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Thermomechanical treatment of 70/30 brass containing iron impurity

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Abstract Iron as a main impurity in cartridge brass reduced ductility and formability of the rolled sheets. In the present investigation the effect of thermomechanical treatment on the formability of 70/30 brass containing iron impurity has been considered. As a new finding it has been shown that thermomechanical treatment can significantly improve ductility of 70/30 brass containing 0.35% iron impurity. This effect is believed to be a result of particle coarsening caused by TMT which affect the recrystallization of the brass sheets.

Introduction

The C26000 alloy, containing 70% copper and 30% zinc, is predominantly used for cartridge case production and has an outstanding record of excellent formability coupled with high strength. On the other hand, the use of scrap is an essential part of production when the maximum economy is required. However, this leads to an increase in the impurity content of various alloys. Recycled cartridge brass is such an example in which the iron impurity drastically reduced the ductility and formability of the semi-finished products.

Traditionally modifier elements like Si and Mn were added as a melt refiner to reduce the iron percentage of brass melt [1]. In addition, an experimental study of cartridge brass L68 containing Pb and Fe indicates that alloying with Mn or Si leads to an increase in the volume fraction of intermetallic compounds of type $MnSi_3$ and Fe_5Si_3, with a reduction in strength characteristics. Furthermore, it has been reported that Mn in general increases ductility, while Si has the opposite effect and an increase in Mn content, with the amount of intermetallic compound particles remaining constant, results in significant softening, whereas an increase in Si content results in hardening [2]. It is also well known the addition of iron and other elements like Si to Cu–Zn alloys lead to grain refinement due to the formation of fine precipitates, which inhibit grain growth [3].

More recently, the influence of additional elements on grain refinement of copper alloys was considered. It was found that the addition of silicon to Cu–Zn alloys increases number of nucleation sites, and the addition of minute amounts of cobalt to Cu–Zn–Si alloys inhibits grain growth. The increase in the number of nucleation sites was considered to be due to the decreasing stacking fault energy upon the addition of silicon. Inhibition of grain growth was considered to be due to the formation of fine precipitates upon the addition of cobalt [4].

The purpose of this study is to investigate the effect of thermomechanical treatment (TMT) on the formability of cartridge brass containing iron impurity, and moreover, to clarify the dominant mechanisms.

Experimental procedure

The starting materials used in this investigation were cast 70Cu–30Zn cartridge brass with 20 mm thickness

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containing (in wt.%) 0.1–0.5 iron impurity. Some of the specimens were hot rolled at 800 °C to 3 mm thickness followed by cold rolling to 2 mm. Some others were subjected to a TMT consisting of cold rolling 10% followed by heat treatment at 800 °C for 10 h. These specimens were then hot rolled to 3 mm thickness followed by cold rolling to 2 mm. In both conditions the rolled sheets were annealed in the temperature range of 450–750 °C.

Uniaxial tensile test specimens, 75 mm long and 12 mm wide prepared from the sheets were pulled to fracture at a cross-head speed of 5 mm min^{-1}, producing an average strain rate of 1×10^{-3} s^{-1} as the specimen extended. Load-extension curves were obtained with the aid of a 25 mm gauge length extensometer, from which the nominal and true stress–strain curves were calculated.

For optical microscopy, specimens were mechanically ground and chemically polished in a solution of $NH_4OH:HNO_3:FeCl_3$ = 10:6:10. The grain size of specimens was determined using the planimetric procedure on the basis of ASTM-E112–96.

Results and discussion

The effect of iron impurity on the ductility of the 70/30 brass at 650 °C annealing temperature is shown in Fig. 1. It is clear iron impurity has a significant effect on the ductility and elongation. Elongation-iron percentage curve shows a steep decline as iron impurity increased and this effect is much stronger for specimens with higher iron percentage.

Nominal stress–strain curves corresponding to an average strain rate of 1×10^{-3} s^{-1}, obtained for different samples annealed at 650 °C, are shown in Fig. 2. As shown in this figure, different conditions of the material showed different behavior in terms of flow stress and elongation. The curves for the TMT conditions show significant plastic deformation before fracture, while for the 0.35% Fe specimen the stress–strain curves exhibit premature failure. It is also evident that the effect of TMT on the ductility is improved when Si is added.

The variation of total elongations with annealing temperature for 0.35% Fe specimens and TMT samples containing 0.35%Fe + 0.5%Si are shown in Fig. 3. It is observed that total elongations of the 0.35% Fe sheets continuously increased with increasing annealing temperature, implies that a continuous recrystallization occurred. For the TMT materials, however, there existed a critical annealing temperature above which, the elongation values abruptly increased and showed a discontinuous pattern. The steep incline in elongation implies that a complete softening due to discontinuous recrystallization has taken place.

Figure 4 shows the optical micrograph of 0.35% Fe sheet annealed at 650 °C and Fig. 5 shows the microstructure of the same specimen followed by TMT and subsequent annealing. It is observed the grain structure

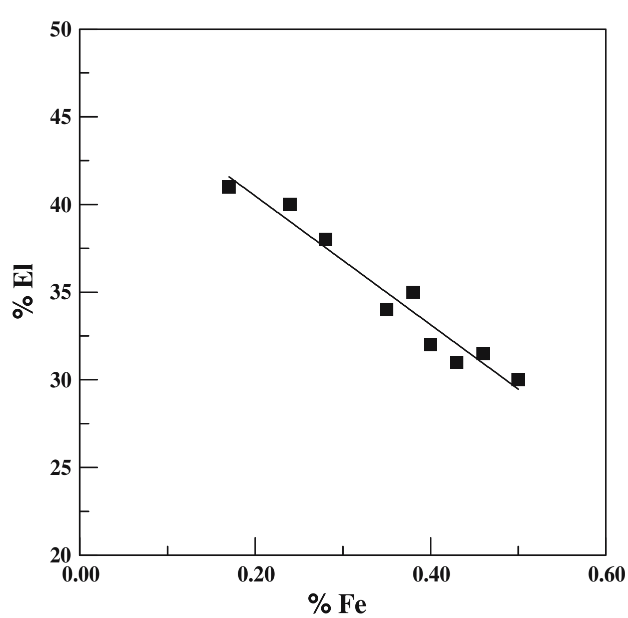

Fig. 1 Variation of elongation plotted as a function of iron percentage at 650 °C temperature in 70/30 brass

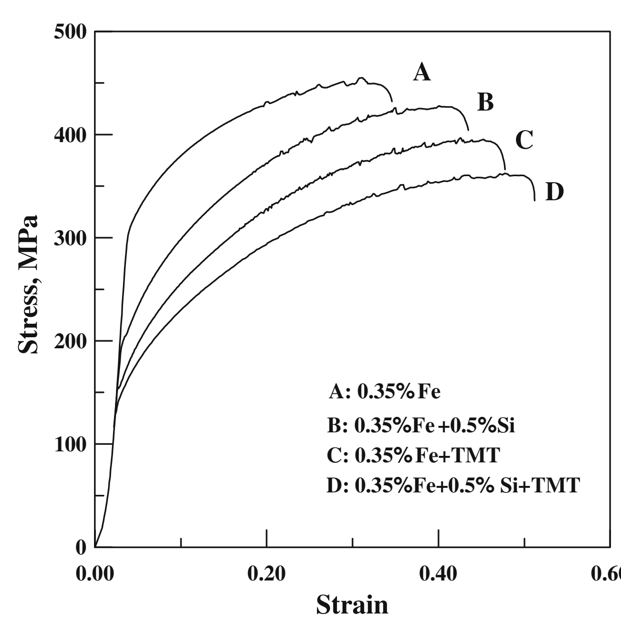

Fig. 2 Nominal stress–strain curves obtained for different samples annealed at 650 °C

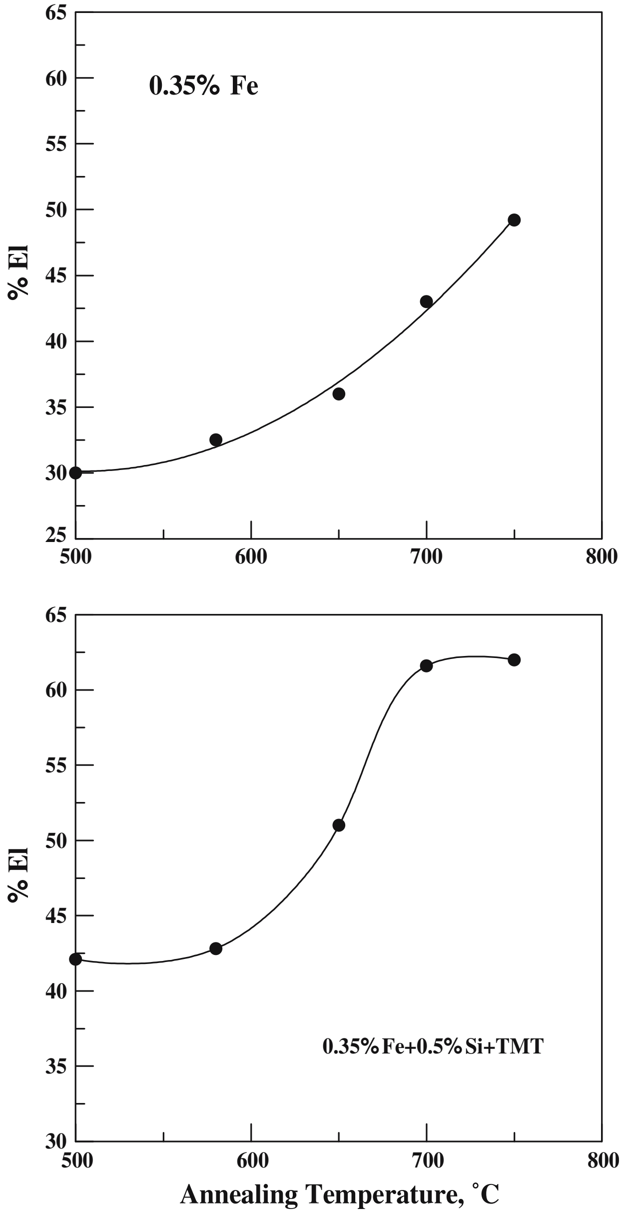

Fig. 3 Variation of elongation with annealing temperature for 0.35%Fe specimens and TMT specimens containing 0.35%Fe + 0.5%Si

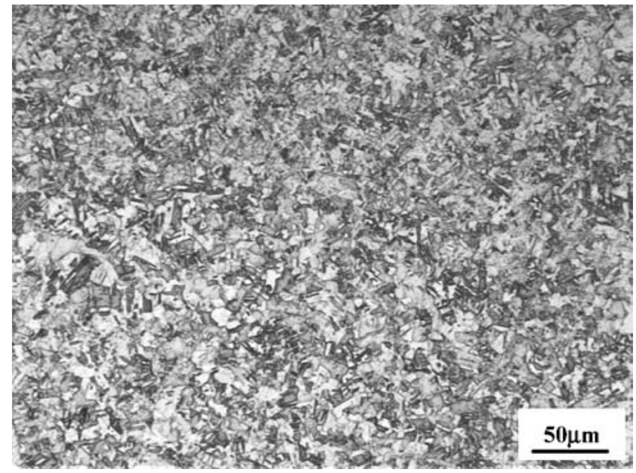

Fig. 4 Optical micrograph of 0.35%Fe sheet annealed at 650 °C

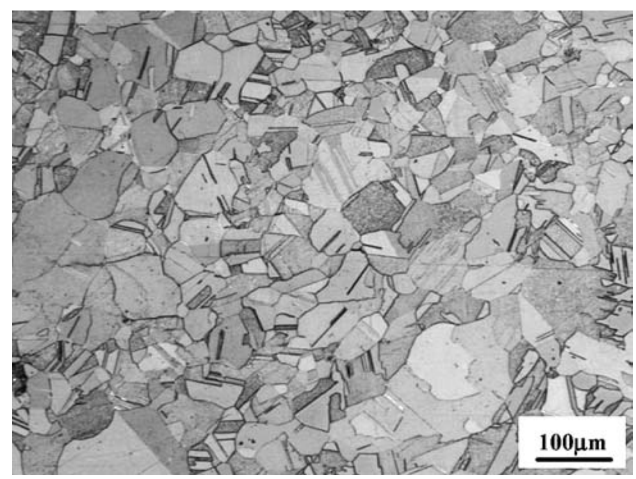

Fig. 5 Optical micrograph of TMT specimen containing 0.35%Fe annealed at 650 °C

is completely developed in TMT samples, a very fine grain structure in 0.35% Fe sheet generated though. The grain size of some specimens at 650 °C and 750 °C annealing temperature are shown in Table 1. It is clear the grain size of the TMT samples are greater and this can be the main cause of superior ductility in this condition.

The major difference between TMT and other specimens is that the elevated temperature treatment removes short wavelength solute segregation, and depending on the thermal history associated with the TMT, precipitates Fe and Si from solution. Fe and Si in solution control recrystallization and thus control formability of these alloys. The microstructure of 0.35% Fe sheet, Fig. 6, contained a dispersion of small round intermetallic particles which are uniformly distributed in the matrix. The structure after modifying with Si, Fig. 7, shows lower volume fraction of larger particles and some newly formed rod like precipitates. These precipitates coarsened after prolonged heating at high temperature during TMT as indicated in Fig. 8.

Numerous investigation have been done on the influence of constituent particles, including fine dispersoids and large primary particles on the recrystallization, texture and mechanical behavior of the alloys. It is well established that the finely dispersed of particles inhibit recrystallization while large particles promote recrystallization [5, 6]. The pinning forces due to particles can be calculated using the Zener pinning equation for a random distribution of spherical particles:

Table 1 Grain size in micron meter for different specimens

	0.2%Fe	0.2%Fe + TMT	0.35%Fe	0.35%Fe + TMT	0.35%Fe + 0.5%Si	0.35%Fe + 0.5%Si + TMT
Anneal at 650 °C	103	125	16	21	19.5	32
Anneal at 700 °C	153	165.5	19	27	23	37.5

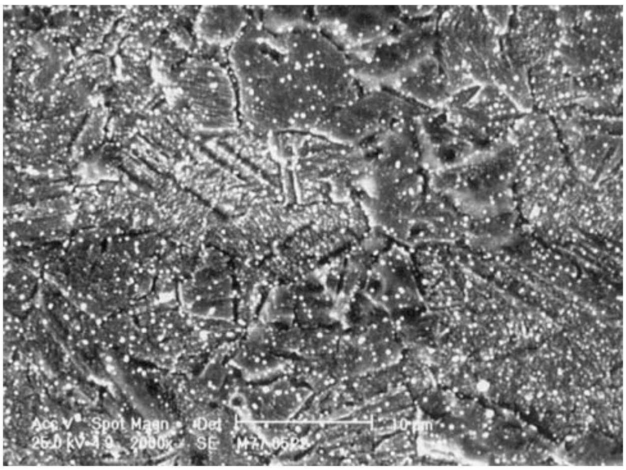

Fig. 6 Microstructure of 0.35%Fe sheet annealed at 650 °C shows a dispersion of small round intermetallic particles

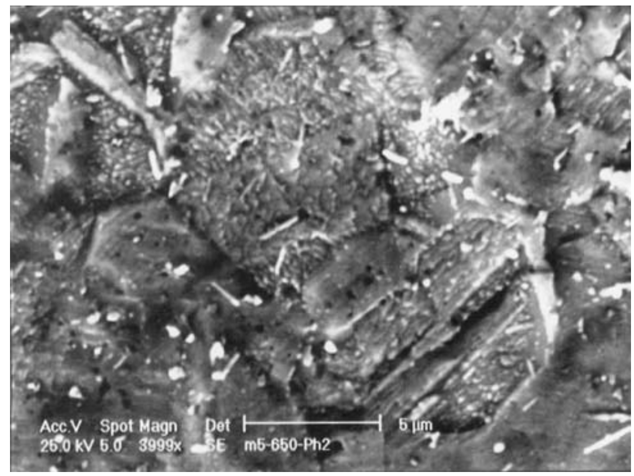

Fig. 7 Microstructure of specimen annealed at 650 °C containing 0.35%Fe + 0.5%Si

$$P_Z = \frac{3F_V\gamma_B}{2r}$$

where F_V is the particle volume fraction, r the particle radius and γ_B the grain boundary energy. The limiting grain sizes at different annealing temperature can be approximated using the Zener limit equation [7]:

$$D_Z = k\left(\frac{r}{F_V}\right)$$

For the TMT specimens with smaller volume fraction of precipitates and larger particles the pinning force must be weaker and this leads to a larger grain size as indicated in Table 1.

It is believed the presence of small particles in 0.35%Fe sheets play important roles in continuous recrystallization. This mechanism is viewed as the pinning of sub-boundries due to small particles at low annealing temperatures and their subsequent coarsening at higher temperature, enabling subgrain growth to occur via the migration of low- and high-angle boundaries [8]. Obviously, the particle coarsening resulted from TMT discards this mechanism.

The strength of metals are proportional to grain size according to the Hall–Petch equation. In spite of the fact that Hall–Petch equation is widely known and accepted, it has been shown that in many cases the scatter in the data was such that σ_0 versus $D^{-1/3}$ or σ_0 versus D^{-1} yielded as good a fit to the experimental results as σ_0 versus $D^{-1/2}$ [9]. Consequently, the yield stress grain size relation in general can be considered as: $\sigma_y = \sigma_0 + kD^{-m}$ where σ_0 is a frictional stress re-

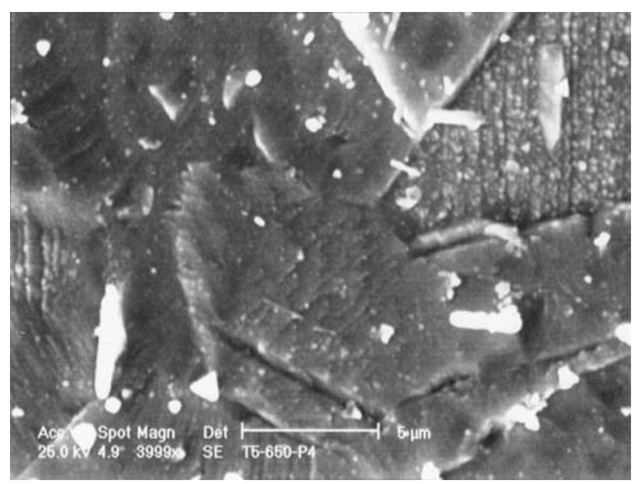

Fig. 8 Microstructure of a TMT specimen annealed at 650 °C containing 0.35%Fe + 0.5%Si

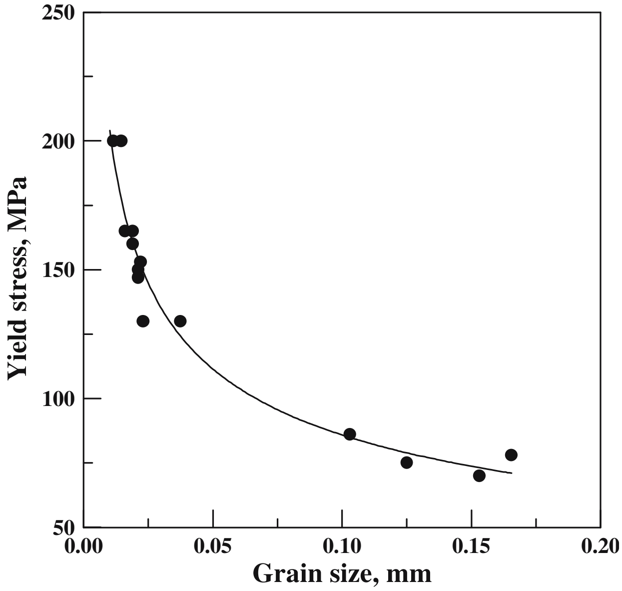

Fig. 9 Variation of grain size plotted as a function of 0.2% yield stress

quired to move dislocation and the exponent m has been found to vary between 1/2 and 1.

The variation of yield stress with grain size for a number of specimens involving both fine and coarse grains are shown in Fig. 9. The data points were subjected to a least-squares software to obtain the coefficients. The values obtained $k = 12.84$ $N/\text{mm}^{-3/2}$, m=0.58 are close to the Hall–Petch equation. However, large deviations from the Hall–Petch equation at small grain sizes were obtained [10, 11]. For grain sizes smaller than 30 μm the best fit yielded $k = 1.59$ $N/\text{mm}^{-3/2}$ and $m = 0.97$.

Conclusions

- Results of the present study show that ductility of 70/30 brass with 0.35% iron concentration improved by TMT consisting of cold rolling 10% followed by heat treatment at 800 °C for 10 h and then hot rolling.
- Despite of other reports Si additive increases grain size of 70/30 brass containing iron impurity and this effect is promoted when specimens are subjected to a TMT.
- It is believed that particle coarsening caused by TMT could affect the recrystallization of the brass sheets containing iron impurity resulted in larger grain size and superior ductility.
- Concerning Hall–Petch relation σ_0 versus D^{-1} yielded a better fit to the experimental results than σ_0 versus $D^{-1/2}$ for fine grain sizes.

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