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Impact of High Temperature and Beta-Phase on Formability of Cylindrical Cups from Cu-28%Zn and Cu-37%Zn Alloys

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Abstract

Cu-Zn alloys are extensively used in industries on account of their strength, ductility, formability and corrosion resistance. Cu-Zn alloys with Zn content higher than 35 wt.%Zn have reduced plasticity due to formation of intermetallic beta-phase. The present work was intended to understand the behaviour of Cu-28%Zn and Cu-37%Zn alloys during deep drawing process of cylindrical cups. Both experimental and numerical analysis were carried out to establish the formability of these alloys. The numerical analysis was implemented using finite element analysis software code of DEFORM-3D. The main conclusion of this work was that the cylindrical cups were ruptured at the punch radius due to equi-biaxial tension induced in the Cu-37%Zn alloy at temperature 750^{o}C. Also, the Cu-37%Zn alloy has experienced the elevated temperature deformation behavior of alpha-beta phases.

Keywords: Cu-28%Zn, Cu-37%Zn, high temperature deep drawing process, formability.

1. INTRODUCTION

Brass is an alloy of copper (Cu) and zinc (Zn). Brass made during the early Roman period seems to have varied between 20 to 28 wt.%Zn [1]. Cu-Zn alloys are widely used as industrial materials because of their excellent properties such as strength, ductility, high corrosion resistance, non-magnetism and good formability [2]. The Cu-Zn brasses consists of nearly 38.95 wt.% Zn at a high temperature. As per the casting technology, Cu-Zn alloys show a single α-phase FCC (face centered cubic) structure below 35 wt.% Zn. Higher than 35 wt.% Zn, the intermetallic β-phase (CuZn) is formed. The β-phase induces precipitation strengthening, but at the cost of the reduced plasticity. For this said reason, industrial Cu-Zn alloys contain no more than 40 wt.% Zn [3].

The tensile strength increases rapidly with increasing the Zn content, however, the increasing tendency slows down above about 20 wt.%Zn. Hence, the zinc content in the present work was limited to 37 wt.% only. In one of the research paper it was observed that with increasing recrystallization temperature within the range 400˚C - 650˚C, the mechanical properties were deteriorated in the properties of the brass and an increase in the plastic properties [4]. In another study, the deformation behavior of alpha and beta brass was investigated at temperatures just above and below the ordering temperature of beta [5]. Deformation of beta, unlike alpha, was found to be highly sensitive to temperature and strain-rate.

Hot deep drawing is a complex process to understand the behavior of sheet materials. Forming limit diagrams make simple to understand the behavior of sheet materials. Nowadays, a number of analytical models are being used to predict the forming limit diagram. In the present work, the formability limit diagrams have been predicted based on the procedure adopted for several materials such as AA1050 [6], AA2014 [7], AA2017 [8], AA2024 [9], AA2219 [10], AA2618 [11], AA3003 [12], AA5049 [13], AA5052 [14], AA5556 [15] and AA6061 [16].

The aim of the current work was to explore the impact of temperature and β-phase in the range 550°C -750°C during hot deep drawing process of Cu-28 wt.%Zn and Cu-37 wt.%Zn alloys. Formability limit diagrams were predicted based on the results obtained from the finite element analysis software code namely DEFORM-3D. The numerical results were validated with the experimental results.

2. MATERIALS AND METHODS

The sheet materials used in the present work were CuAl5 and CuAl8 alloys. Uni-axial tensile tests were conducted to find tensile strength of these alloys at room temperature and high temperatures. Lever rue of phase diagrams was used to amount of α and β phases of these alloys at three operating temperatures of deep drawing process of cylindrical cups. The cylindrical cups were deep drawn using hydraulic press as shown in figure 1. The finite element modeling and analysis namely D-FORM 3D software was employed to predict formability limit diagrams. In the present work, moving blank die was used to hold the blank at a predefined speed different to the punch speed. The contact between blank/punch and die/blank were coupled as contact pair. The mechanical interaction between the contact surfaces was assumed to be frictional contact and modeled as Coulomb's friction model.

Figure 1: Hydraulic type deep drawing press.

3. RESULTS AND DISCUSSION

The target dimensions of cylindrical cups were 60 mm diameter and 75 mm height. The strain rate and coefficient of friction, punch velocity, and blank holder velocity were maintained constant at $10s^{-1}$, 0.15, 1.5 m/s, and 0.3 m/s, respectively. The blank holder was movable along with punch. The tensile strength of Cu-28wt.%Zn and Cu-37wt.%Zn alloys is dropped with increasing temperature as shown in figure 2. With the increasing temperature of recrystallization within the range of 400˚C - 750˚C, the plastic properties of the Cu-28wt.%Zn and Cu-37wt.%Zn alloys are found to increase. Brass which has FCC structure exhibit low stack fault energy (SFE) [17] and the stack fault energy decrease rapidly when the zinc content of brass increases.

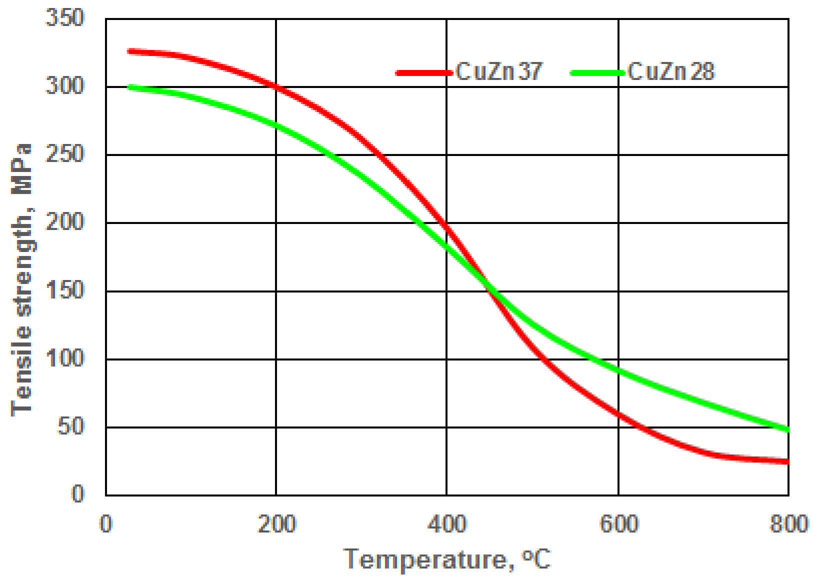

Figure 2: Effect of temperature on tensile strength.

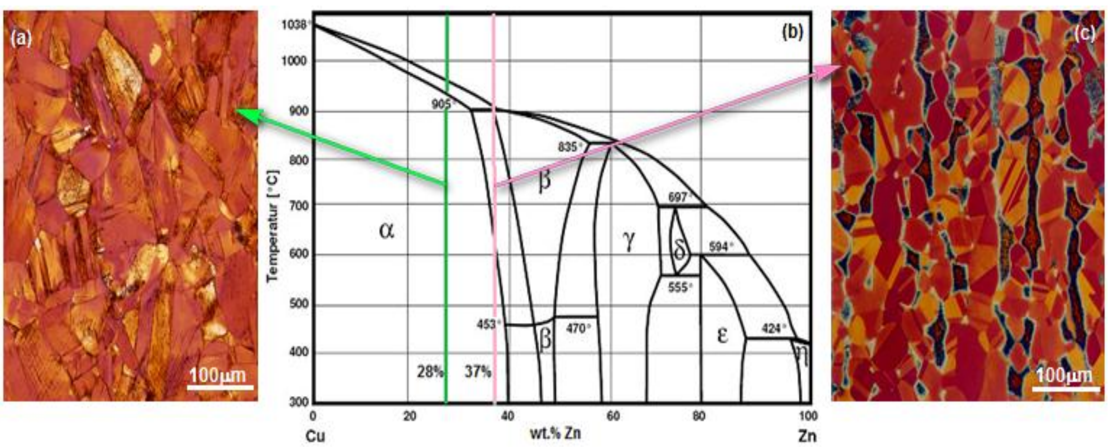

Figure 3: Phase diagram of Cu-Zn alloy: microstructure of hot formed (a) Cu-28%Zn and (b) Cu-37%Zn

As seen from Cu-Zn binary phase diagram shown figure 3, the formation of β-phase increases with increasing content of Zn in the Cu-Zn alloys and with increasing temperature. The α-phase has FCC structure and the β-phase BCC structure. The β-phase is harder than α-phase. Hot formed microstructures as revealed in figure 3a and figure 3c exhibit deformed grain structures with considerable slip (BCC and FCC phases) at 750°C.

3.1 Effect of Temperature on von Mises Stress

The effect of drawing temperature on the von Mises stress is shown in figure 4. Within the operating temperature 650°C, the von Mises stress decreases with increasing temperature for both the alloys of Cu-28%Zn and Cu-37%Zn. The trend is different during the initial stages of deep drawing up to stroke length of 30 mm at temperature 750°C. From 35 to 70 mm of stroke length, Cu-28%Zn alloy at temperature 750°C behaves as that of 550°C and 650°C. From 70 to 75mm of stroke it suddenly rises indicating high local plastic deformation consequently resulting thinning of the sheet material in the side walls of the cups (figure 5a). At temperature 750°C the Cu-37% Zn behaves differently. For the stroke length between 35mm – 50mm, the sheet material behaves as that at temperatures of 550°C and 650°C. Above 50 mm of stroke length Cu-37%Zn alloy has experienced very severe plastic deformation leading to the rupture at the punch radius of the cup (figure 5b).

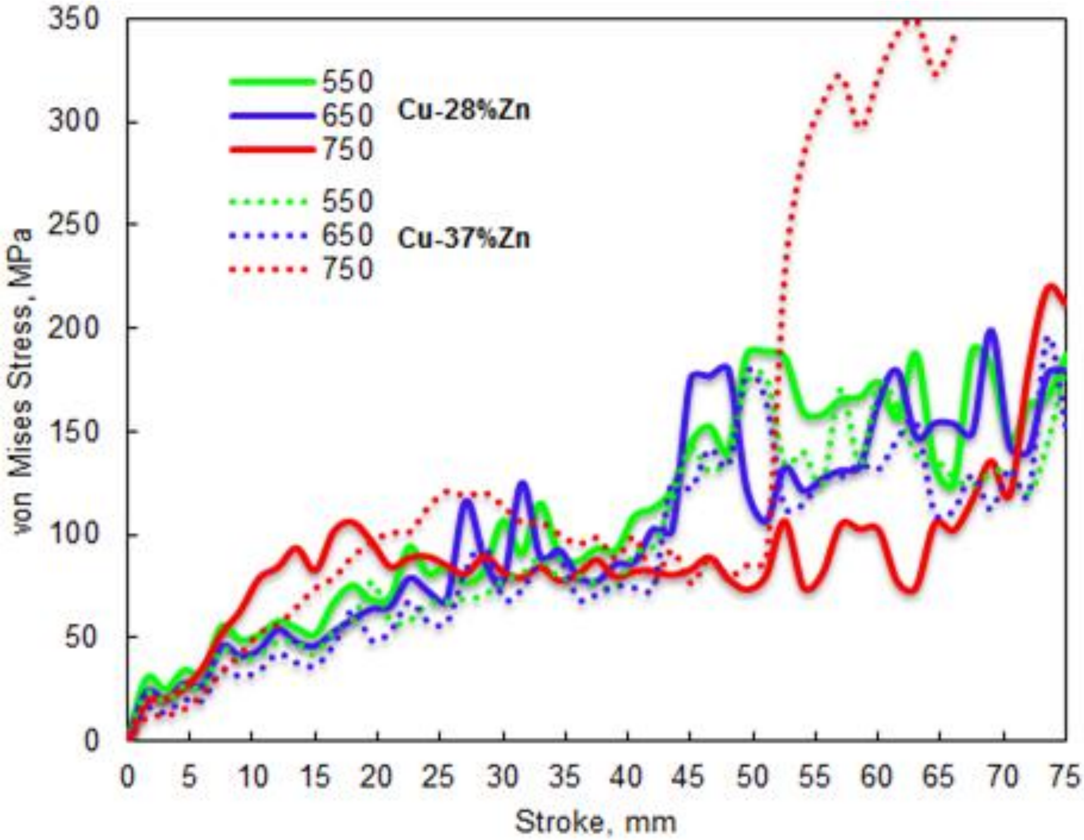

Figure 4: Effect of temperature on von Mises stress.

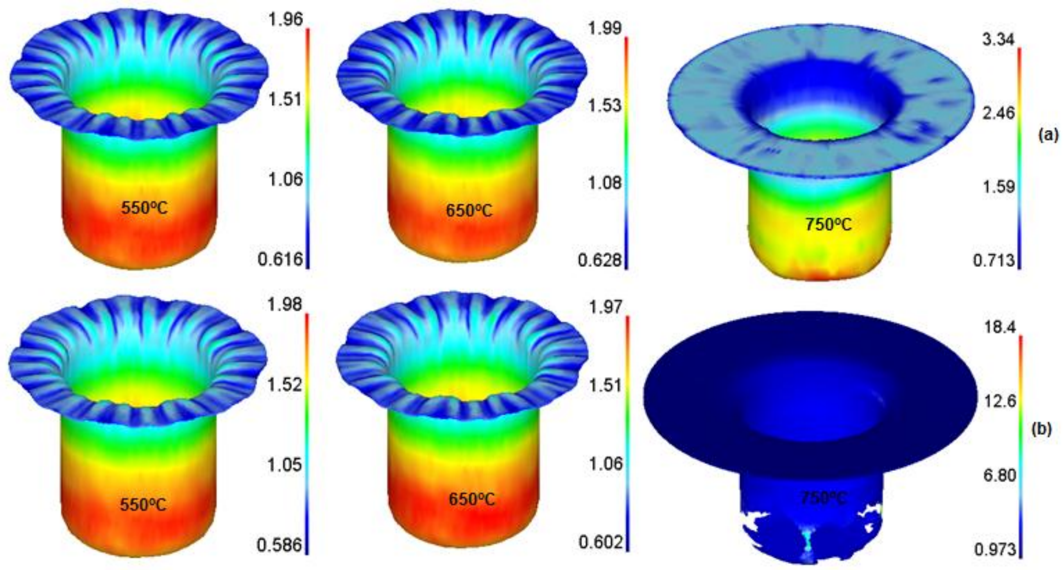

Figure 5: Effect of temperature on surface expansion ratio: (a) Cu-28%Zn and (b) Cu-37%Zn alloy.

3.2 Effect of Process Variables on Formability

Effect of temperature on the formability of cylindrical cups drawn from Cu-28%Zn and Cu-37%Zn alloys is shown in figure 6. At 550ºC and 650ºC, the formation of wrinkles is noticed in the flange area of cups as seen from figure 5. The formation of wrinkles is due to different yield stresses along different directions in the sheet material prior to deep drawing. Also, the compressive stresses are responsible for the formation of wrinkles in the flange area of the cylindrical cups. While, Cu-28%Zn and Cu-37%Zn alloys have experienced the equi-biaxial tension in the cylindrical cups at temperature 750ºC. The equi-biaxial tension is very high in the Cu-37%Zn alloy due to increased hardness on account of β-phase formation. This leads to ruputure at the punch radius as shown in figure 5b. At 850ºC, the deep drawing process is dominated by shear phenomena only as shown in figure 11. At 650ºC and 750ºC the sheet material has experienced the formation of wrinkles in the flange area due to compression during deep drawing of the cups.

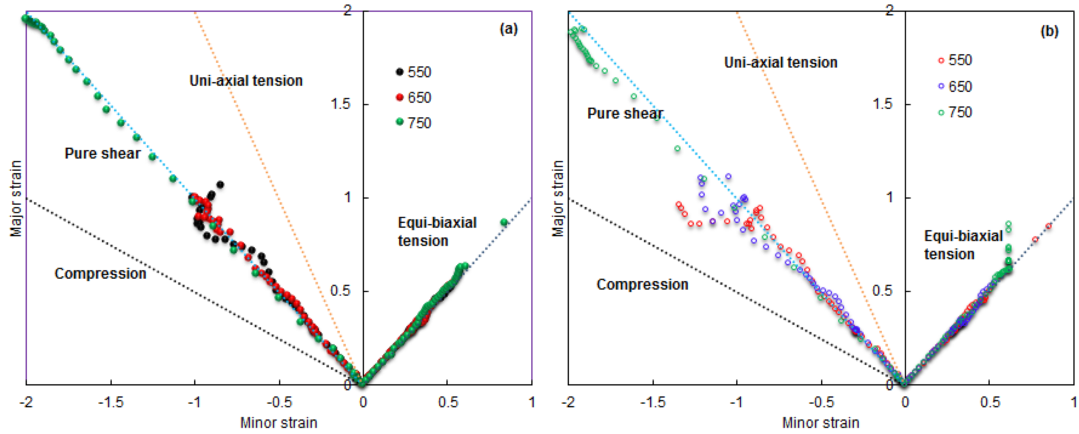

Figure 6: Effect of temperature on formability of (a) Cu-28%Zn and (b) Cu-37%Zn alloys.

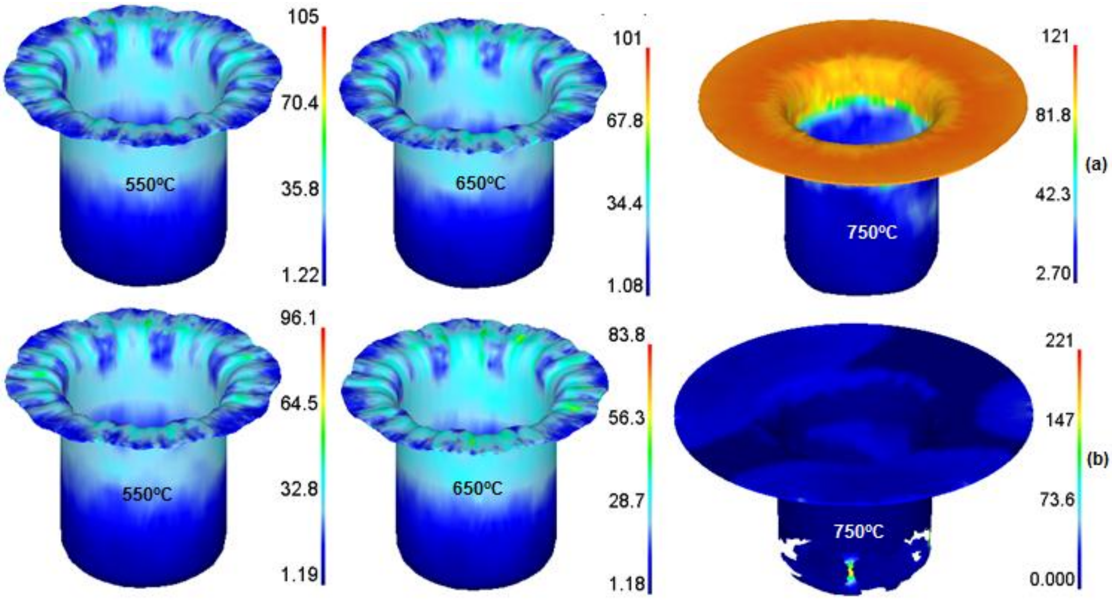

Figure 7: Effect of temperature on shear stress: (a) Cu-28%Zn and (b) Cu-37%Zn alloy.

The shear stresses of Cu-28%Zn and Cu-37%Zn alloys are, respectively, 215 MPa and 266 MPa. Shear stresses induced in the cylindrical cups are within the permissible limits only as shown in figure 7. Hence, the rupture in the cylindrical cups drawn from Cu-

37% Zn is not due to the shear stress, but it is due to equi-biaxial tension and formation β-phase (which is brittle) at temperature 750°C. The results obtained from the finite element analysis are in good agreement with the experimental results as the same phenomenon is seen in the cups drawn experimentally as shown in figure 8. The Cu-37%Zn alloy experiences the elevated temperature deformation behavior of two-phase bi-crystals of alpha-beta, with inter-phase boundary normal to the tensile axis, depended on the deformation of the individual phases.

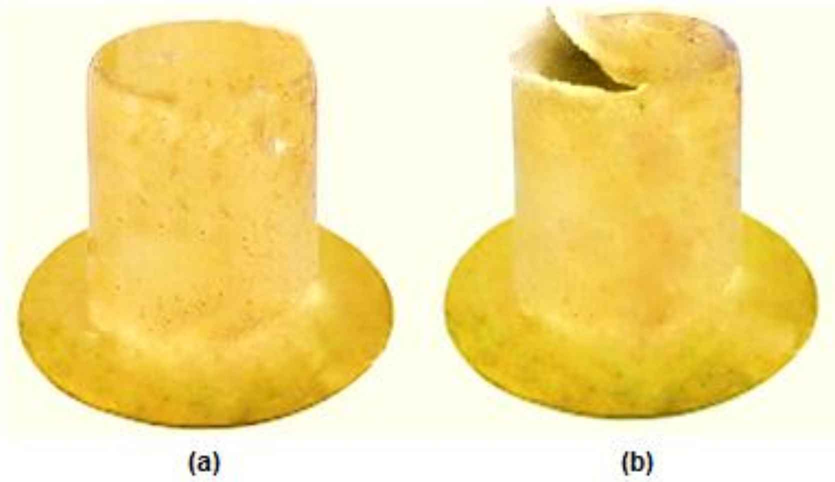

Figure 8: Experimentally deep drawn cups: (a) Cu-28%Zn and (b) Cu-37%Zn alloys.

4. CONCLUSIONS

The numerical analysis could enable to model the hot deep drawing process for the formability of cylindrical cups from Cu-28%Zn and Cu-37%Zn alloys. The cups drawn from Cu-28%Zn alloy would not rupture at three operating temperatures 550°C, 650°C and 750°C; whereas the cups from Cu-37%Zn alloy were ruptured at the punch radius at 750°C. In the Cu-37%Zn alloy, alpha and beta phases were witnessed at 750°C leading severe plastic deformation.

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