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Rationalization of duplex brass hot deformation behavior: The role of microstructural components

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ABSTRACT

The sharing role of microstructural micro-constituents on hot deformation behavior of a 60/40 duplex brass was investigated through hot compression testing at predetermined temperatures in the range of 400–800 °C under the strain rates ranging from 0.001 to 0.1 s^{-1}. The hot working parameters (strain rate sensitivity, and apparent activation energy, Q) were determined for different conditions of the applied thermomechanical processing. Assuming the Hyperbolic Sine functional behavior to analysis the deformation behavior of the alloy and also applying the rule of mixture in order to determine the share of each phase in strain accommodation, the interaction coefficients of alpha phase, P, and beta phase, R, were precisely estimated. The results indicate that the experimental material exhibits usual Dynamic Recrystallization (DRX) behavior such as single-phase materials; but in comparison to the conventional alloys DRX is postponed at 500 and 600 °C. Moreover, it is seen that the deformation mechanism at different temperatures has been severely depend on the order–disorder transformation of the beta phase in mixture. In fact this transformation is considered to play the main role in beta phase recrystallization retardation. However, at lower Zener Holloman (Z) values, the strain accommodation is mainly taken place in beta phase and the chief deformation mechanism is believed to be grain boundary sliding (GBS). Accordingly there crystallization of alpha phase is limited due to the lower strain accommodation. In contrast, at higher Z values, the alpha phase controls the governing deformation mechanism and the dynamic recrystallization of alpha grains may well lead to the microstructural grain refinement.

1. Introduction

In general the alloys consisting of soft and hard phases would offer desired combinations of high strength and good ductility if the related mixtures have been correctly managed [1–4]. In many cases, the plastic deformation behavior of two-phase alloys is characterized by large differences in strain and/or stress bearing of the phases, and the mechanical properties reflect a synergistic interaction of their properties [5–8]. The plastic incompatibility between the phases may cause both a strong contribution to strain hardening and high local stress concentrations. These may lead to premature fracture by void initiation and propagation, unless relieved by flow localization [9,10]. These characteristics upraise the need for characterizing the optimum thermomechanical processing (TMP) scheme, where the differences between thermal deformation behaviors of each phase would be affected by the presence of the other phase under hot working conditions. The successful application of a duplex structure requires a correct description of its properties by taking into account the interactions between the related micro-constituents. Up to date various fundamental investigations have been carried out to understand the deformation behavior of two-phase materials (e.g., two-phase bi-crystals of alpha–beta brass and duplex stainless steels)at ambient and high temperatures [9,11–13]. Hingwe et al. [14] introduced the interphase boundaries as a barrier to plastic strain accommodation in duplex bi-crystals. In the case of duplex stainless steel [9], the interface boundary sliding and preferential shearing in the ferrite were considered as the strain accommodation mechanism. They also showed that the nature of the interphase and the spatial-phase distribution would play an important role in acting any aforementioned mechanisms. In this context, Kawazoe et al. [15] have studied the slip behavior of the duplex brass bi-crystals under cyclic deformation and the elastic mismatch between each phase was realized to be responsible for different slip characters activated in both alpha and beta phases. It was concluded that the

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stress–strain curves of any duplex brasses were strongly dependent on the orientation and volume fraction of the present phases. Padmavardhani and Parsad [16,17], investigated the hot deformation behavior of the α and α–β brass using processing maps. In this respect, the authors [18] and Xiao et al. [19] developed a constitutive model to describe the hot deformation behavior of the duplex brass. They found that since the β phase was significantly stronger than α one in the applied hot working temperature range, it would affect the load transfer and therefore the strain transfer characteristic between the micro-constituents in the duplex structure. However some controversial discussions over the dominant restoration processes in each micro-constituent have still remained.

From mechanical point of view, the law of mixtures based on uniform criteria is normally followed in the wrought material; this is a good indication of strain partitioning between phases. Having this approach in mind, many researchers have worked on the modeling of strain partitioning [20–22]. Accordingly the relation between the hot working behavior of duplex stainless steel (DSS), volume fraction of the constituents and the values of partitioned stress–strain in each phase were well described by the law of mixture [22,23]. Several variants of this principle have been proposed for modeling the stress and strain distribution in the constituent phases.

The present work deals with the rationalization of high-temperature flow behavior of α–β brass through analyzing the corresponding flow curves as well as hot-working response of each micro-constituent. The microstructural evolution of each phase under the applied thermomechanical processing is also addressed.

2. Experimental procedure

The experimental duplex brass was received in as-extruded condition, the chemical composition of which is given in Table 1. The initial microstructure of the as-received material is composed of feathery like alpha phase, holding the stacking fault energy (SFE) of ~15 mj/m^{-2} [24,25], dispersed in the beta phase matrix possessing the SFE of ~14 mj/m^{-2} [26] (Fig. 1). Annealing twins and recrystallized grains of alpha phase are the main characteristics of the initial microstructure. The compression tests were conducted according to ASTM E209 [27] standard using cylindrical specimens. The isothermal hot compression tests were carried out at temperatures of 400, 500, 600, 700 and 800 °C (673–1073 K) under the strain rates of 0.1, 0.01 and 0.001 s^{-1}. The reduction in height was 60% by the end of the compression tests. The specimens were first heated up to the deformation temperature and held isothermally for 5 min. prior to the straining. The compression tests were executed using GOTECH AI7000 universal testing machine coupled with a programmable resistance furnace and a tool geometry that allows for rapid quenching the specimens. A very thin Mica plate was used to minimize the friction effect. The applied load was recorded using a high accurate load cell (Model: SSMDJM – 20 kN) providing the capability of measuring the load forces down to 0.1 kg. The displacement data were used to compute the true strain values.

To examine the microstructure, the specimens were sectioned parallel to the compression axis and mounted using cold curing resin. These were then grinded and mechanically polished. The microstructures were revealed using saturated sodium thiosulfate solution holding 1 g addition of $K_2S_2O_5$. Eventually, the generated microstructures were characterized using optical microscopy. Moreover, for investigation of the order–disorder transformation temperatures for the as-received specimen, the differential scanning calorimetry method has been made by a Mettler Toledo, Star SW 9.20 calorimeter. The specimen has been put into the furnace at 200 °C and heated to the 600 °C with heating rate of 50 °C/min, in order to simulate the heating condition of specimens under hot compression testing.

Table 1
The chemical composition of experimental lead-free duplex brass (wt%).

Cu	Fe	Pb	Sb	Bi	Zn
61.00	< 0.15	< 0.15	< 0.005	< 0.002	Bal.

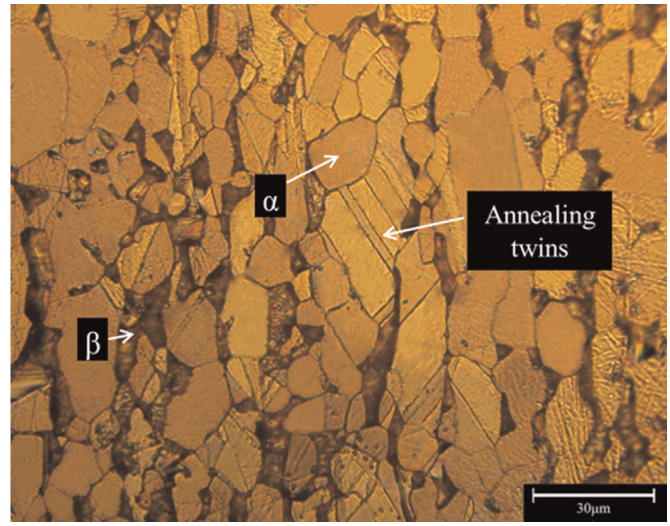

Fig. 1. The initial microstructure of the experimental material (as-extruded lead-free duplex brass).

3. Results and discussion

3.1. Characteristics of the flow curves

A series of typical true stress–true strain curves obtained through isothermal hot compression tests are presented in Fig. 2. As is seen the flow stress increases significantly by decreasing the temperature and increasing the strain rate. This indicates that there is a positive sensitivity inflow stress verses variations of deformation temperature and strain rate [28]. The general characteristics of the flow curves are similar at all deformation conditions. The flow curves exhibit a peak stress, followed by a dynamic softening regime down to the steady state behavior, which are typical characteristics of dynamic recrystallization (DRX) [2,29–31]. Accordingly, DRX is considered as the dominant restoration mechanism during hot deformation of the experimental alloy.

It is well understood that the characteristic points of flow curve and their relationship with processing variables have a great importance in clarifying the hot deformation behavior of the alloys. In this respect, the peak point of flow curves and the point corresponding to the onset of steady state flow should be noticed. The strain rate, $\dot{\varepsilon}$ (s^{-1}), and the deformation temperature, T (K), is often incorporated into a single parameter known as Zener–Hollomon parameter, Z, given by [2]

$$Z = \dot{\varepsilon}\ \exp\left(\frac{Q}{RT}\right) \tag{1}$$

where Q (J/mol) and R denote the apparent activation energy and gas constant (=8.314 J/mol K), respectively. In order to investigate the effect of hot deformation parameters on the microstructural