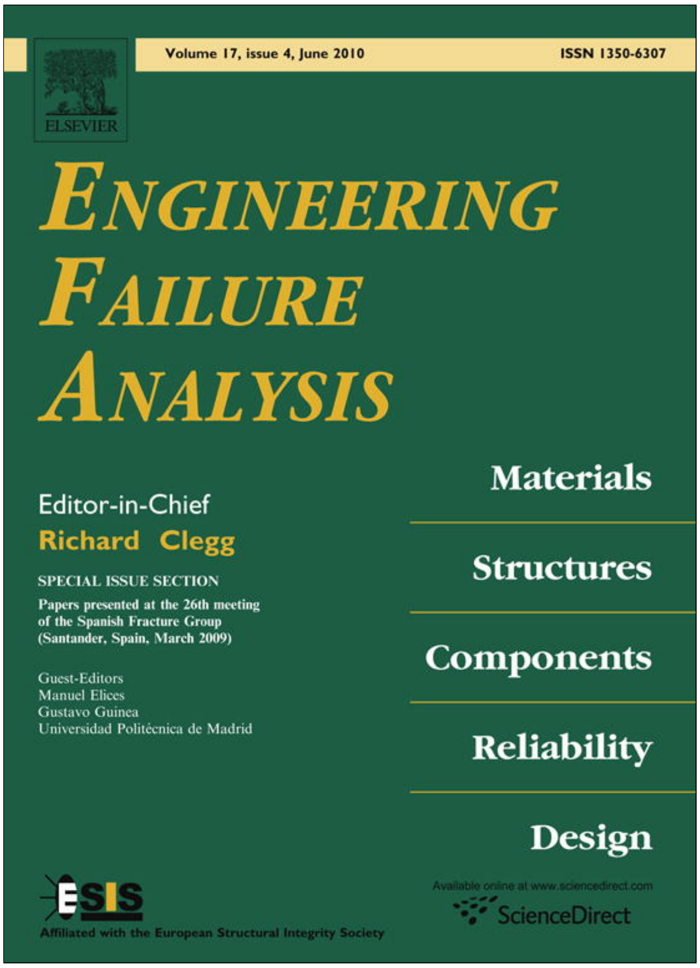
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Comparative study of the parameters influencing the machinability of leaded brasses

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ABSTRACT

One of the main applications of brasses is the manufacture of fluid carrying systems. The shape of the final product is usually made by means of machining the rolled or extruded standard bars, so that effective and low cost machining operations are required. Leaded brasses are extensively used when a good machinability is required.

Two leaded brasses bars (CuZn39Pb3 alloy) with the same geometry but with different behaviour in saw cutting operations have been characterized in this work. Chemical composition, mechanical and microstructural properties have been studied in order to clarify the observed differences during saw cutting machining.

Significant differences have been found with respect to the size and distribution of lead globules and phase volume fractions ($\alpha + \beta'$), that have been explained due to the existence of different solidification and cooling patterns in both products; being the lead distribution the most important characteristic relative to the leaded brass cutting performance.

1. Introduction

Brasses have an attractive combination of properties, namely, good corrosion resistance, good wear properties, high thermal and electrical conductivity. Hence, they are extensively used in the manufacture of a lot of components of the electrical industry, automotive and the manufacture of valves and fittings, among others. Dealing with the manufacture of fittings and valves, these components are usually shaped as a semi-finished product by means of rolling or extruding a compact or hollow bar, followed by stamping, cold forming or machining operations.

High copper contents (larger than 60%) are needed to produce products by cold working in order to have a good enough formability. When a good machining behaviour is required, lead is added (until 3%). The benefits conferred by the presence of lead has been appreciated for many years to facilitate chip fracture, reduce cutting forces, increase the machining rate and productivity, reduce tool wear and enhance surface finish [1,2].

A CuZn39Pb3 alloy (according to UNE-EN 12164 [3]) was studied in this work. The studied alloy is used for the manufacture of a piping element and this product is obtained from a prismatic extruded bar. The bar is saw cut before the final stamping process. Two bars with different saw-cutting performance have been studied in order to find the relationship between the alloy microstructure (phase distribution) and material saw-cutting behaviour.

Brasses with more than 36% of Zn, like the one used in this work, are two-phase alloys: with α and β' phases, and are characterized to have good hot workability above 450 °C, when β' transforms to β. Moreover, when machining operations

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are also required, a certain amount of lead is recommended to be added (leaded brass). So, when good machinability and high ductility at high temperature are both needed, an appropriate selection of alloying elements, a correct manufacture process and good operational parameters are needed in order to attain an adequate microstructure which facilitates product shaping and provides good final mechanical properties.

2. Experimental procedure

Two prismatic brass bars with the same geometry (square section 14 × 14 mm and 300 mm length) were studied. Fig. 1 shows a general view of the samples. Sample 1 had exhibited a good saw-cutting behaviour but, on the contrary, sample 2 gave rise to much larger tool wear levels.

2.1. Chemical analysis

Chemical analysis was performed on the surface and centre of every bar.

2.2. Mechanical test

Tensile tests were carried out using cylindrical specimens machined coaxially to the long bar direction according to UNE-EN 10002-1:2002. A 100 kN load capacity Instron universal testing machine was used with a rate of 1 mm/min in the elastic zone and 21 mm/min in the plastic zone.

Furthermore, Vickers hardness tests were also performed in the cross section of the bars. At least three Vickers diamond indentations were made on every bar under a 10 kg load.

2.3. Microstructural study

This study was performed on transversal samples taken from every bar. Samples were mounted in a bakelite holder, ground and polished until 1 μm diamond past and etched with a dissolution of 25 ml of HCl, 25 g of $FeCl_3$ and 100 ml of water.

Phase counting and distribution was carried out by means of an Leica image analysis software. Two different areas were analyzed: the centre of the cross section and a zone close to the surface. Grain size was determined according to the UNE-EN ISO 2624 standard [4] using the image comparing method. An optical microscope was used for the microstructural study.

3. Results

3.1. Chemical analysis

Table 1 shows the chemical composition of both bar samples. While sample 2 fulfills the standard specification, sample 1 has lead and copper contents out of the standard range and also shows a slightly different composition between their surface and centre regions.

3.2. Mechanical tests

The tensile and hardness tests results are shown in Table 2. Sample 2 has a larger yield strength and tensile strength but a slightly lower hardness than sample 1. The ductility parameters are similar in both samples.

Fig. 1. Prismatic bars. Samples 1 and 2.

Table 1
Chemical analysis of the leaded brass bars (wt%). S-surface; C-centre.

Sample	Element								
	Cu	Zn	Pb	Sn	P	Fe	Ni	Si	Al
1/S	55.8	39.8	3.79	0.176	0.012	0.221	0.056	0.0075	0.026
1/C	57.1	38.0	4.42	0.181	–	0.254	0.049	<0.004	0.025
2/S	57.1	39.6	2.80	0.203	0.0083	0.163	0.056	0.0051	<0.010
2/C	57.8	39.3	2.39	0.170	<0.006	0.196	0.057	<0.009	<0.005
UNE-EN 12164	57–59	Bal.	2.5–3.5	<0.30	–	<0.30	<0.30	–	<0.050

Table 2
Mechanical properties of the studied samples.

Sample	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Reduction of area (%)	Hardness HV10
1	320	364	23.0	37	131 ± 5
2	346	394	22.5	38	125 ± 1

3.3. *Microstructural study*

Figs. 2 and 3 show the typical alpha–beta (α–β') structure of brasses with high zinc contents. Both samples have a noticeably different microstructure: sample 1 has a lower grain size in the centre of the section, larger α-phase volume fraction (see Table 3) and a more uniform and equiaxial grain morphology.

Significant differences on the lead globules sizes have also been found, as can be appreciated in the unetched images given in Figs. 5 and 6. Lead globules are clearly distinguished before etching, as lead particles appear as dark and discrete globules (lead is practically insoluble in solid copper). Most lead globules appear at the α/β grain boundaries. Sample 1 has larger lead globules and also a higher lead content (see Table 1) than sample 2, in which lead globules are smaller, but better distributed.

Fig. 4 shows one of the largest lead globules (20 µm approx.) present in sample 1.

4. Discussion

The obtained results regarding the different cutting-saw behaviour of two CuZn39Pb3 brass bars can be summarized in the following points:

- Sample 2 fulfills the requirements for a CuZn39Pb3 alloy according to UNE-EN 12164, while sample 1 has not enough copper and an excess of lead to meet the standard requirements. No significant differences were found in the others elements, unless a higher iron content in sample 1.
- Sample 2 has a higher yield strength and tensile strength and no significant differences were obtained between the ductility parameters of both samples. Also, any important difference was found in hardness.

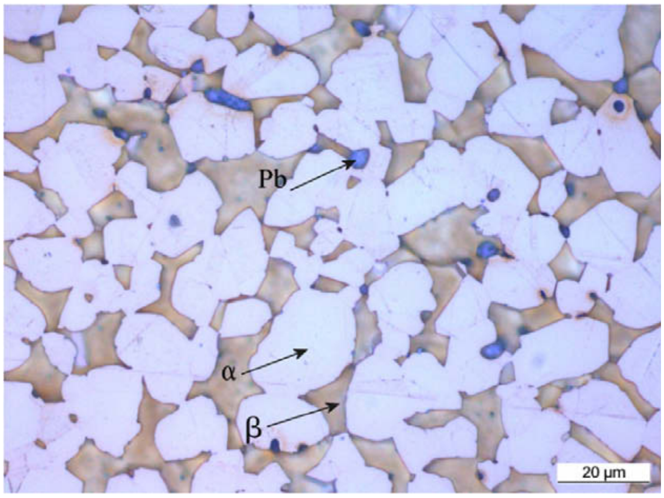

Fig. 2. Microstructure of sample 1/C. α-phase (α), β-phase (β), lead globules (Pb).

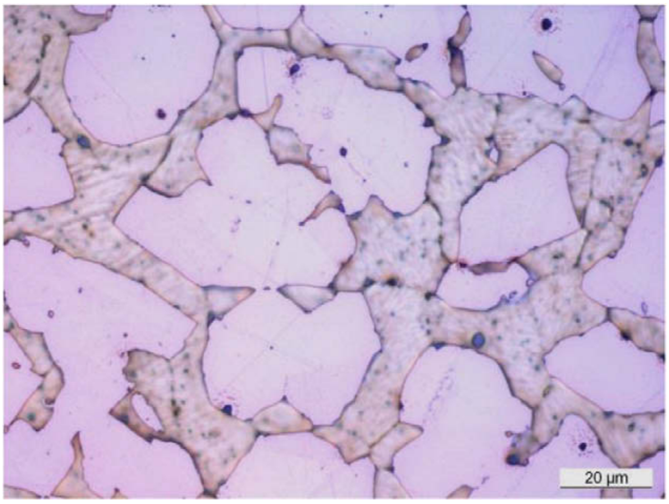

Fig. 3. Microstructure of sample 2/C.

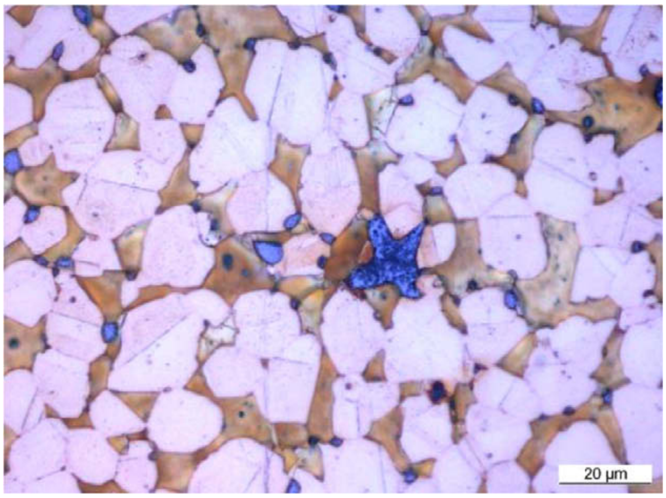

Fig. 4. Detail of large lead globules on sample 1.

Table 3
Grain size and α-phase volume fraction results.

Sample	Zone	Mean grain size (μm)	α-phase volume fraction (%)
1	Centre	12	69.2 ± 1.3
	Surface	10	64.5 ± 2.2
2	Centre	25	56.6 ± 0.6
	Surface	12	60.9 ± 1.9

- Both samples have a duplex α–β' microstructure with smaller, more uniform and equiaxial grain morphology in sample 1. The average size of lead globules is much larger in sample 1, and the presence of very large globules has also been detected on this same sample, given an unfavorable surface/volume ratio in comparison with sample 2, in which lead globules are more uniformly distributed. Moreover, α-phase volume fraction was larger in sample 1.

The lead globule morphology of sample 1 (larger globules and lower surface/volume ratio) has been the main reason for the bad saw-cutting behaviour observed on this brass bar. It is also known that a lead content larger than 3.25% does not increase brass machinability [5].

The difference on the mechanical properties between both samples can be explained because of the larger β-phase volume fraction, characterized by a higher hardness [6], observed in sample 2.

Another point to be considered in order to explain the microstructure differences between both samples is the cooling rate after solidification. This cooling rate seems to be larger in sample 2, to give a better lead dispersion and smaller lead

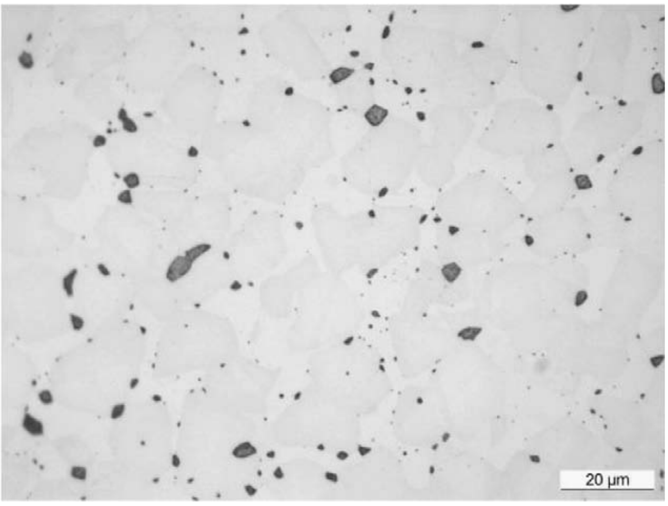

Fig. 5. Lead globules, sample 1 (unetched).

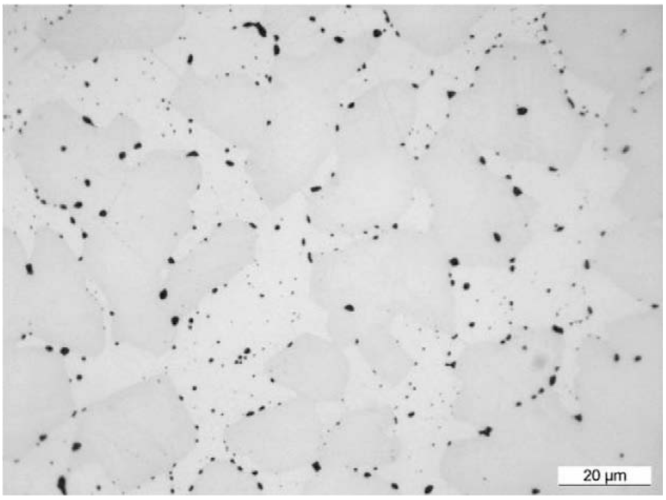

Fig. 6. Lead globules, sample 2 (unetched).

globules, taking into account that lead precipitate from the last liquid at the end of the brass solidification process, according with its low melting temperature, 327 °C. Moreover, differences between phase volume fractions and grain sizes between both samples can be explained from the extrusion process conditions (pass schedule, percent reduction, etc.), that usually is performed at temperatures higher than 750 °C, in the β domain [7] (see Fig. 7). A higher cooling rate after extrusion (non-equilibrium cooling) gives not enough time to attain the equilibrium between α and β phases, and an excess of β' phase would be finally present at room temperature (see Fig. 7).

Any other aggregate or inclusion has been observed in the samples, but only a higher iron content was detected on sample 1, which can also give rise to an small machinability reduction.

5. Conclusions

The bad cutting-saw behaviour and high tool wear levels of sample 1 of CuZn39Pb3 alloy was due to the presence of too large lead globules, not well enough dispersed on its microstructure as to lubricate efficiently the tool during cutting operation. As lead is totally insoluble on copper and precipitate at the end of the solidification process, the distribution of lead globules is not affected by the extrusion process and the most suitable way to obtain a smaller and better dispersed lead globule distribution would be to use a higher cooling rate after solidification.

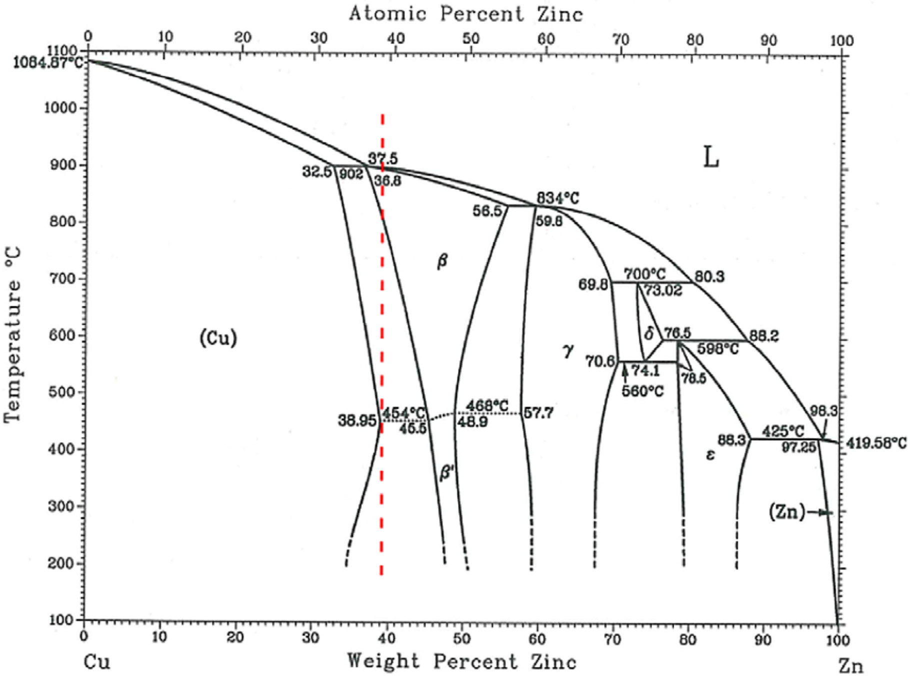

Fig. 7. Copper–Zn equilibrium diagram.

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