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# Analysis of the fracture criticality of biphasic brass

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## Abstract

Some hydraulic brass components were subjected to in service structural failures. In the present work some case histories were analyzed and revealed that such failures were determined by the material microstructural characteristics dependent not only on the alloy composition, but also on the adopted production techniques. The study highlighted that the β phase orientation significantly affects the fracture behavior of the studied biphasic brass. Moreover the effect of different applied stresses that caused component failure was analyzed.

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*Keywords:* Brass, failure analysis, hydraulic components.

## 1. Introduction

Brasses have a wide range of engineering uses because they are versatile. The key strengths of this class of materials are the good corrosion resistance in many media and the fact that brass can be easily worked and joined. Brasses can easily be fabricated by casting, extrusion, rolling, drawing, hot stamping and cold forming. Because of their unique combination of properties they are ideal for many industrial applications such as screws, nuts, valves, tube fittings, heat exchangers, taps, plumbing hardware and electrical components as described by the Copper Development Association (2005). Brass properties depend upon the quantity of zinc in the alloy but can be usefully modified by the addition of alloying elements in order to improve strength, machinability or corrosion resistance. Up to 3% of lead is often added to alpha-beta brasses with the aim of providing free machining properties. In fact lead forms a discontinuous phase all over the material and decreases the friction coefficient between the tool and the

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alloy, moreover it reduces the tool wear rate because it favors chip fragmentation as said by Vilarinho et al. (2005). These alloys are widely used for producing critical hydraulic components, thus it is important to understand mechanisms which govern their deformation and fracture. This would help to optimize the manufacturing process and to diagnose the failure mechanisms that affect critical components. Toulfatzis et al. (2014) and Pantazopoulos et al. (2012) investigated the relationship between microstructure and mechanical properties for both leaded and lead-free brasses. A further essential aspect is the knowledge of brass component defects that can be caused by metalforming processes and that can produce either in-service failures or collapse during the component's processing as highlighted by Chunlei et al. (2016), Mapelli et al. (2013), Pantazopoulos et al. (2003) and Pantazopoulos et al. (2008).

Case studies of broken brass components highlighted that there may be different factors that cause failures. In lead-free brass taps for instance bismuth may have an important role in improving machining process but it lowers ductility. In fact bismuth tends to segregate into grain boundaries with consequent alloy embrittlement. In these cases it is important to control alloying element distribution during the production process. Other frequent causes of sudden failures are stress corrosion cracking (SCC) due to the combined effect of tensile stress and a selected corrosive environment or dezincification processes that can be ascribed to high chlorine concentration coming for example from drinking water treatments. In extruded components intergranular fractures similar to those caused by SCC and parallel to the extrusion direction may occur. When no inclusions or weaknesses are detectable, these cracks are usually caused by the hot shortness failure mechanism which is due to a combination of high extrusion speed and high pre-extrusion rod temperature.

It is not uncommon that hydraulic joints or brass taps experience failure causing considerable damages caused by uncontrolled water leaks. These failures, as already said, are due to alloy structural and metallurgical defects, or excessive loads caused by human action. In the latter case, as a result of the tap root analysis it can be found that the failure is determined by an incorrect procedure followed by the specialist (excessive torque, incorrect positioning etc.) or a wrong operation by the user (inadvertently applied excessive loads). A detailed analysis of the fracture surfaces might be decisive in settling these litigations, as it allows the identification of the loading mode which caused the failure.

In this work three failed hydraulic components, a hydraulic joint and two taps, have been examined.

## 2. Experimental

The brass nominal composition of the analyzed components was:

| | |
|---|---|
| Hydraulic joint : | 59.4 Cu, 37.3 Zn, 2.2 Pb, 0.4 Sn, 0.4 Ni, 0.3 Fe; |
| Tap failed by flexural stress: | 57.7 Cu, 38.2 Zn, 2.5 Pb, 0.8 Sn, 0.5 Ni, 0.6 Fe; |
| Tap failed by torsional stress: | 58.3 Cu, 38.7 Zn, 1.7 Pb, 0.4 Sn, 0.4 Ni, 0.5 Fe. |

The components were sectioned and different transversal sections have been analyzed to study the crack path.

Fracture surfaces visual inspection has been performed followed by morphological analysis carried out by SEM equipped with EDS (Energy Dispersive Spectroscopy) analysis.

Microstructural characterization of the alloy was carried out on mounted polished sections of the broken component.

Specimen grinding was performed with abrasive SiC papers, followed by polishing performed by using 1 μm alumina. In order to reveal the alloy microstructure etching was performed using $FeCl_3$ solution.

## 3. Results and discussion

A brass hydraulic joint broken in service was analyzed in order to identify failure causes.

Fig. 1 shows the crack developed unhindered in the longitudinal direction. The crack orientation is normal to circumferential stresses acting on the component that are induced by tightening forces. Even assuming clamping overstressing, a close observation of the broken joint highlights that the crack propagated in a clear way along the cylindrical generatrix of the component.

Figures 2 and 3 show the alloy microstructure along the transverse and longitudinal sections, both characterized by the presence of α and β phases. As far as the microstructure in Figure 3 is concerned EDS analyses of the bright phase (55% Cu, 45% Zn) revealed that it is the β phase, while the dark phase (62%Cu, 38% Zn) is the α phase. The small white areas, visible in this figure, are lead reach phases. In the optical micrographs (Fig. 2) the α phase is bright, while the β phase is dark. The quantity of β phase, which is about 25%, is the typical value characterizing these alloys. By observing the alloy microstructure in Fig. 2b it is also evident that the β phase has a preferential orientation along the longitudinal direction. In fact, being the studied component obtained by machining an extruded bar, grains are oriented in the extrusion direction.

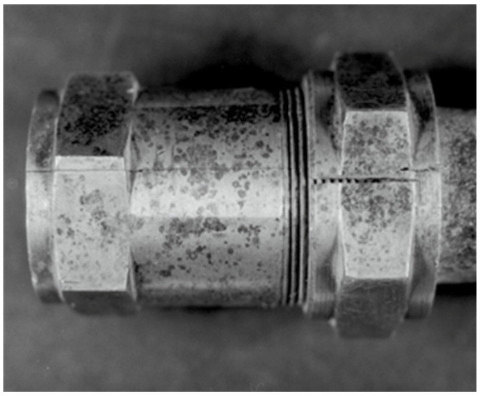

Fig. 1. Macrograph of the broken hydraulic joint

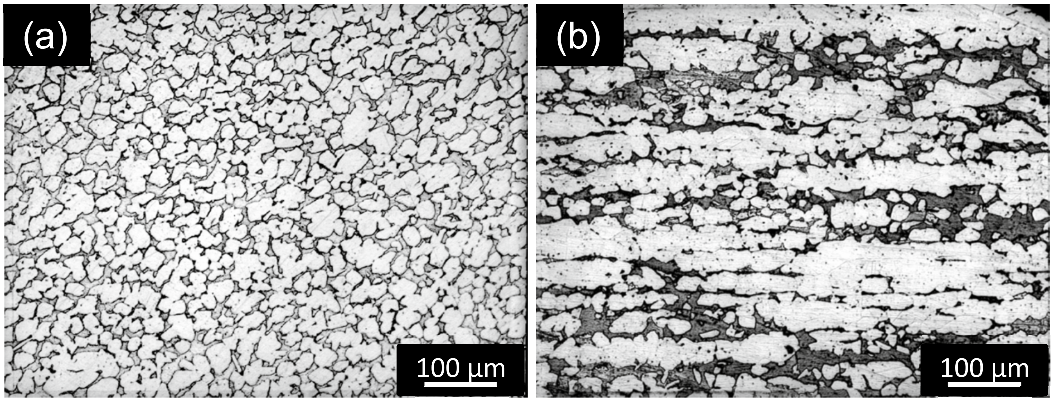

Figure 2. Optical micrographs showing the alloy microstructure perpendicular (a) and parallel (b) to the extrusion direction.

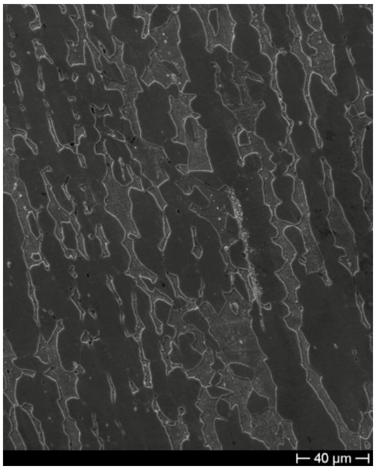

Fig. 3. SEM micrograph showing the alloy microstructure of as-extruded alloy parallel to the extruded direction.

A careful observation of crack paths reported in Figs. 4 and 5 highlights that cracks developed prevalently through the β phase, which is brittle, by following an intergranular path (Fig. 5). Crack propagated throughout the component from the inner toward the outer part, as demonstrated from secondary crack paths (Fig. 6).

Generally speaking stress corrosion cracking induces the formation of branched cracks characterized by a high number of thin secondary cracks. In this study we observed only few secondary cracks with blunt tips: this indicates that the mechanical applied load is the main cause of the failure.

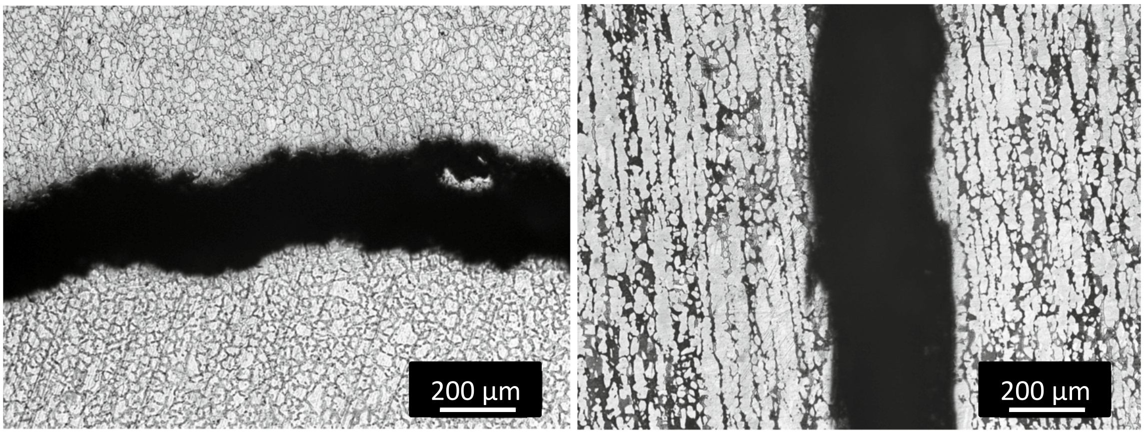

Figure 4. SEM micrographs showing the crack path perpendicular (a) and parallel (b) to the extrusion direction

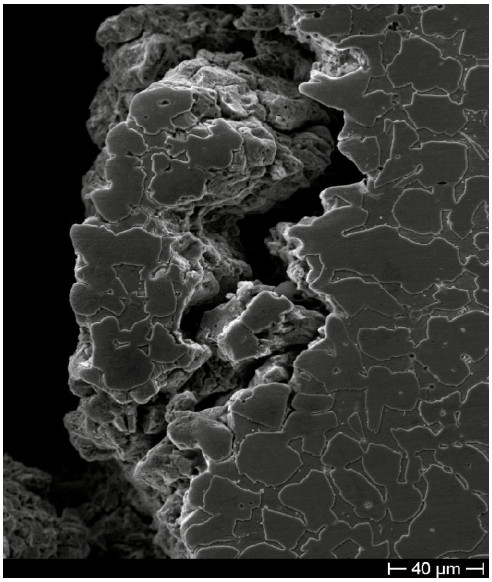

Figure 5. SEM micrograph showing the crack path perpendicular to the extrusion direction.

In order to verify the effect of the alloy microstructure on the component behavior in service, the same type of component has been produced by means of hot forging. In this case the microstructure appears homogeneous without any preferential orientation (Fig. 7). This hydraulic joint was used in the same conditions of the failed one, but it did not fail in service.

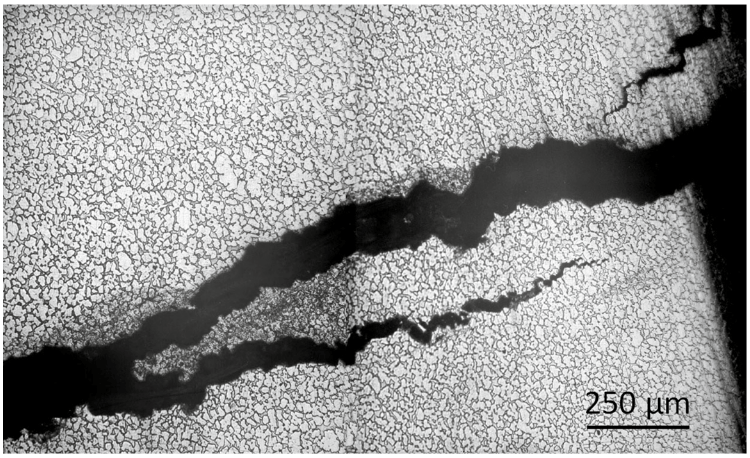

Fig. 6. Micrograph showing primary and secondary cracks.

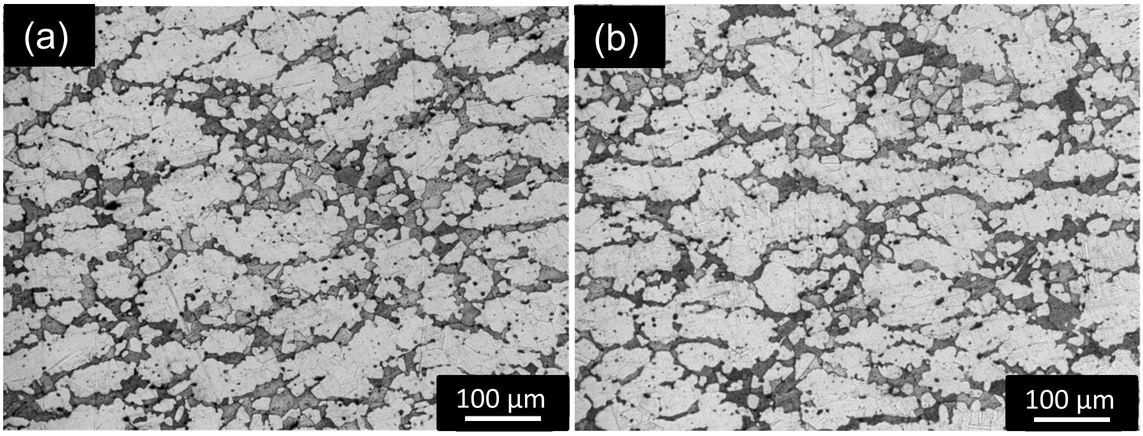

Figure 7. Optical micrograph showing the forged alloy microstructure: transversal (a) and longitudinal (b) sections.

Figure 8 shows a tap that failed due to the application of a flexural stress. In this case fracture initiation occurs in the threaded area of the component where there is stress intensification at the tip of the thread. The fracture surface is characterized by a brittle morphology (cleavage) in the crack initiation area (Fig. 8b) and by a mixed morphology with some dimples in the propagation area, while the final fracture shows a considerable plastic deformation (Fig. 8c).

In Fig. 9 the fracture surface of another brass tap that failed because of torsional stress is shown. This surface shows circular grooves due to the used tool (Fig. 9a) and material curls (Fig.9b) that are generated by torsional stress and that are inclined relative to the fracture plane. In this case the fracture is almost ductile throughout the all component.

All these observations allow to identify the causes and  the loading mode which caused brass failure.

## 4. Conclusions

From this study it is evident that biphasic brass fractures caused by metallurgical defects have a very different morphology in comparison with those caused by overstresses or anomalous stresses arisen in service. In particular fractures determined either by the β phase oriented normally to the stress or by beryllium rich phases, present in some lead free brasses, are brittle. Failures due to overstresses or anomalous stresses can be easily identified. They usually start in the threaded areas of the component, where there is stress intensification. The fracture initiation area has a brittle morphology, followed by an area characterized by a mixed mechanism, then by dimpled zones and finally by a fracture surface showing a considerable plastic deformation.

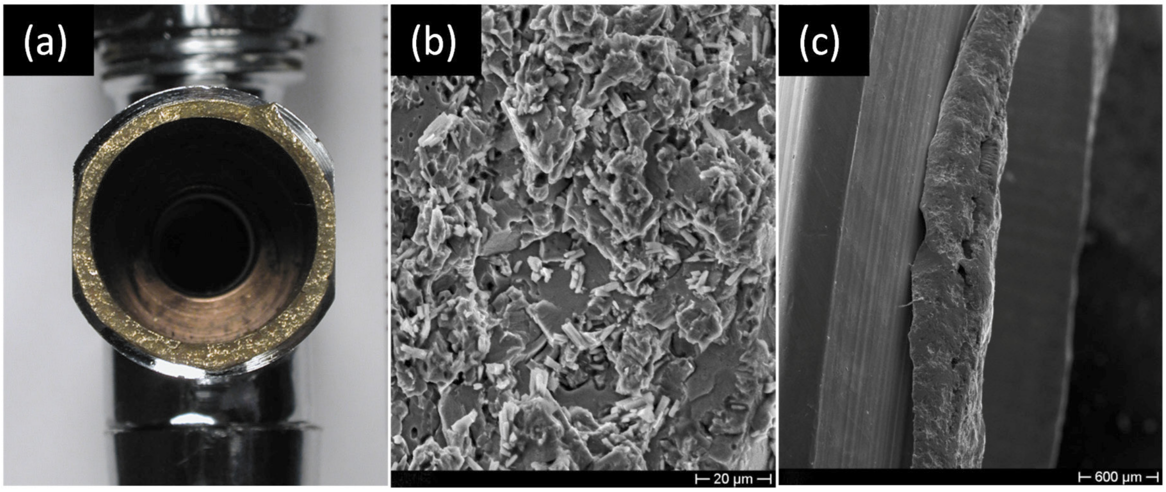

Figure 8. Tap failed by applying flexural stress: macrograph of the fracture surface (a), SEM micrograph of the final fracture area (b), SEM micrograph of the fracture surface (c).

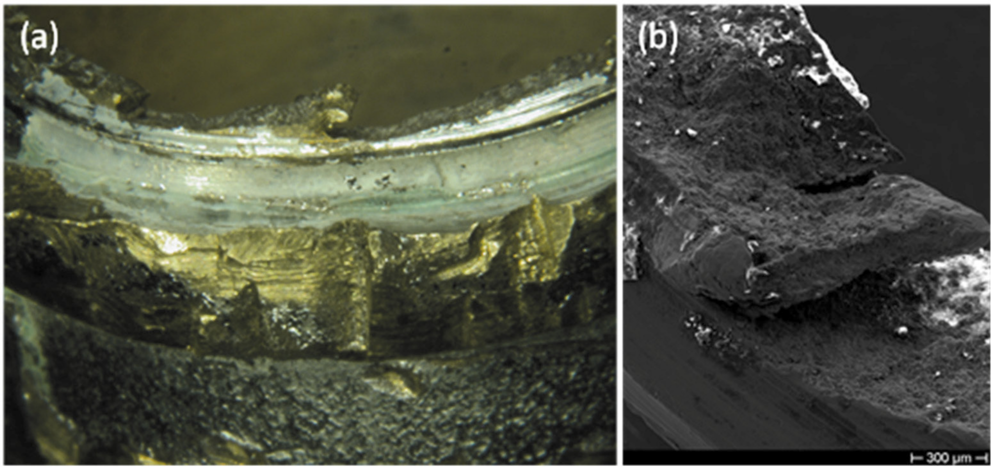

Figure 9. Macrograph (a) and SEM micrograph (b) of the fracture surface of a tap failed by applying a torsional stress.

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