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Non-dendritic structural 7075 aluminum alloy by liquidus cast and its semi-solid compression behavior ①

LIU Dan(刘 丹)[1], CUI Jian-zhong(崔建忠)[1], XIA Ke-nong(夏克农)[2]

1. *College of Materials and Metallurgy, Northeastern University, Shenyang 110006, P. R. China;*
2. *Department of Mechanical and Manufacturing Engineering, Melbourne University, Australia*

Abstract: Fine, equiaxed, non-dendritic structure needed by semi-solid processing was obtained by liquidus cast, i.e. 7075 wrought aluminum alloy cast from liquidus temperature. The microstructures after heat treatment at different temperatures and time in the semi-solid range were observed, and the compression deformation behavior at different temperatures (490 ~ 600 ℃) and strain rates (5×10^{-3} ~ $5 s^{-1}$) was investigated by means of Gleeble-1500 thermal-mechanical simulator. The results show that the deformation resistance of the non-dendritic structure attained by liquidus cast in semi-solid is remarkably lower than that of conventional dendritic structure. The formability of non-dendritic structure is better than that of dendritic structure.

Key words: aluminum alloys; liquidus cast; semi-solid processing; compression **Document code:** A

1 INTRODUCTION

Semi-solid metal procession is generally used to refer to any processing of a metallic alloy between its solidus and liquidus temperatures. It is recognized as a technology offering several potential advantages over conventional cast and forge, such as low temperature work, reduction of porosity, low forming efforts, long mould life and good flow ability. Since metal thixotropic behavior was found in 1970s[1], research work has been proceeding in many countries, but it is slow to be industrialized in semi-solid processing today[2~6]. Metal semi-solid processing need deep research and development, slurry making is one of the most important parts in semi-solid processing; mechanical stirring[7,8], electromagnetism stirring[9] and partially remelting of conventional casting alloy[10] that need complicated process and expensive equipment are the main ways today. In this paper, the method of liquidus cast is used to obtain fine, equiaxed, non-dendritic structure 7075 Al alloy with simple equipment and less expense to accelerate the development and application in semi-solid processing.

2 EXPERIMENTAL

The material used was commercial 7075 aluminum alloy with composition (mass fraction, %) of Al-5.28 Zn-2.36 Mg-2.24 Cu-0.16 Cr. The liquidus and solidus temperatures of the alloy are 635, 477 ℃ by DTA, respectively. The 7075 aluminum alloy used in the form of rolling slab was heated to about 750 ℃ in a graphite crucible using a resistance-heating furnace and the melt was held on 750 ℃ or cooled down to 640, 635, 633 ℃, respectively, before cast into a cylindrical steel mould with an outer diameter, inner diameter and height of 106, 70 and 100 mm, respectively at room temperature.

Samples from billets cast at different temperatures were observed to reveal the solidification microstructures. Samples of 10 mm × 10 mm × 30 mm cast from liquidus temperature were reheated to 560, 580, 600 ℃ and holding for 2, 20 and 60 min, respectively, before being quenched. The microstructures were observed to understand the change of the primary grains. At the same time, Q-900 image analyzer was used to analyze the average size of the primary grains, the circularity and the volume fraction of the primary grains.

Samples of d8 mm × 15 mm were machined from the billets cast at 635 ℃ and 750 ℃, and then (according to Fig.1) heated at a rate of 5 ℃/s to different deformation temperatures (490, 560, 580, 600 ℃) and compressed at the deformation rate of $5\times10^{-3} s^{-1}$ after holding for 1 min by Gleeble-1500 thermal-mechanical simulator. Curves of stress-strain relation were obtained. In order to assess the sensitivity of the alloy in semi-solid state to the rate of deformation, a few additional tests with the deformation rates $\dot{\varepsilon}=5\times10^{-3}, 5\times10^{-2}, 5\times10^{-1} s^{-1}$ at 560 ℃ were performed. A few samples were quenched after compression immediately to examine the microstructure and the microsegregation in the liquid phase.

3 RESULTS AND DISCUSSION

3.1 As-cast microstructures at different cast temperatures

Fig.2 shows the microstructures of the billets

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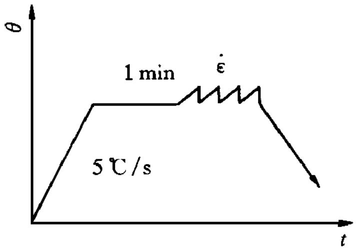

Fig.1 Technology of compression
t —Heating time, min; θ—Deformation temperature, ℃

cast at different temperatures (750, 640, 635, 633 ℃). The cast temperature influenced the as-cast microstructures. The typical dendritic arms can be clearly seen in the billet cast at 750 ℃. The rosette grains, which may be formed before casting, were observed in the billets cast at 640 ℃ and 633 ℃, respectively. The solidification structure is completely different in the billet cast at 635 ℃, the liquidus temperature (Fig.2(c)). The primary grains are fine, equiaxed and non-dendritic, and characterized by image analyzer which shows that the average grains size is approximately equal to 42.59 μm, the average circularity is approximately equal to 1.584, the equal area circle diameter (the grain's longer axis diameter) is 15 ~ 55 μm, and circularity (perimeter^2/(4π × area)) is 1.171 ~ 2.662. The volume fraction of the primary solid phase is 56.41 %.

The cast temperature has considerable influence on the solidification microstructure. It is impossible to attain the fully non-dendritic microstructure at upper or lower liquidus temperature. The lower the cast temperature and the higher the alloy composition, the narrower the columnar zone, and the wider the equiaxed zones. However, the higher the cast temperature, the less the possibility of forming equiaxed zone. When the cast temperature approached liquidus temperature, the formation of equiaxed solidification would be promoted[11].

With liquidus cast, the melt before pouring has no superheat and the whole melt would certainly be undercooled after cast (some crystals might even be formed during pouring). The whole melt may be undercooled and copious heterogeneous nucleation may take place throughout the melt, and this may lead to the complete elimination of the columnar zone in the cast and to the formation of fine, equiaxed grains in the entire cast[12]. It has been noticed that the formation of non-dendritic microstructure with liquidus cast must be at a certain cooling rate. Result from Ref. [13] by the author shows that fine, equiaxed, non-dendritic structure can be obtained by liquidus casting a wrought aluminum alloy 2618 in the steel mould at room temperature. When the cooling rate was too slow, the non-dendritic grains became coarser

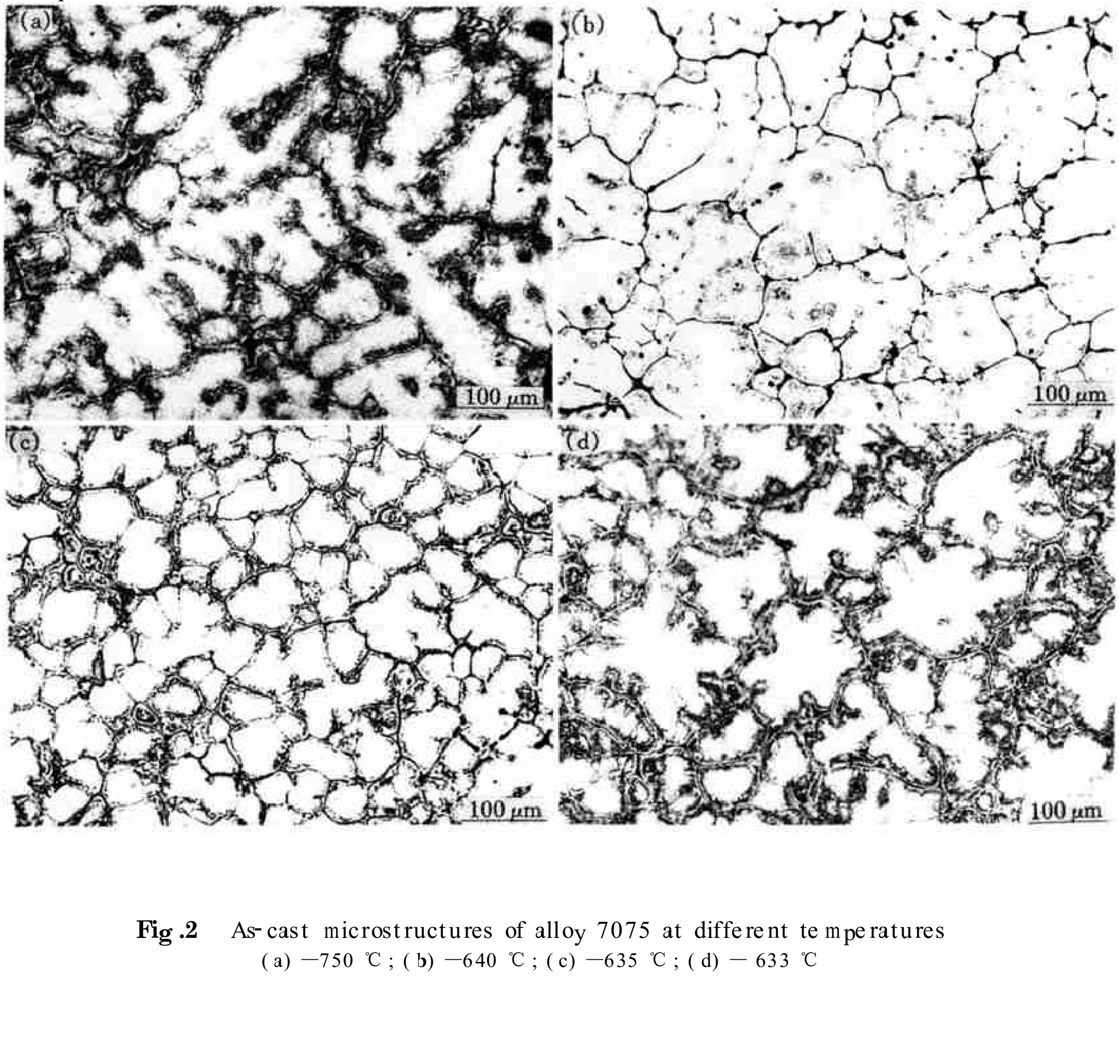

Fig.2 As-cast microstructures of alloy 7075 at different temperatures
(a) —750 ℃; (b) —640 ℃; (c) —635 ℃; (d) — 633 ℃

slightly in the billets cast from liquidus temperature in the steel mould with 300 ℃ and 500 ℃ preheating temperature , and some coarse intermetallic particles appeared at the same time . When the cooling rate was too fast , the global grains would be lost and the fine dendritic grains appeared in the billet cast from liquidus temperature in the copper mould with water-cooling . So a certain cooling rate must be requested by liquidus cast in order to attain fine , equiaxed , non-dendritic microstructure .

3 .2 Reheating microstructure of liquidus cast 7075 alloy

Fig .3 shows the reheating microstructures of the billet cast from liquidus temperature in the steel mould at room temperature which were reheated to 560 , 580 , 600 ℃ and held for 2 , 20 and 60 min , respectively in a resistance-heating furnace . Fine , non-dendritic primary grains was little changed and remained very fine and equiaxed , and fine liquid layer can be found at grain boundaries in the samples which were reheated to 560 , 580 , 600 ℃ and held for 2 min . With the reheating temperature increased , grains were little changed . However , after the samples were reheated to 600 ℃ and held for 20 , 60 min , respectively , the grains grew apparently with longer holding , and the intermetallic particles appeared both inside grains and at boundaries . It was caused by particle coalescence with the reheating time increased during the reheating period .

3 .3 Deformation resistance of compression in semi-solid state

Fig .4 shows the curves of stress-strain relation at various deformation temperatures (490 , 560 , 580 , 600 ℃) for conventional and liquidus cast 7075 aluminum alloy . The deformation resistance in semi-solid state for liquidus cast alloy is lower than that for conventional cast alloy . As the deformation temperature increases , the deformation resistance decreases . An unusual materials softening phenomenon , opposite to the hardening of the solid material , is observed for both conventional cast alloy and liquidus cast alloy in semi-solid state . The stress decreases when the peak strain of about 0 .06 is exceeded .

The curves of stress-strain relation at various deformation-rates (5×10^{-3} , 5×10^{-2} , $5 \times 10^{-1}\ s^{-1}$) for $\theta = 560$ ℃ are shown in Fig .5 . As the deforma-

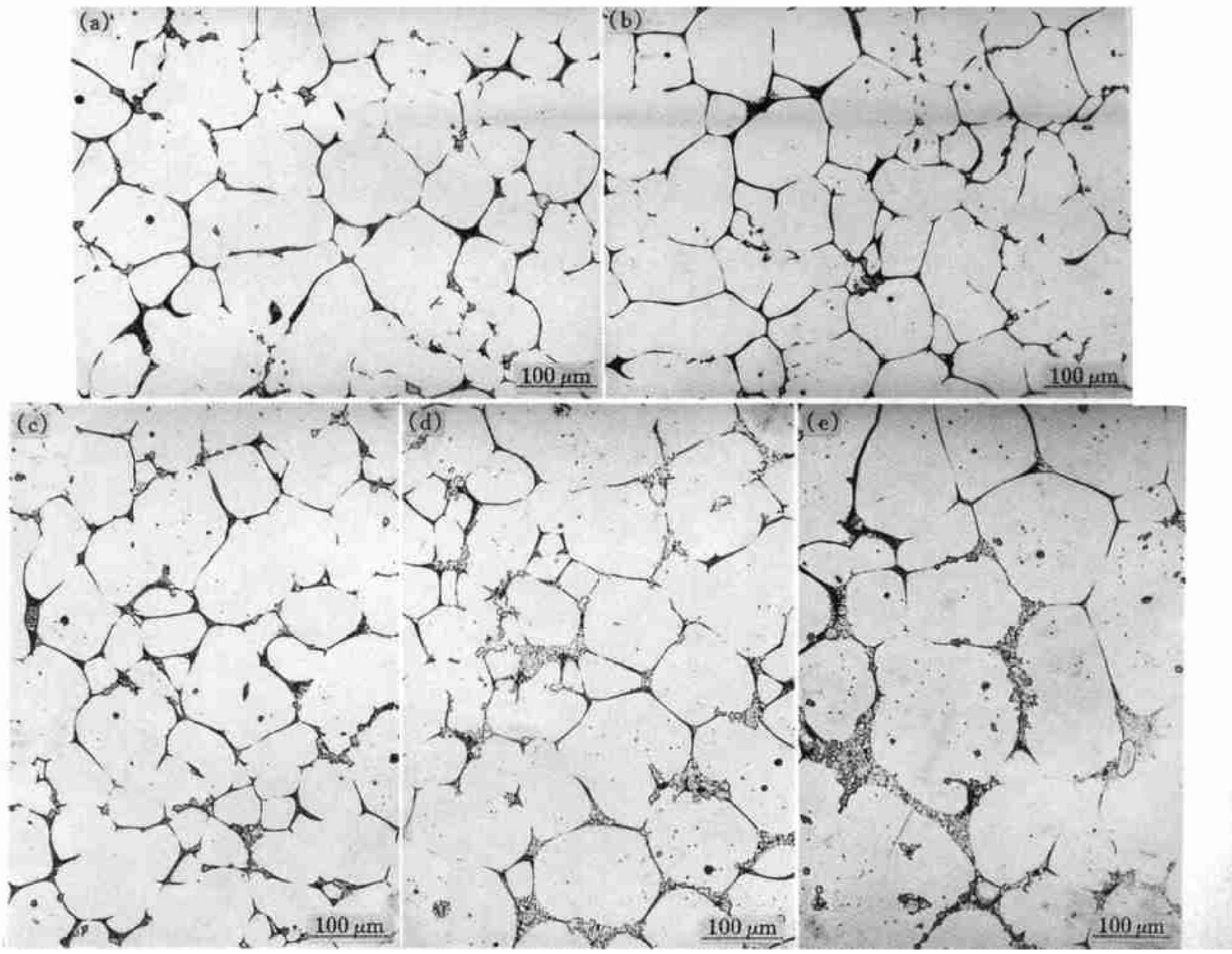

Fig .3 Microstructures of liquidus cast 7075 Al alloy reheated to various temperatures and held for various times
(a) —560 ℃ , 2 min ; (b) —580 ℃ , 2 min ; (c) —600 ℃ , 2 min ; (d) —600 ℃ , 20 min ; (e) —600 ℃ , 60 min

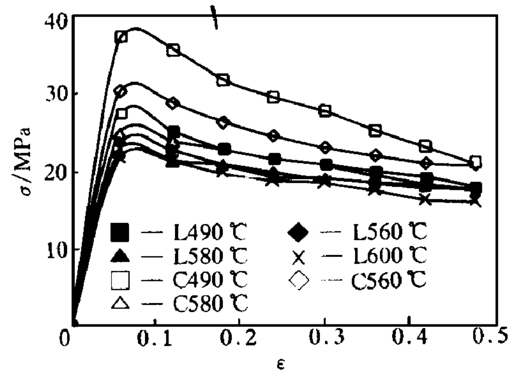

Fig.4 Curves of stress-strain relation for 7075 alloy at different temperatures ($\dot{\varepsilon}=5\times10^{-3}\,s^{-1}$)
L-Liquidus cast alloy; C-Conventional cast alloy

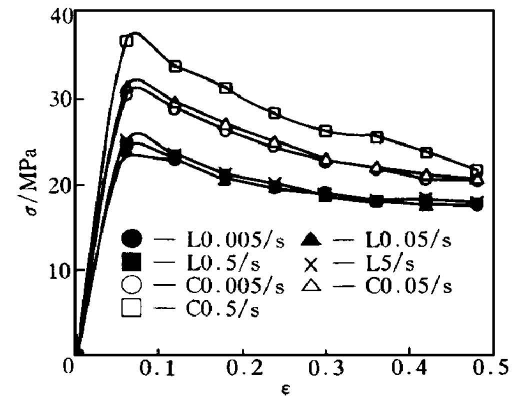

Fig.5 Curves of stress-strain relation for 7075 alloy at different deformation rates ($\theta=560$ ℃)
L-Liquidus cast alloy; C-Conventional cast alloy

tion rate increases, the stress increases, and phenomenon of materials softening can be observed. The stress decreases when the peak strain of about 0.06 is exceeded for both conventional cast structure and liquidus cast structure.

Due to the partially melting of the grain boundaries, presence of the liquid phase involves the change of the mechanism of deformation and kinetics of the metal flow in semi-solid state for liquidus cast 7075 aluminum alloy. The plastic deformation is performed mainly by means of the slip between the global primary grains and by global primary grain rotation. The influence of the deformation of grains is negligible in this case. This mechanism of deformation leads to a decrease of the deformation-resistance. As the temperature increases, the deformation is easier to result in the lower deformation resistance because of increasing liquid phases. Continuous nets, which were formed by coarse, dendritic primary grains, hinder the proceeding of the deformation in conventional cast structures and result the increasing of deformation-resistance in semi-solid state. As though liquid phase appeared on the grain boundaries for conventional cast alloy in semi-solid state too, the deformation of the coarse dendritic arms hinders the proceeding of the deformation and results higher deformation resistance.

There are different cracks and liquid deviation appeared on the external appearance after compression in semi-solid state for both conventional cast alloy and liquidus cast alloy. It became apparent with increasing the deformation temperature and deformation rate. Liquid phase appeared in the grain boundaries when the samples were heated to semi-solid state. Liquid phase separated from the grain boundaries as a result of the external force, and no liquid and solid phase close to it filled in time, which result in cracks appeared along the grain boundaries. According to the results, closed forge must be used to avoid cracking and obtain products that have the homogeneous mechanical characteristics for semi-solid material forge.

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