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The effect of pressure and pouring temperature on the porosity, microstructure, hardness and yield stress of AA2024 aluminum alloy during the squeeze casting process

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ABSTRACT

The effect of pressure and pouring temperature on the microstructure, porosity, hardness and yield stress of AA2024 aluminum alloy during squeeze casting process was investigated. At a constant pouring temperature (700 °C), by increasing the applied pressure up to 140 MPa, the hardness increased from 125 HBN to 152 HBN while the yield stress increased from 235 MPa to 340. Moreover, by increasing the applied pressure (to 140 MPa) and reducing the pouring temperature (at 700 °C), the DAS size and the porosity diameter decreased to 12.5 and 0.25 μm, respectively. Thus, the density increased to 2.75 (g/cm^3). At a pressure of 140 MPa and 700 °C, an ultra-fine grain structure with an average grain size of 80 nm was observed. At squeezing pressures greater than 70 MPa, the effect of pouring temperature was less important.

1. Introduction

Squeeze casting process offers benefits such as low porosity, high density, microstructure refinement, improved mechanical properties and equiaxed structure compared to conventional casting methods reported by Abou El-khair (2005). As shown by Franklin and Das (1984) and Ghomashchi and Vikhrov (2000), the quality of the castings is determined by the pouring temperature, applied pressure, the mold preheating temperature and metal superheat. Although low pouring temperature causes low fluidity, the imposed pressure during the squeeze casting process compensates for it. On the other hand, Chadwick and Yue (1989) reported that high pouring temperature leads to the formation of hot cracks in the metal mold and makes the molten metal to spill out of the space between the mold cavity and the core, forming flash defects. According to Tian et al. (2002) the imposed pressure during the process affects the microstructure, phase diagram, cooling rate and the porosity content. At high imposed pressures, heat transfer coefficient increases to about 10 times more than that of pressureless processes, as reported by Lee et al. (2002) and Postek et al. (2005). Ghomashchi and Vikhrov (2000) believed that the melting point of most metals increases by increasing pressure, thus changing the phase diagram. This change in the phase diagram yields an improvement in the microstructure and mechanical properties which is caused by a sudden undercooling.

Moreover, the imposed pressure activates the metal feeding mechanisms which reduce the shrinkage porosity and therefore improve the mechanical properties as shown by Sawatzky (2000). Chadwick and Yue (1989) reported that under the applied pressure during squeeze casting, small and well distributed precipitates are formed. Lee et al. (2002) reported that the higher the applied pressure, the higher the melting point and the higher the under cooling, resulting also in finer grains. Hajjari and Divandari (2009) argued that the reason for having finer grains and smaller dendrite arm spacing (DAS) is the high cooling rate during squeeze casting process. In fact, by increasing the imposed pressure, the strength and flexibility increases as shown by Dai et al. (2012).

Considering the effects of grain size and porosity content on the mechanical properties, it is important to identify the optimum pressure and temperature in order to decrease the grain size and porosity content. The effects of applied pressure and pouring temperature on the microstructure of AA2024 aluminum alloy were examined.

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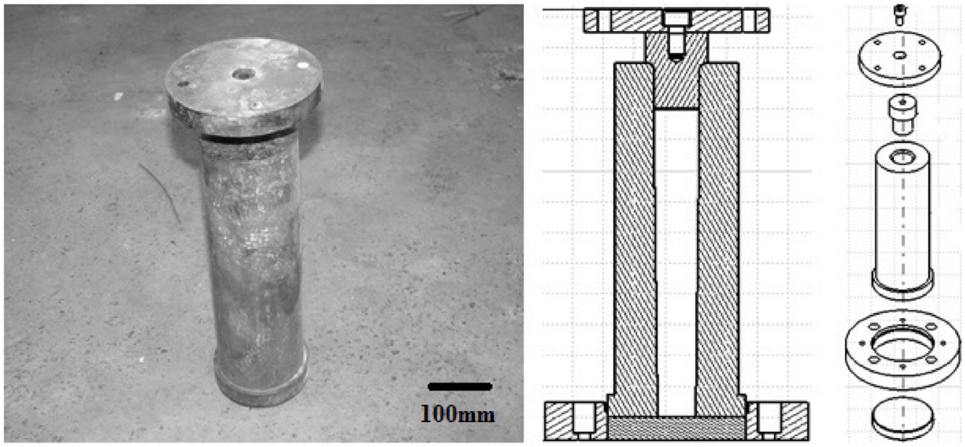

Fig. 1. Dimensions and geometry of the mold in the squeeze casting.

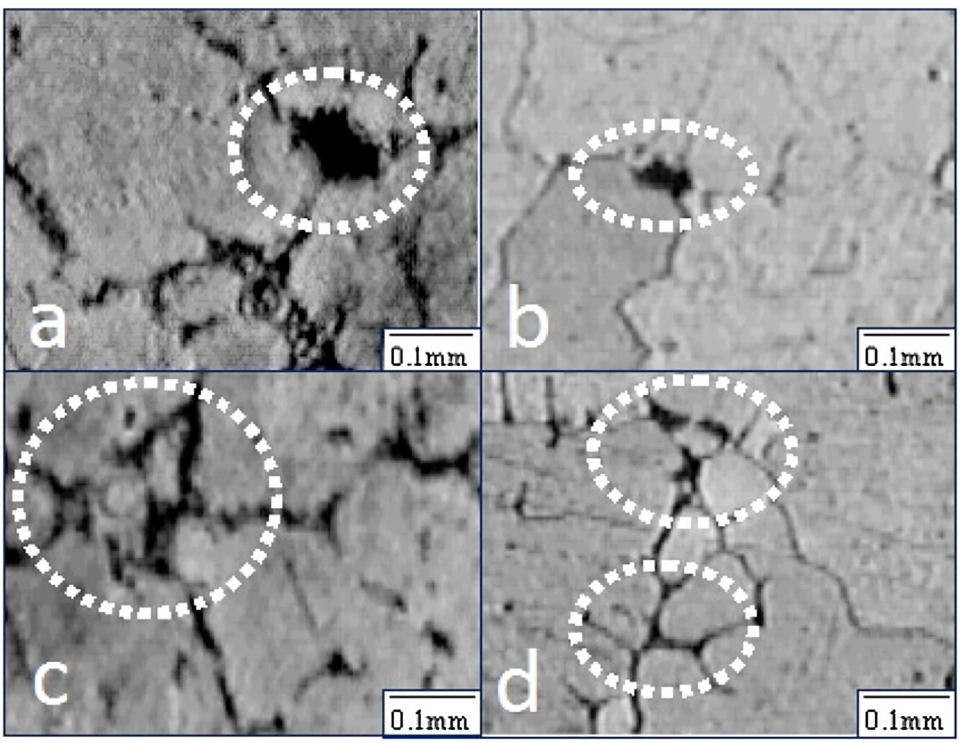

Fig. 2. Defects in cast AA2024 aluminum alloy: Gas holes in a) gravitational casting at pouring temperature of 800 °C, b) Squeeze casting at 140 MPa and 800 °C, shrinkage porosity, c) gravitational casting, d) squeeze casting under 140 MPa and 800 °C.

Table 1
Chemical composition of AA2024 alloy (wt%).

Fe	Zn	Ti	Ni	Mn	Mg	Cu	Si
0.20	<0.10	0.10	<0.10	0.34	1.10	4.40	0.18

2. Materials and methods

The chemical composition of AA2024 aluminum alloy is shown in Table. 1. The steel mold with an internal radius of 30 mm and a height of 170 mm and cylindrical preheat temperature were set to 200 °C and the molten was poured into the mold (Fig. 1) at temperatures of 800 °C, 750 °C and 700 °C. The pressure of 70 MPa, 100 MPa and 140 MPa was then applied until the end of the solidification. Microstructural investigations were performed using optical (OM-Olympus BX51M) and scanning electron microscope (SEM-Vega Tscan) equipped with a WDS detector. Moreover, atomic force microscope (AFM) was used for investigating the microstructure at higher magnifications. To evaluate the hardness of the samples, Brinell hardness test (using a controllable hardness test machine) was used. To calculate the dendrite arm spacing (DAS), the length of the primary dendrite arms were measured in three different points of the microstructure and were divided to the number of secondary dendrites arms spacing. The porosity content of the samples was determined using Archimedes method. Radiographic (plain X-rays) images of the specimens were produced. The compression test was performed on the samples with 8 mm diameter and 12 mm height at room temperature using an Instron-5564 tensile test machine at a strain rate of 1 mm/min toobtain the yield strength.