Development of processing maps for DC cast 7065 aluminum alloy

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Abstract. The deformation behavior and microstructure evolution of DC cast 7065 aluminum alloy was studied in the temperature range of 340-460 °C and strain rate range of 0.1-8 s\textsuperscript{-1}. Processing maps were developed to evaluate the efficiency of the hot deformation and to identify the instability region. The results show that the optimum range of processing conditions are in the strain rate range of 0.01-0.1 s\textsuperscript{-1} and temperature range of 380-410 °C, where the efficiencies are much higher when compared to other regions. The peak efficiencies for the 7065 alloys is evaluated in the region of T=380-460 °C and ε=0.01-0.1 s\textsuperscript{-1}. Recrystallized grain was observed under these deformation conditions. The dynamic softening is more pronounced at higher deformation strain rate and deformation temperature.

Keywords: Aluminum alloy; Hot deformation; Processing map

1. Introduction

The 7000 series alloys, typically, 7075, 7050, 7055 and 7085 alloys, are based on the Al-Zn-Mg system, have a combination of high strength and fracture toughness, as well as resistance to stress corrosion cracking by proper heat-treatment that renders them very useful in the aircraft and aerospace industry applications [1-3]. Recently, a novel 7065 alloy was developed based on these alloys, which exhibits higher comprehensive properties such as strength, toughness, corrosion resistance, quench sensitive, etc. Workability is usually defined as the amount of deformation that a material can undergo without cracking and reach desirable deformed microstructures at a given temperature and strain rate. Improving workability means increasing the processing ability and improving properties of the materials, this
probably can be achieved by optimum processing parameters. However, the investigation on the hot deformation behavior of the 7065 alloy seldom being reported.

In our previous work, billets of 7065 alloy 150 mm in diameter were obtained through direct chill (DC) casting. The aim of this present investigation is to study the hot deformation behavior and microstructure evolution of a DC cast 7065 alloy using processing map.

The processing map technique has been widely used to understand the workability of many materials in terms of the various microstructural mechanisms operating at the different deformation conditions [4-6]. The technique was developed on the basis of the dynamic materials model (DMM) by Prasad et al., with the complementary relationship between the rate of visco-plastic heat generation induced by deformation and the rate of energy dissipation associated with microstructural mechanisms occurring during the deformation process. A dimensionless efficiency index \( \eta \) was used to represent the power dissipation through microstructural mechanisms and is given as:

\[
\eta = \frac{2m}{m+1}
\]

Where \( m \) is the strain rate sensitivity of flow stress:

\[
m = \frac{\partial (\ln \sigma)}{\partial (\ln \varepsilon)}
\]

The contour plot of the iso-efficiency \( \eta \) values on the temperature-strain rate field constitutes the processing map. The dissipation characteristics vary for different microstructural mechanism, each domain on the map corresponds with a single dominant mechanism operating under those conditions of the domain. In addition to the \( \eta \) contours, the instability criterion given by the equation

\[
\xi = \frac{\partial \ln (\frac{m}{m+1})}{\partial \ln \varepsilon} + m < 0
\]

Is applied to delineate the temperature-strain rate regimes of flow instability on the processing map. A detailed description of \( \eta \) value in the interpretation of the domains, was given by Prasad and Sasidhara [7].

2. Experimental procedure

The 7065 aluminum alloy (nominal chemical compositions are listed in Table 1) was prepared using 99.94wt% pure Al, 99.92wt% pure Mg, 99.99wt% pure Zn, Al-49.7wt%Cu, Al-5wt%Zr and Al-5wt%Ti master alloys. The alloys were melted in an induction furnace and DC cast to produce billets 150 mm in diameter with a pouring temperature of 780°C and casting velocity of 3 mm/s. After degassing, certain amount of Al-5wt%Be master alloy was added to the melt at the temperature of 800°C, then held for 20 min before casting. The billets was homogenized at 470°C for 12h and follow by air cooling. The initial microstructures of the as-cast and homogenized alloys are shown in Fig.1 (a) and Fig.1 (b), respectively. They comprise \( \alpha \)-aluminum dendrite with Al-Cu-Mg-Zn eutectics and coarse intermetallic compounds segregated into the interdendritic regions. After homogenization, the \( \alpha \)-aluminum dendrite transforms to equiaxed crystals, and the coarse intermetallic compounds dissolve into the \( \alpha \)-aluminum.

| Table 1. Nominal chemical compositions of the 7065 alloys (wt.%) |
|-------------------|---|---|---|---|---|---|---|
| Alloy | Zn | Cu | Mg | Zr | Others each | Others total | Al |
| 7065 | 7.6 | 2.1 | 1.7 | 0.1 | 0.05 | 0.15 | Balance |

To investigate the hot deformation behavior and microstructural evolution of the 7065 alloy, isothermal and constant-strain rate compression tests were performed on a Gleeble 1500 testing system over a range of strain rates (0.1, 0.3, 1, 4 and 8 s\(^{-1}\)) and temperatures (300, 340, 380, 420 and 460°C).
Compression test specimens of 15 mm height and 10 mm diameter were cut from the central region of the billets along the longitudinal direction. The specimens were annealed for 1 hour at the testing temperature in a salt bath prior to deformation. The specimens were coated with lubricant and deformed to 60% the initial height then water quenched immediately after the test. The compressed specimens were sectioned parallel to the compression axis for metallographic examination. The metallographic samples were mechanically ground and polished using standard routines. The microstructure was examined with an optical microscope (ZEISS Axio vert. A1) and a scanning electron microscope (ZEISS EVO 18).

![Images of microstructures](a) as-cast and (b) homogenized

### 3. Results and discussion

#### 3.1. Microstructures of the compressed samples

The microstructures of the samples compressed at different conditions are shown in Fig.2. The figures illustrate that when the sample was deformed at 300°C and strain rate of 8 s⁻¹, there are extensive intermetallic compound particles in the matrix (Fig. 2(a)). When increase the deformation temperature to 380°C, the intermetallic compound particles decrease(Fig. 2(b)). When increase the deformation temperature to 460°C, there is little intermetallic compound particle in the matrix, leaving discontinuous particles on the grain boundaries.

![Images of microstructures](a) T=300°C; (b) T=380°C; (c) T=460°C

#### 3.2. Flow stress-strain behavior

Typical true stress-true strain curves obtained by compression test are shown in Fig.3, where Fig.3(a), Fig.3(b), Fig.3(c) , Fig.3(d) and Fig.3(e) correspond to deformation temperature of 340, 340, 380, 420 and 460 °C, respectively. In general, the curves are characterized by an initial sharp increase in flow stress and followed by a slow decrease, all the flow stress finally reached a steady state at a strain of 0.2. As can be seen, the flow stress of the alloy is a strong function of temperature and strain rate. At a given strain rate, the peak stress increases with decreasing the deformation temperature, and at a given...
temperature, the higher the strain rate is, the higher the peak stress is. It is observed that the strain hardening is decreased with the increase of temperature and decrease of strain rate. It can be seen that the curves at the strain rate of 8 s$^{-1}$ show a little difference compared with that of the other strain rates. At the strain rate of 8 s$^{-1}$ and deformation temperature of 300°C, the flow stress reach a steady state at a strain of 0.2, while the deformation temperature increase to 340, 380, 420 and 460°C, the flow stress decrease when the strain is increasing, and reach a small valley at the strain of about 0.25, then the flow stress gradually increase with the increasing of strain. The higher the deformation temperature is, the more obvious the flow stress decrease. Dynamic softening is a common characteristic for many alloys deformed at elevated temperature and high deformation strain rate [8]. In the present study, the dynamic softening seems more pronounced at higher deformation strain rate and deformation temperature.

Fig.3. True stress-true strain curves of the 7065 alloys at various conditions: (a) 300°C; (b) 340°C; (c) 380°C; (d) 420°C and (e) 460°C
3.3. Processing maps

The processing maps were constructed following the procedure adopted by Prasad [9]. According to the true stress-true strain curves at different temperatures and strain rates in compression test, the log flow stress versus log strain rate data were fitted using a cubic spline. So the flow stress data can be obtained at finer temperature and strain rate intervals. Then the strain rate sensitivity \( m \) was calculated as a function of strain rate using Eq. (2). The efficiency of power dissipation and instability parameter are calculated using Eqs.(1) and (3) and were plotted in temperature-strain rate plane to obtain the power dissipation map and instability map, respectively. A superimposition of the instability map on the power dissipation map gives a processing map.

The processing maps constructed for the 7065 alloy at strain of 0.2 and 0.4 are shown in Fig.4(a) and (b), respectively. The contour numbers represent constant efficiencies of power dissipation and the shaded regions represent flow instability regions where \( \xi < 0 \). A high deformation efficiency is desirable and is characterized by the parameters of optimum workability where matrix flow localization and particle damage is low. The maximum power dissipation efficiencies for the 7065 alloy are in the region of \( T=380-460 \, ^\circ C \) and \( \varepsilon=0.01-0.1 \, s^{-1} \). However, in these regions, the flow instability occur when the deformation temperature increase to 410 \(^\circ C\) at the stain of 0.4, and 430 \(^\circ C\) at the stain of 0.2. So in general, the optimum range of processing conditions are in the strain rate range of 0.01-0.1 \, s^{-1} \) and temperature range of 380-410 \(^\circ C\) where the efficiencies (28-33%) are much higher when compared to other regions.

![Fig.4. Processing map generated at different strain: (a) 0.2 and (b) 0.4](image)

(Contour numbers represent efficiency of power dissipation. The instability regions where \( \xi < 0 \) are demarcated shaded regions)

![Fig.5. Recrystallized grains observed for the specimen compressed at temperature of 460 \(^\circ C\) and strain rate of 8 \, s^{-1}: (a) low magnification; (b) high magnification](image)
In the high efficiency region the process of dynamic recovery and dynamic recrystallisation (DRX) occur. DRX is a beneficial process in hot deformation since it not only gives stable flow and good workability to the material by simultaneously softening it but also reconstitutes the microstructure [10]. Typical microstructures of the specimen compressed at temperature of 460 °C and strain rate of 8 s⁻¹ are shown in Fig.5, where Fig.5(a) and Fig.5(b) correspond to the low magnification and high magnification, respectively. Microstructural analysis in these regions revealed that the α-aluminum dendrite in the initial microstructure have been replaced by recrystallized grains. It can be seen from Fig.3(e) that the flow stress of the specimen compressed at temperature of 460 °C and strain rate of 8 s⁻¹ decreases obviously after reaching the peak, which is a typical curve of dynamic softening.

4. Conclusion
Hot compression tests were performed on 7065 aluminum alloy. The flow stress was obtained in the temperature range of 300-460 °C and strain rate range of 0.1-8 s⁻¹. Processing maps have been developed and the conclusions are given below:

1. The peak efficiencies for the 7065 alloy is evaluated in the region of T=380-460 °C and ε=0.01-0.1 s⁻¹. Recrystallized grain was observed under these deformation conditions.
2. The optimum range of processing conditions are in the strain rate range of 0.01-0.1 s⁻¹ and temperature range of 380-410 °C, where the efficiencies are much higher when compared to other regions.
3. The dynamic softening is more pronounced at higher deformation strain rate and deformation temperature.

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