys with low lead content can be applied in projects without the need for lubricating oil.

The microstructure of the CuSn8Zn4Pb1 alloy typically consists of a uniform distribution of stain phases dispersed in the copper matrix (ASM Metals, 1992.) The distribution and size of these phases could be influenced by the cooling rates employed during solidification, exemplified in Figure 1.

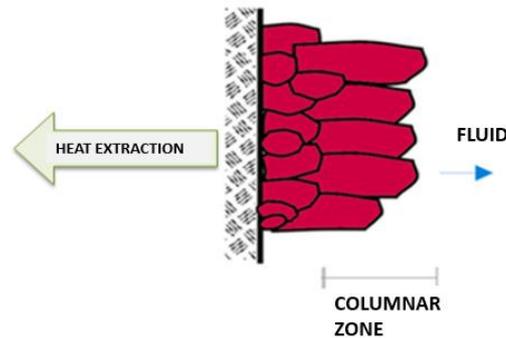


Figure 1. Influence of cooling on grain solidification.

One of the most interesting factors in evaluating micro and macro structures of metals is the fact that, in most cases, the available analytical techniques allow observations of two-dimensional sections of characteristic three-dimensional structures. This seemingly simple transformation requires special treatment (Colpaert, 2008). The mechanical and microstructural characterization of bronze to tin alloys paves the way for high-strength and hardness materials.

Copper-based alloys are preferred for application in marine environments due to their excellent corrosion resistance. However, there is concern about the potential health associated with the use of lead in free machining alloys used in many piping accessories (Rohatgi et al., 2000). Lead is a common addition to commercial bronze alloys, with modern so-called lead-free machining blocks commonly containing about 3 wt-% of lead, guiding to acquiring the desired properties, for example, improving machining. The addition of lead to the bronze is considered to improve machining, improving the breakdown of the chip, reducing the cutting force, decreasing tool wear, and allowing for better roughness and surface tolerance. Lead is a heavy metal and harmful to the environment, there are many studies related to the use of lead-free alloys in various areas (Schultheiss et al., 2016).

The tin is an important component of this alloy, Cu-7%Sn, in the raw fusion state, the dendritic zone of  $\alpha$ , and the eutectoid zone of  $\alpha + \delta$ , where the phase  $\delta$  is continuous. The tin is limited to 7% in the c90300 alloy, so it will not affect ductility. The tin is an important component of the alloy to make it wear-resistant (Nobel et al., 2014). Based on the phase diagram of Figure 2, in which the solubility of Cu in Sn is isobaric.

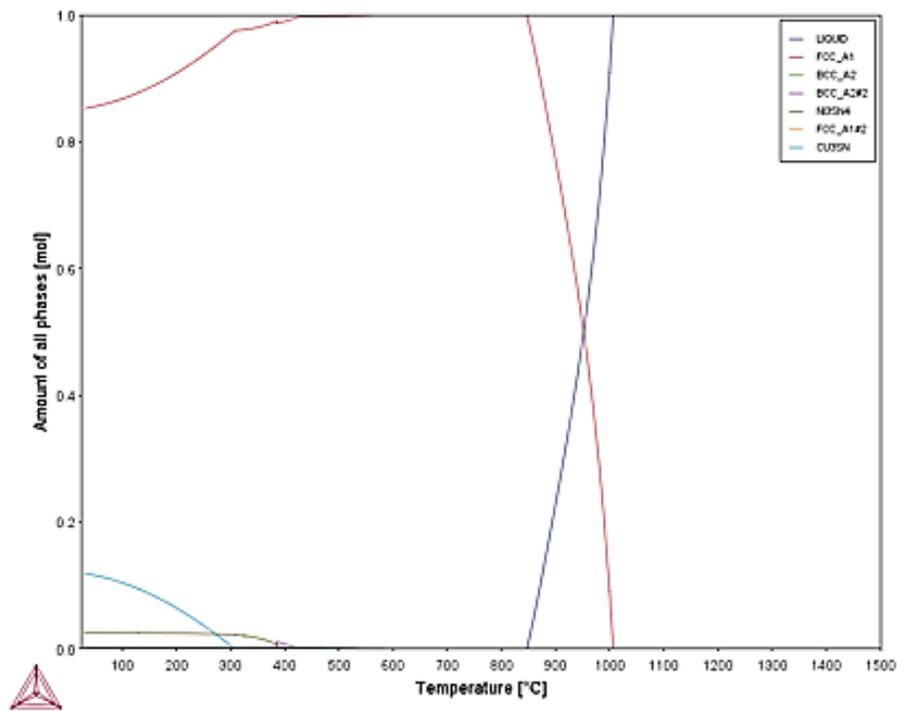


Figure 2 - Thermocalc- Predicted phases based on Sn percentual regarding the Cu alloy.

This study aims to present the analysis of the material, paving the way for new applications and demonstrating the economic and environmental feasibilities of the CuSn8Zn4Pb1 alloy, commercially known as SAE620 (Kestursatya et al., 2003). The equivalence of similar alloys is shown in Table 1, legitimizing its applicability. This material is commonly used in handles used in mechanical systems that are responsible for supporting axis loads (Mayilsamy et al., 2020) (Takateru, 2018). It should be noted that this study did not consider any influence of thermal treatment on the alloy.

Table 1. TM620 - Performances equivalence as bearing the following alloys.

Standards	EQUIVALENCE			
ABNT E-PB-161 (BRAZIL)	C90300	C90500	C90700	C90800
UNS/ASTM (USA)	C90300	C90500	C90700	C90800
SAE (USA)	CA903	CA905	CA907	-
DIN 1705/1715 (GERMANY)	-	G CuSn10Zn	G CuSn10	G CuSn12
BS-1400 (ENGLAND)	G2	G1	PB3	PB2
JIS H5111/H5113 (JAPAN)	BC2	BC3	PBC2	-
NF A53-700 (FRANCE)	CuSn8	-	-	CuSn12

## 2. MATERIALS AND METHODS

The material used for the tests was CuSn8Zn4Pb1 bars, the chemical composition analysis was carried out using the X-ray fluorescence method, aiming to identify and validate the composition of the material compared to the SAE 620 standard, the bronze alloy was supplied by the company Termomecanica São Paulo SA in round bars with a diameter of 20mm manufactured using the horizontal continuous casting process in the chemical composition referred to as TM620, the company's patented metal.

The sample for microstructural analysis was embedded and prepared according to the ASTM E3 standard, Fig. (3), by successive polishing in a metallographic slipper, and immersed in a reagent composed of 10.7% hydrochloric acid and 3.4% iron chloride for 25 seconds.

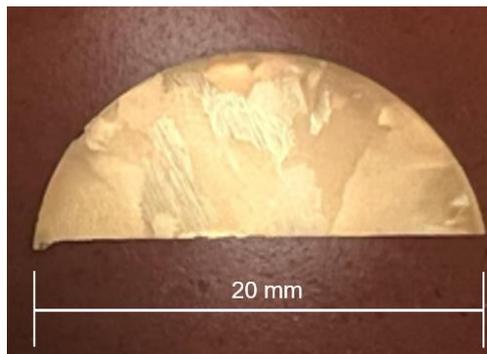


Figure 3. Sample -built-in alloy CuSn8Zn4Pb1.

Chemical composition analysis was carried out using X-ray fluorescence spectrometry on the EDX 720 spectrometer and optical emission spectrometry OES was performed on the MetalLab 75-80J.

The hardness tests were carried out through Brinell's test, using a Future Tech LC 200 RB durometer, a load of 62.5 kgf, and a sphere of 2.5 mm was applied and followed the procedures of the ABNT standard NBR 6394, measurements were performed in the cross-section of the sample and in the longitudinal section of that sample as shown in Figure 4. Microstructural characterization was developed through analysis by optical microscopy according to ASTM12.

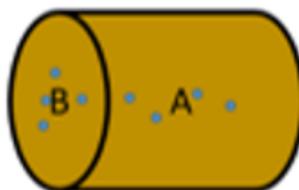


Figure 4. Design and indication of the indentations made during the Brinell hardness test.

### 3. RESULTS AND DISCUSSION

According to the metallographic analysis carried out in sample 1, a raw fusion structure was found with the formation of column dendrites with microconstituents dispersed between the dendritic arms, as shown in Figure 5.

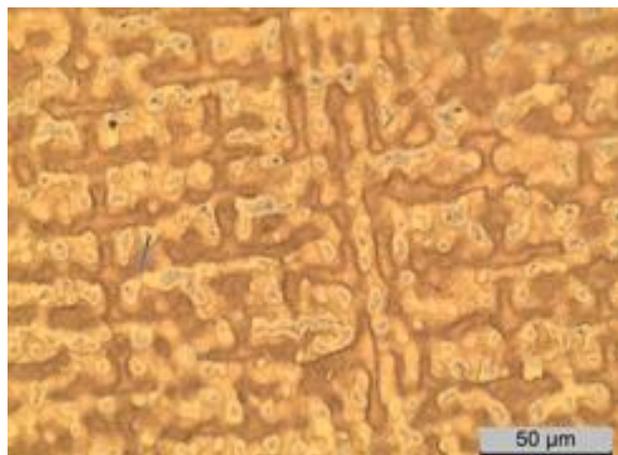


Figure 5. Micrograph of sample 1 - Magnification 500x.

Figure 6, shows the micrograph of sample 2 in which it is possible to notice a raw fusion structure with the formation of column dendrites with intermetallic microconstituents scattered between the dendrite arms.

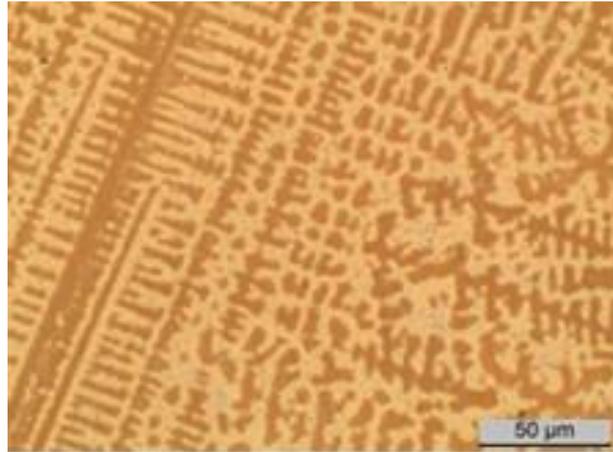


Figure 6. Micrograph of sample 2 - Magnification 500x.

The microstructural analysis is shown in Figure 7, it was possible to note the presence of three phases of the segregated lead, the phase  $\alpha+\delta$  and phase  $\delta$  continues, and the consequence of the high cooling rate, different from that of the literature and beneficial to the application of the material in the bearing

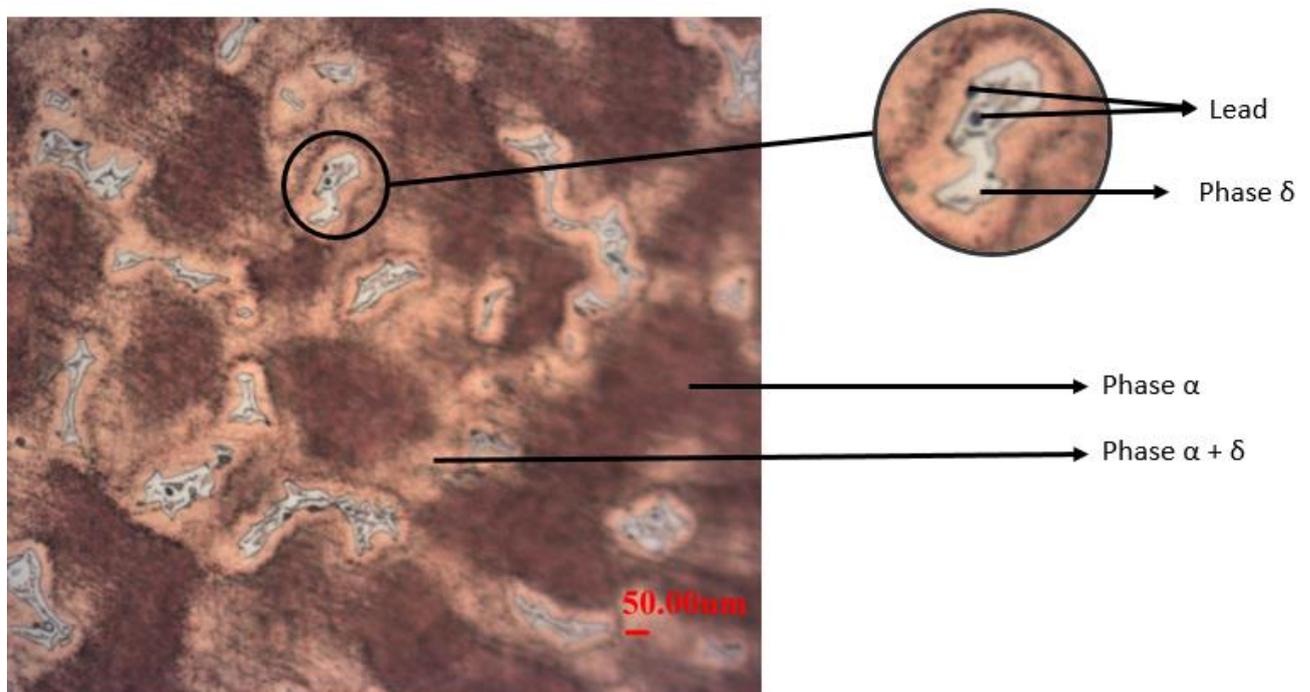


Figure 7. Detailed micrograph obtained from optical microscopy of the sample.

The results of the chemical analysis, conducted using Optical Emission Spectrometry (OES), are detailed in Table 2. This table provides crucial information about the chemical composition of the sample, including the elements and their concentrations. The analysis reveals that the presence of specific elements, such as Tin, plays a significant role in increasing the hardness of the sample. To understand the increased hardness, it is essential to examine the distribution of the elements in the microstructure of the sample, as illustrated in Figure 7. The microstructural particles are visible, and the correlation between the chemical composition of the sample and the formation of these particles can be inferred. It is noted that the uniform distribution of these microstructural phases in the copper matrix is one of the main contributing factors to improved mechanical properties.

Table 2. Results of Analysis of Spectrometry by optical emission (OES).

Elements	SAE 620 (%)	Average (%)
Pb	0,00 – 0.30	0.31
Zn	3.0 – 5.0	3.47
Fe	0.2	0.03
Sn	7.5 – 9.0	7.48
P	0.05	0.03
S	0.05	0.00
Al	0.005	0.00
Si	0.005	0.01
Cu	86.0 – 89.0	88.6

The X-ray fluorescence spectrometry test is presented in Table 3. A notable observation is the absence of elements such as phosphorus (P), iron (Fe), sulfur (S), aluminum (Al), and silicon. (Si). The absence of the mentioned elements is relevant because these elements often play important roles in the properties of metal alloys. Phosphorus, for example, can affect the brittleness of the alloy (Kang et al., 2022). The lack of aluminum and silicon is also remarkable, as both have implications for the formation of inclusions and their casting properties (Sadayappan et al., 2008).

Table 3. Results of chemical analysis by optical spectrometry X-ray fluorescence.

Chemical Elements	SAE 620 (% wt.)	Sample 01 (% wt.)	Sample 02 (% wt.)
Pb	0.00 – 0.30	0.46	0.49
Zn	3.0 – 5.0	3.67	3.70
Sn	7.5 – 9.0	10.26	9.30
Cu	86.0 – 89.0	85.61	86.82

Based on the results, it was observed that the amount of straw found was 10.26% in sample 1 and 9.30% in sample 2 values corresponding to the standard of SAE 620, which can generate an influence on hardness.

In the Brinell hardness tests, an average hardness of 147.95 HB was measured for the body of the sample and 78.32 HB for the center of the specimen, Table 4 shows the values found in the indications.

Table 4. Results of mechanical properties obtained from the Brinell hardness tests.

Indentation Tests	Body of sample (HB)	Top of the sample (HB)
1	138.8	71.0
2	148.4	79.4
3	151.6	83.3
4	153.0	79.3
Average	147.9	78.2
Standard deviation	5.5	4.5

#### 4. CONCLUSION

The initial conditions of the material were evaluated right after the continuous coating process, without the influence of heat treatments. The analytical parameters were based on the standard specification for continuous casting of copper alloys, with satisfactory and expected results within the current standard. The main element of the "bronze to tin" alloy is copper, with an average molecular mass of 86.90% by weight extracted by optical spectrometry and X-ray fluorescence analysis. The presence of concentrated in at 7.48% by weight ensures improvements in mechanical properties. The lead found at 0.31% by weight allows the alloy to be machined, even in small proportions, so as not to influence the Sn characteristics. Indicating that the composition of the CuSn8Zn4Pb1 alloy is highly selective about the elements present, which can be intentionally controlled during the manufacturing process. The solubility of lead in the outer layer, due to the cooling process and the solubility of lead in the alloy, is beneficial in bulk applications for high loads and low rotation. The material has high mechanical resistance and an adequate thermal expansion coefficient. Because of the lead segregation that occurs in the outer layer, the hardness was analyzed, which meets the average of 147.95 HB in the body of the material, and in the center of the materials, we have an average of 78.32 HB, meeting expectations within the expected standard according to ISO-4382-1-2002. It is understood that because lead solubility is concentrated in the last cooling layer, there is consequently less hardness in the center of the material, facilitating the machining process in the casing sleeve, the main application of the alloy. Furthermore, the composition of the material was presented by analysis of optical emission spectrometry and X-ray fluorescence. Corroborating the composition of the pattern can be analyzed the structures according to the metallographic analysis performed. It was found a crude fusion structure with the formation of dendritic columns and dendritic arms, a secondary state between 38.8% and 49.84%, and intermetallic microconstituents dispersed between the dendritic arms confirming what was expected in the continuous casting process supported by up to 12% Sn, the Sn segregation is formed by the high cooling rate, which presents the benefits in the formation of the material that the industry needs, tribological studies mainly dry contact are recommended to confirm the claims of the benefits of the material's applicability to the industry.

#### 5. ACKNOWLEDGMENTS

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#### 6. REFERENCES

- ASM Metals., 1992. Properties and Selection: "Nonferrous Alloys and Special-Purpose Materials". ASM International, v.2.
- ASTM E3., 2017. "Standard guide for the preparation of metallographic specimens". v.e0003-11R17.
- Colpaert, H., 2008. *Metalografia dos produtos siderúrgicos comuns. (in Portuguese)*, E. Blucher.
- Equey, S., Houriet, A., & Mischler, S., 2011. Wear and frictional mechanisms of copper-based bearing alloys. *Wear*, 273(1), 9–16.
- Finley, M. I., 1970. Early Greece: The Bronze and Archaic Ages, Norton, 1970.
- Hutchinson, B., 2016. Brass alloys. *Materials Science and Technology*, 32(17), 1743–1743.
- Kang, Y., Zhang, G., Xu, H., & Niu, J., 2022. Effect of phosphorus on interface characterization of steel–copper bimetal in solid–liquid composite casting. *Materials Today Communications*, 30, 103037.
- Kestursatya, M., Kim, J. K., & Rohatgi, P. K., 2003. Wear performance of copper–graphite composite and a leaded copper alloy. *Materials Science and Engineering: A*, 339(1–2), 150–158.
- Mayilsamy, P., Kumareshababu, S. P., Nayan, K., & Srinivasan, S. A., 2020. Mechanical property study on C90300 copper composites reinforced with rare earth oxide. *Materials Today: Proceedings*, 27, 2533–2536.
- Molian, P. A. et al., 1991. Sliding wear characteristics of non-equilibrium Cu-Pb alloys. *Wear*, 146(2), 257–267.
- Nobel, C., Klocke, F., Lung, D., & Wolf, S., 2014. Machinability Enhancement of Lead-Free Brass Alloys. *Procedia CIRP*, 14, 95–100.
- Rohatgi, P. K., Nath, D., Kim, J. K., & Agrawal, A. N., 2000. Corrosion and dealloying of cast lead-free copper alloy–graphite composites. *Corrosion Science*, 42(9), 1553–1571.
- Sadayappan, K., Sahoo, M., & Michels, H. T. 2008. Copper and Copper Alloy Castings.  *Casting*.
- Schultheiss, F., Johansson, D., Linde, M., Tam, P. L., Bushlya, V., Zhou, J., Nyborg, L., & Ståhl, J. E., 2016. Machinability of CuZn21Si3P brass. *Materials Science and Technology*, 32(17), 1744–1750.
- Takateru, U., 2018. Development of Lead-Free Copper Alloy Casting; Mechanical Properties, Castability, and Machinability. *Metal Indonesia*, 26, 34.
- Thomson, J., Zavadil, R., Sahoo, M., Dadouche, A., Dmochowski, W., & Conlon, M., 2010. Development of a Lead-Free Bearing Material for Aerospace Applications. *International Journal of Metalcasting*, 4(1), 19–30.

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