AN INVESTIGATION ON THE EFFECTS OF ECAP ON THIXOTROPIC MICROSTRUCTURE OF AA7075 ALUMINUM ALLOY

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Abstract: With Zn as the primary alloying addition, alloy from the 7000 family offers higher tensile strength than many steel especially in T6 temper. These family are widely employed for aircraft, wheels and major structural components, due to its high strength-to-density ratio. Semi-solid forming has many advantages such as able to produce high density material, long tool life, less production forge and near net shape. Also less liquid fraction then cast, results as less shrinkage. Semi-solid products are more durable then cast ones because of non-dendritic microstructure and less porosity, also cheaper than both cast and forged products. ECAP is an operation that involves simple shear deformation by severe plastic deformation processes. However, the material will not be subjected to any cross sectional changes. No cross sectional changing is the most important feature that distinguishes it from conventional methods.
In this study, one of the most important wrought alloys for aerospace applications, AA7075 was used. In order to get the best semi-solid forming feedstock, thixotrophic character has been determined in terms of predeformation rate, heating temperature and holding time.
Keywords: AA7075, Semi-solid Processing, ECAP

Introduction

With copper as the main alloying addition, alloys from the 7XXX family offer high strength at low specific weight and are widely employed in the form of forged parts for aircraft structural components (I.J. Polmear 1996 and J.E. Hatch 1984). However, they suffer low forging speeds, require high pressures (M. Goncalves 2002) and are thus assigned a low forging index. Hence, it is very attractive to forge these alloys in the semi-solid state for technical as well as economic reasons. Thixoforging process offers higher productivity, lower pressures and energy consumption, longer die life and more uniform microstructures than conventional forging at competitive cost (K. Kiuchi 2014)

Semi-solid research and develop studies are ongoing and usually contain pre-feedstock preparations and semi-solid forming. Forming of a metal in semi-solid state can only be managed with a material which has globular microstructure showing thixotropic behaviour (Kirkwood 1994; Choi and Park 1998; Tzimas and Zavaliangos 2000). Although different methods have been invented in order to get this microstructure, most of them are complex and need special apparatus (Bergsma 1996; Tzimas and Zavaliangos 2000; Margarido and Robert 2003; Liu et al. 2003). But SIMA process, based on partially melting, recrystallization and occurring of equiaxed globular microstructure, is easy to use, has simple equipment and minimum subsequent problems. Thus, researchers widely prefer SIMA process (Young et al. 1983; Yong et al. 2001; Dong et al. 2003; Zoqui 2003; Chayong et al. 2004; Wang et al. 2008; Akar 2011). While casting and forging of aluminium alloys in the semi-solid state have received a great deal of attention in recent years M.C. Flemings (1991) and Birol (2001) there are very few reports on ECAP based thixoforging (S.K. Kim 2007). In this study, feed stock of semi-solid forging will be deformed by ECAP (Equal Channel Angular Pressing) which is one of the severe plastic deformation processes. ECAP is an operation that involves simple shear deformation. While squire or circular cross sectioned material is passed into the "L" shaped die, which have horizontal and vertical channels with an inner angle (Φ) and an outer angle (Ψ), will be severe plastic deformed by shear forges at the intersection of two channels. However, the material will not be subjected to any cross sectional changes. No cross sectional changing is the most important feature that distinguishes it from conventional methods.

Materials and Methods

The EN AW-7075 alloy (Table 1) was supplied as industrially cast bar in T4 temper. Differential scanning calorimetry (DSC) was employed to determine the solidus and liquidus temperatures and thus the solidification interval of the present alloy. 3mm diameter disc samples, weighting about 30 mg were cut and placed into alumina pans in an argon atmosphere using a SETARAM Labysys DSC unit. The samples were heated at a rate of 2.5 Kmin-1 between 450 □C and 700 □C. The heat flow vs. temperature curves obtained by DSC were used to calculate the change in liquid□solid fractions with temperature.

Table 1. Chemical composition of the EN AW-7075 alloy used in the present investigation (wt %).

Zn	Mg	Cu	Cr	Mn	Fe	Si	Al
5.1-6.1	2.1-2.9	1.2-2.0	0.18-0.28	<0.3	<0.5	<0.4	87.1-91.4

ECAP die was machined with 120° inner and 20° outer angles and 50 mm longs were sectioned from extrded bar as ECAP samples. The samples, 10mm in diameter, subjected to ECAP procedure for only one pass. ECAP die and plunger heated up to 250°C and pressing performed at the same temperature.

Approximately 50 mm long slugs were sectioned from the as-received ECAPed bar. A medium frequency induction coil (12 kHz, 12.5 kW) was used to heat these slugs into the semi-solid temperature range at a rate of approximately 300 °Cmin-1. Temperature was monitored with a K-type thermocouple inserted in a 3 mm diameter hole drilled at the center of the slugs. Slugs were then soaked in this temperature range for up to 5 minutes to allow globularization of the grains. Thixoforging was performed with a DARTEC model universal tensile testing equipment modified into a vertical press.

The test specimens for microstructural examination were prepared by standard polishing methods. All specimens were grinded by using the Metcon Forcipol 2V rotating polishing machine with various grades of SiC papers up to 2400 grid. Specimens were subjected to fine polishing by using 1 µm diamond paste and then final polishing by using 0,06 µm colloidal silica suspension. Specimens were cleaned with water and dried with acetone before etching. Polished specimens were immersed into Keller's etchant (190 ml distilled water, 5 ml HCI, 3 ml HNO3, 2 HF) for 20 seconds and washed with warm water in order to neutralise residual of etchant. Different etchant solution (2 g NaOH, 100 ml distilled water at 50°C) was used to appear grain boundaries and also to obtain better contrast. Leica optical microscope was used for microstructural examination.

Results and Discussion

The DSC spectrum of the present alloy and the change in solid fraction with temperature (dFS/dT) across the melting interval are plotted in Fig. 1. The solidus and the liquidus temperatures are estimated from Fig. 1 to be 485.9 °C and 645.3 °C, respectively. Even if thixoforming processes are often carried out with as much as 50 to 70% solid in the feedstock, in order to prevent same operation difficulties, alloy was heated up between 580 - 600°C. In this range solid fraction in % 80 - 87.

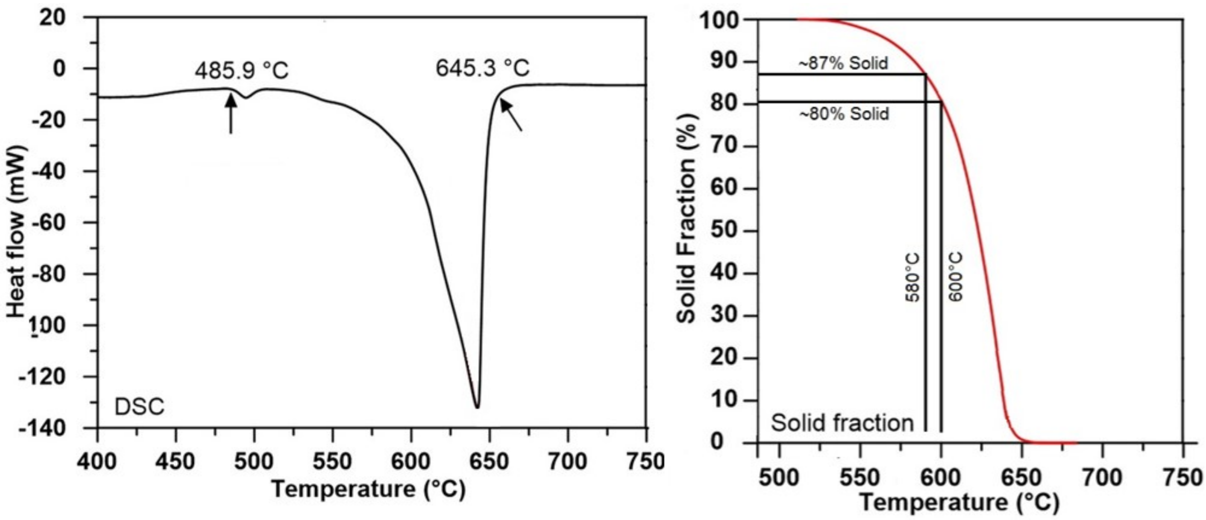

Figure 1. DSC scan of the melting interval and change in solid fraction with temperature across the melting interval.

Equiaxed α-Al grains and strings of intermetallic particles are seen in the microstructure of as-cast feedstock (Fig. 2a). After one pass ECAP operation, it is seen that grains have been transformed to fibrous α-grains and aligned in the pressing direction by shear forces (Fig. 2b). All type of structures including of dendritic are tending to transform spherical microstructure under required thermal conditions. Spherical transformation is easier and fast at semisolid region. During the heating stage, liquid is formed around the solid phase, by melting of the eutectic, and the solid tends to transform globular shape, to reduce internal surface energies. Changing in grain shape with soaking time and holding temperature of ECAPed samples are shown in Fig. 2 c to f. Heavily distorted microstructure creates the location of the re-crystallization nucleation. During the heating stage, as the temperature increases, re-crystallization is occurred in the solid state and new grains nucleate and start to grow. When the temperature reaches to solidus, new grains are penetrated by liquid and become globular equiaxed. It can be seen that by increasing soaking temperature and time, amount of liquid.

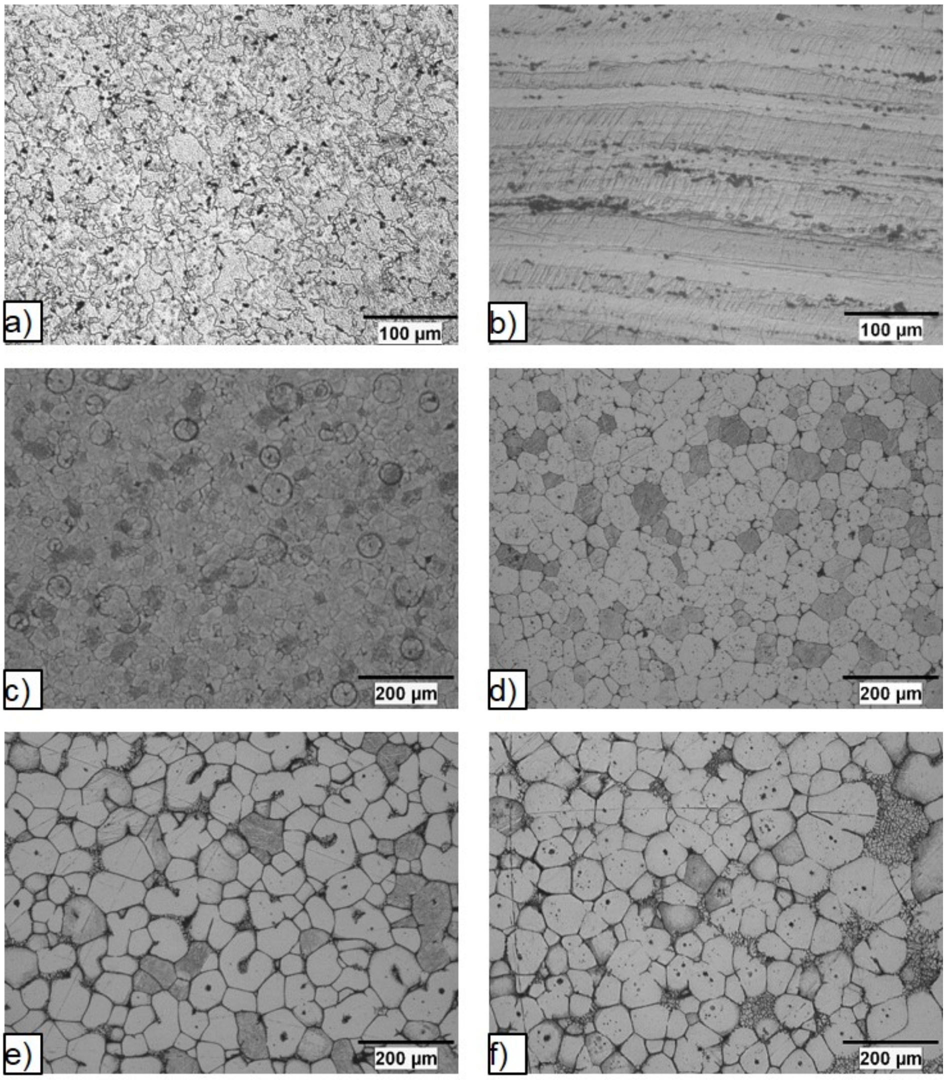

Figure 2. Microstructures of 7075 (a) as-cast, (b) ECAPed and quenched in water during semi-solid soaking at 580 °C (c) without isothermal holding, after (d) 5 min.; during semi-solid soaking at 600 °C (e) without isothermal holding, after (f) 5 min.

phase located at grain boundaries increases and penetrate between the solid grains. So grains have become increasingly more globular and can be seen that to heating lover temperature and holding more time acts as conditions of higher temperature and less time. The temperature and time compensate for each other as seen fig. 2d and 2f.

Conclusion

All type of structures is tending to transform spherical microstructure under required thermal conditions. Heating in semisolid region encourages the grains more globular. Not only heating enough for required globularization but also pre-deformation is needed. ECAP process can be easily used for pre-deformation without any cross sectional change. Increasing heating temperature and time expedite globularization but the grains are tending to grow easily. In order to achieve the best microstructure for semi-solid processing temperature and time combination must be determined.

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