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Effect of chemical composition and processing variables on the hot flow behavior of leaded brass alloys

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ABSTRACT

Hot compression tests were carried out on CuZn39Pb2 and CuZn39Pb3 leaded brasses in the temperature range of 600–800 °C at strain rates of 0.001–1 s^{-1}. The stress–strain curves at low temperatures were characterized by a single peak, while at high temperatures, the flow curves were characterized by a long plateau associated with dynamic recovery. The phase diagram of Cu–Zn–Pb system drawn by the Thermocalc software showed that increasing Pb could shift the phase border between α+β and β towards the Zn corner, thereby increasing the volume fraction of α at the deformation temperatures. Hot deformation at low temperatures, e.g., 600–700 °C, changed the strings of cornered α islands to more globularized discrete ones. However, the conventional dynamic recrystallization could not be observed. At 800 °C, fine α particles formed through dynamic recrystallization were coexistent with acicular ones formed through quenching of β from high temperatures. It was found that at low temperatures, e.g., below 700 °C–750 °C, Pb could contribute to avoiding flow localization in both alloys. At 800 °C, more Pb could dissolve into β leading to more tendency to flow localization. The results showed that at low temperatures, i.e., below 700 °C, both materials exhibited higher strength than that predicted by the law of mixture. At high temperatures, particularly beyond 700 °C, the predicted values of the law of mixture lay below the experimental flow stresses. This was attributed to the decrease in the volume fraction of α and more dissolution of Pb into β.

1. Introduction

Cu–Zn brass alloys are widely used in different industries due to their corrosion resistance and good mechanical properties. Other alloying elements may also be added to impart special characteristics to brass. Lead, which is nearly insoluble in Cu alloys, is used to improve machinability of leaded brass [1]. However, Pb, Bi or other elements that are used to impart machinability often deteriorate the low and high temperature ductility of brass [2,3]. Depending upon the chemical composition of brass, a single-phase α (with fcc structure) or β (with bcc structure) or a two-phase (duplex) α+β microstructure may be formed. The hot deformation behavior of brasses with different microstructures has been the topic of some investigations in the past decades [4–7]. During hot deformation, α, which is characterized by low stacking fault energy (SFE), undergoes dynamic recrystallization (DRX) [7,8], whereas dynamic recovery (DRV) is the restoration mechanism of β [8]. This imparts superplastic behavior to the duplex brass alloys at high temperatures and low strain rate deformations. The mechanisms of DRX and DRV are the same as well documented in the literature on copper, steel and other alloys [9–13].

Despite few investigations conducted on the hot deformation behavior of duplex leaded brass, the hot flow curves have been hardly interpreted. This is attributed to the different restoration mechanisms of α and β. From similar investigations into duplex stainless steels [14,15] and Ti alloys [16,17], it can be inferred that different deformation mechanisms of constituents complicate the tracing of the microstructural evolution and modeling of the flow curves during hot working.

Different approaches, some based on the constitutive equations [5,18] and some others on the self-consistent models and the law of mixture rule [19–21], have been so far adopted to model the flow curves of duplex alloys. Despite the fact that the law of mixture rule has not been generalized to consider the change in the strength of the constituents with deformation temperature, it has been used to predict the hot flow curves of some multiphase materials [14,21–23]. Before applying this method on duplex leaded brass, two challenges should be dealt with firstly, the influence of Pb particles on the hot flow behavior of brass and secondly, the effect of chemical compositions of α and β at

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different deformation temperatures on their strength level. Hence, the present work aimed at studying the hot deformation behavior of duplex leaded brass with regard to the effect of Pb and calculating the flow curves using the law of mixture rule.

2. Experimental procedures

Two leaded brasses with different Pb contents and chemical compositions according to Table 1 were used in this investigation. The starting materials were supplied with cold drawn initial condition. The initial microstructures of the materials shown in Fig. 1 indicate that both alloys consist of α and β. In the micrographs, the matrix phase is β and the lighter island that contains most of dark particles of Pb is α.

The cylindrical specimens with 10 mm in diameter and 15 mm in height were machined from the supplied starting materials according to ASTM E209 standard. Hot compression tests were carried out on the specimens at temperatures of 600 °C, 650 °C, 700 °C, 750 °C, and 1073 K (800 °C). The isothermal compression tests were applied at strain rates of 0.001 s^{-1}, 0.01 s^{-1}, 0.1 s^{-1}, and 1 s^{-1} by the Zwick–Roell testing machine.

Table 1
Chemical composition of the brass alloys used in this investigation.

Alloy	Zn	Pb	Sn	Fe	Ni	Cu
CuZn39Pb2	39.4	2.29	0.036	0.048	< 0.005	Rem.
CuZn39Pb3	39.8	2.87	0.094	0.043	< 0.005	Rem.

The specimens were preheated at test temperatures for 10 min before hot compression. Lubrication of the flat surfaces of the specimens was done by using graphite. The specimens were compressed to 50% reduction in height (ε=0.7) and the load–stroke data were recorded. The load–stroke data were converted to true stress–true strain curves using standard equations.

The specimens were immediately water-quenched after hot compression to preserve the deformation microstructure. The deformed samples were sectioned parallel to the compression axis and prepared by standard metallographic techniques according to ASTM E3–11. After etching by a reagent composed of 100 ml H_2O, 20 ml HCL and 5 g iron (III) chloride, the hot compressed samples were examined by optical microscopy.

3. Results and discussion

3.1. Flow curves and microstructures

The typical true stress–strain curves of the materials calculated from the load–stroke data at various temperatures and two strain rates of 0.001 s^{-1} and 1 s^{-1} are shown in Fig. 2. The results indicate that at low temperatures, i.e., 600 °C and 700 °C, and all strain rates (0.001–1 s^{-1}) the flow stress of CuZn39Pb2 is higher than that of CuZn39Pb3. It is also notable that the difference between flow curves decreases with increasing temperature so that at 800 °C, the flow curves are nearly overlapped.

The observations should be addressed with regard to the differences in the chemical compositions of the alloys. It is easy to discuss the results with respect to the different amounts of Cu

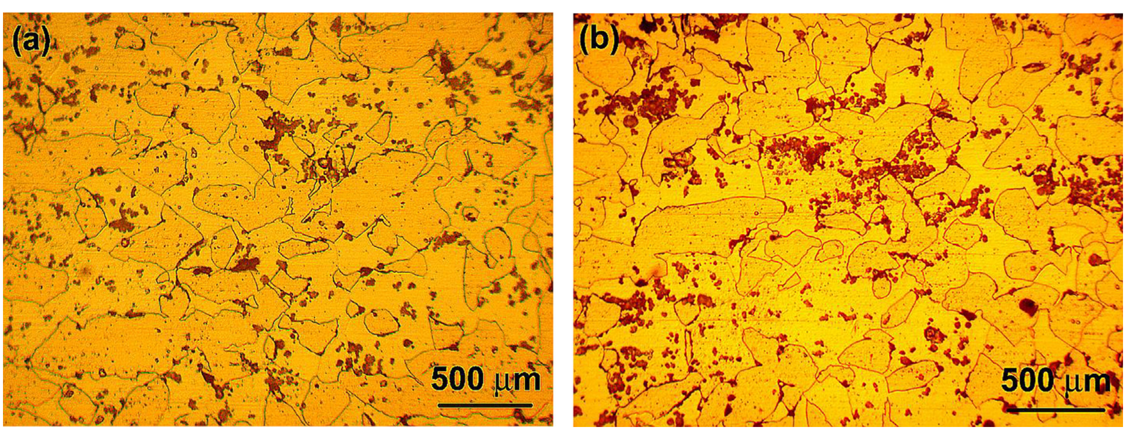

Fig. 1. Microstructure of the as-received materials used in this investigation: (a) CuZn39Pb2 and (b) CuZn39Pb3.

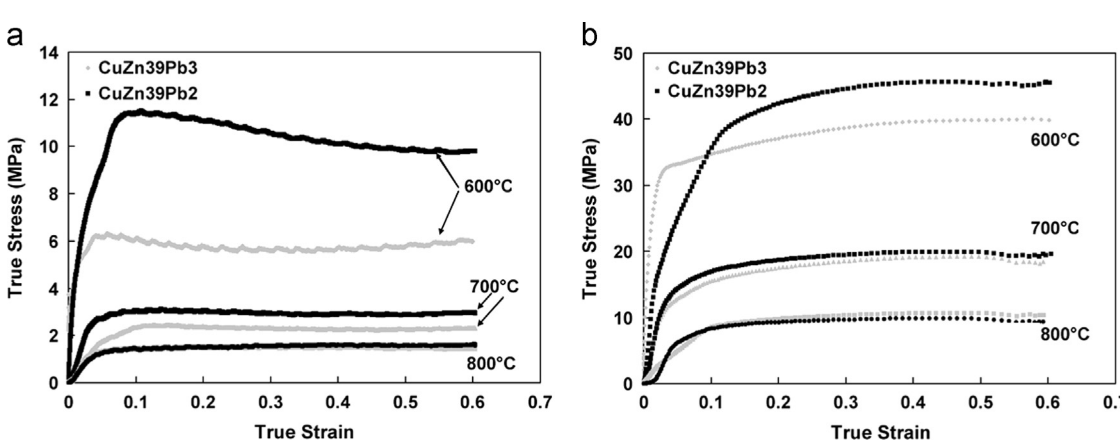

Fig. 2. Representative true stress–strain curves of the studied alloys at various temperatures and strain rates of (a) 0.001 s^{-1} and (b) 1 s^{-1}.