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Challenges in Producing Reliable Tensile Properties by SIMA 7075

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Abstract

Aluminium alloys are one of the preferred materials especially for land and air transportation because of their high strength and low-density properties. Although production using casting method is economical yet it has some disadvantages. Shrinkage which is occurred due to the density difference between the solid and liquid metal is prevented by feeders which need to be calculated. Liquid metal should be transferred to the mould without any turbulence. As a result, sprues are needed to be designed precisely. On the other hand, aluminium alloys can also be shaped by forging at semi-solid temperatures. There are some advantages compared to the traditional forging methods of improving die life due to the lower tonnage values. In this study, semi-solid produced 7075 aluminium alloy die filling capabilities were investigated. To achieve semisolid structure strain induced melt activated method (SIMA) was used. The desired structure was achieved at 635 °C and 30 minutes of duration of heat treatment. After determining the optimum parameters, metallographic analysis, density calculations, porosity distribution and tensile tests were carried out. It was found that the reproducibility of SIMA produced 7075 alloy was quite low. A proper tensile test result was achieved only 7 of the total 15 tests and the mean value was 386 MPa. The main reason for this scattered in mechanical properties could be the chemical composition of the alloy and the rapid solidification of the liquid eutectic phases. It is important to define the best fitting process parameters and controlling them precisely will be the most important factors for future studies.

Keywords: Mechanical Properties, Product Development, AA7075 Alloy, Semi-Solid Processing, Thixocasting

1. Introduction

Till early 1970s metallurgists had pursued two main processes to shape metals [1]. If metals are to be formed, starting material to be used is either liquid or solid. However, during the early seventies, Spencer and Flemings [2, 3] investigated hot tearing in steels and found that the viscosity of the melt during the solidification decreased while stirring of the melt and solidifying melt become a viscose slurry. This newly discovered semi-solid state of metal brought some advantages. This new approach is to remove the need to heat the metal up to its melting point while shaping a material. As a result, there are advantages such as increasing mould life because of the lower pressure usage, decreasing energy consumption, end product quality and eliminating difficulties of working with liquid metal. In addition, the absence of defects such as porosity and segregation which occur during the solidification of the liquid metal, and eliminating runner and feeders reduce the subsequent machining operations [4]. By this method, net-shape or near-net shape parts can be produced. This newly discovered technology has developed rapidly and new alternative approaches had begun. Among these, there were alternative approaches such as passive mixing, electric current induction, electromagnetic mixing and intense cold deformation of dendritic primary material can be called. The aim was to reach the appropriate microstructure and to overcome the disadvantages of mechanical mixing [5]. In this way, heterogeneity of the dendritic structure is eliminated and globular and homogeneous microstructure can be obtained. Semi-solid metal production is basically divided into two main titles: Rheocasting and thixocasting [6]. Rheocasting uses liquid metal as a starting material to produce semi-solid slurry while thixocasting uses cold or hot deformed non-dendritic solid material and then heat treated to semi-solid temperature [7]. The aim is to obtain fine spherical grains. This method is called SIMA (strain induced and melt activated) [8-9].

Jiang [10] compared the RAP (recrystallization and partial remelting process) and SIMA processes for different holding temperature and durations. They concluded that both processes average grain sizes first increased then decreased with increasing temperature for 20 minutes of holding times. For SIMA process increasing the temperature from 580 °C to 610 °C is increased the grain size and over 610 °C average grain sizes are decreased. Behzad B. [11] investigated the mechanical properties and microstructural evolution of 7075 alloy during SIMA process. They investigated temperatures between 600-620 °C and several holding times between 5 to 35 minutes. Heating temperature 600 °C and 610 °C for 25 minutes considered as the best condition for SIMA and grain sizes were smaller at 610°C temperature than the 600 °C. Bolouri [12] investigated the coarsening mechanism of 7075 alloys during SIMA process. Various temperatures and holding times were investigated. With increasing temperatures, they found severe segregation, entrapped liquid droplets and alloying elements between grain boundaries. Turkeli [13] studied several temperatures between 400 to 625 °C degrees because of the semisolid range is between 477 to 635 °C and found that 575 °C is ideal for semi-solid structure for 7075 aluminium alloy. Mohammadi [14] studied microstructural evolution of 7075 aluminium alloy. 560, 570, 580, 590, 600 to 610 °C and 10, 20, 30 minutes of holding times were investigated. 580 °C and lower than 30 minutes of holding times were founded optimal for extrusion ratio of 20 for 7075 aluminium alloys. Rikhtegar [15] have investigated the mechanical properties of 7075 alloy which is thixoformed by forward extrusion process. They realized that T6 heat treated samples fractures surfaces look ductile while the spherical samples have brittle appearance. Tan [16, 17] studied SIMA process for 2024 and 7075 alloys and after SIMA process samples were heat treated and quenched. Effect of different temperatures for quenching water was investigated and compared with mechanical tests and bifilm index.

In this work, tensile test samples were produced from 7075 alloy by SIMA process and Weibull analysis was used to assess the reliability of test results.

2. Experimental study

7075 was provided as 30 mm extruded rods and samples were produced from these rods. A total of 15 cylindrical bars with 85 mm height was prepared. Spectral analysis and chemical composition of 7075 is given in Table 1.

Table 1.
Chemical composition of 7075 alloy

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti
0.4	0.5	2	0.3	2.9	0.28	6.1	0.2

A spanner like AISI 1040 steel mould was used to shape and produce semisolid samples. Dimension of the mould is given in Figure 1.

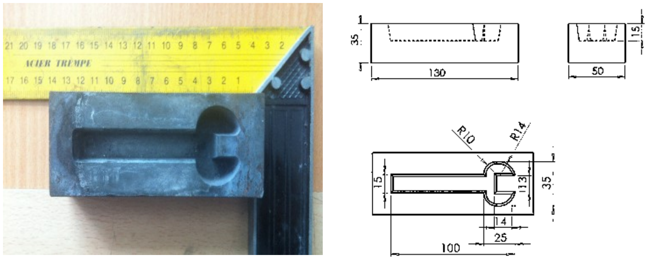

Fig. 1. Dimension and picture of the AISI 1040 steel mould

All samples were placed on to the steel mould one by one and heated up to 635 °C degree and heat treated for 30 minutes in VULCAN 3-550 atmospheric resistance furnace and the semisolid structure was established. Mould and the semisolid sample were taken from the furnace as is and pressed with 5-tonne press machine while sample and the mould are still at this temperature and tried to fill the mould with semisolid metal.

T6 heat treatment process was carried out to the samples at 481 °C for 1 hour and later solution treated for 12 hours at 121 °C. Then, densities of the samples were measured by Archimedes principle.

15 tensile test samples were produced from cast specimens. The dimension of the tensile test samples is given in Figure 2. The test was carried out in accordance with ASTM E-8 standard. Weibull [18-19] analysis was used to evaluate the results.

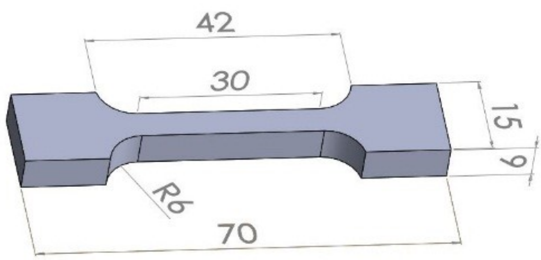

Fig. 2. Dimensions of produced tensile test samples

3. Results and discussion

Cylindrical samples were cut in the required length and heated to 635 °C and held for 30 minutes. After samples were pressed into the mould, the density of the samples were measured as an indication of calculating the volumetric pores in the samples. Then, samples were machined to the standard tensile test dimension and densities were measured again. The results are given in Figure 3 and 4. It can be seen that densities were increased after machining.

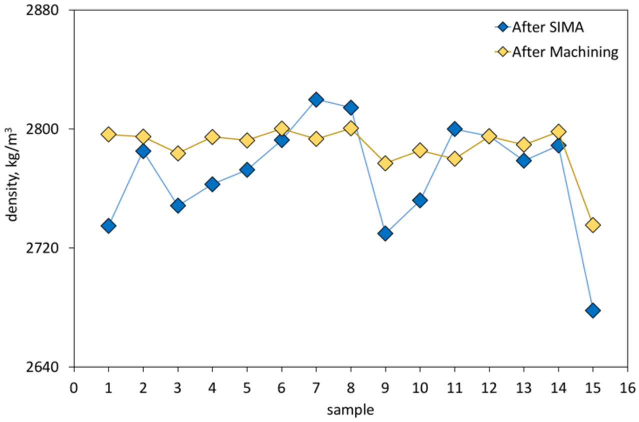

Fig. 3. Density distributions of test samples after SIMA process and after tensile test preparation.

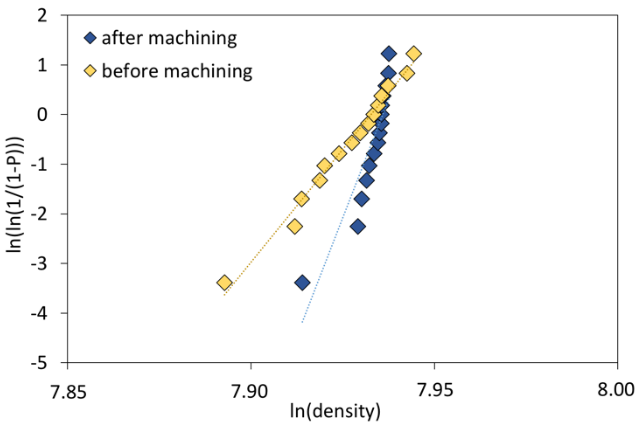

Fig. 4. Compari son of the Weibull distribution of densities

According to Weibull analysis, the characteristic densities before machining was 2762.8 kg/m^3 and after machining, this value was 2795.3 kg/m^3. There exists 1.16% difference where the machined samples show higher density. This is mainly due to the removal of pores that are closer to the surface by machining. It also indicated that the part of samples that were filled into the mould cavity had denser structure compare to the part that was in contact with the top die.

As can be seen from the Figure 3 densities of the produced samples after SIMA process are quite low. But the densities of the machined tensile test specimens were higher. It is also important to note that they were machined from the bottom of the mould. During the pressing process, the semisolid material tried to fill the mould is compressed into a limited volume at the bottom of the mould. But material which could not be compressed into the mould and stayed on the surface spread to all directions and produced burrs and these areas created low-density zones.

The density difference between the theoretical density and the produced samples density after SIMA process were calculated as 1.7%. But the results are highly fascinating. After machining the difference is approximately 0.79%. Especially these differences are clearly seen in the samples numbered as 1, 4, 7 and 8. Scattered density results changed after machining and the densities of the samples produced from the bottom of the mould have 1% scatter which is very low and produced more reproducible results. This shows that semisolid processing of 7075 is not so reliable and there could be too many parameters involved. Particularly, the most important parameter is the microstructure and the condition of the raw material. Any heterogeneity in the extrusion process would result in abnormal grain growth.

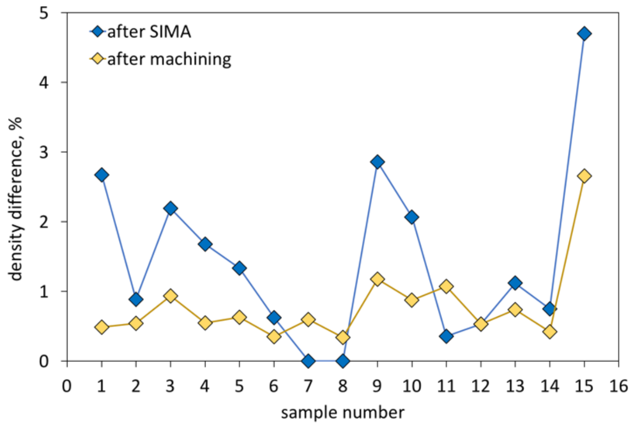

Fig. 5. Difference between theoretical density and measured density

SIMA produced 7075 aluminium samples tensile test results are given in Figure 6 and as can be seen from the figure, tensile strength is approximately measured as 386 MPa. This result obtained from seven of the 15 samples (49%) that were produced. The remaining eight of the samples were cracked right after the test load was applied. These prematurely cracked samples were not included in the Weibull analysis.

Causes of fracture are that is necessary to form liquid phase around the spherical grains in order to be able to perform a semi-solid forming process to SIMA. At this point, the material can easily provide sliding motion during pressing. However, this liquid phase is likely to form heterogeneously precipitates during the instant solidification after pressing, or it may be a consequent effect of precipitating secondary phases around the spherical solid α-phase. There is a possibility that this precipitating secondary phases could have a strength reducing effect. Although the T6 heat treatment was applied to the samples afterward, the heat treatment conditions were based on standard temperature and duration values of T6 heat treatment. Therefore, sudden breaks may be observed in the tensile tests as a result of insufficient heat treatment conditions. Similar results have been observed in the studies conducted by Özdeş [20] with the 2024 alloy.

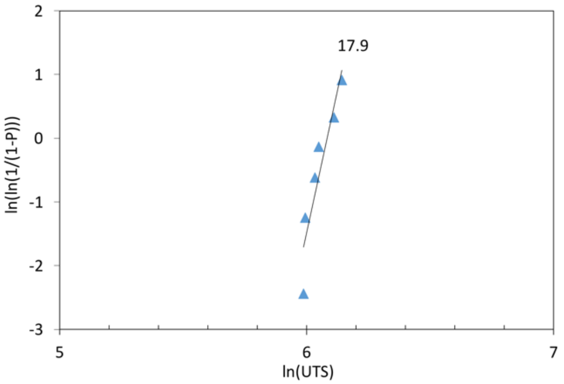

Fig. 6. Weibull analysis of the tensile test samples which were produced with SIMA process. (UTS: Ultimate Tensile Strength)

The Weibull modulus for tensile tests was calculated as 17.9. The characteristic value of so is calculated as 454.1 MPa according to the Weibull analysis. Least square analysis was used to calculate this value. The values for elongation at fracture was not evaluated simply due to the fact that these values were quite low as 0.2%. As mentioned above, almost half of the samples had shown premature fractures. As can be seen on SEM images taken from the fracture surface of tensile test samples, most of the microstructure is in the form of pure grains. This reveals that there were too many pores. Although the SIMA process is carried out under pressurization of the test piece, yet pores were found. These pores could be due to the cleanliness of initial raw material. One of the sample (Fig 7a) had shown typical ductile fracture. On the other hand, in Figure 7c, some fine dendrites can be seen. This could only occur if the liquid fraction of material is high in between the spherical grains. And then, this liquid solidifies quickly when placed under die mould.

4. Conclusions

SIMA process is used for near-net-shape production of aluminium alloys which provides several advantages. However, in this work, it was found that the obtaining of homogeneous spherical grains in extruded 7075 alloy was quite difficult to achieve by SIMA process. The chemical composition of the alloy suggests the presence of several eutectic phases which results in rapid solidification of these liquid phases. As a result, tensile properties scatter widely and reliability of the process becomes weak. Out of 15 tensile bars, 8 bars show premature fracture and remaining data revealed 454.1 MPa tensile strength and 0.2 % elongation at fracture which was calculated by Weibull analysis characteristic value.

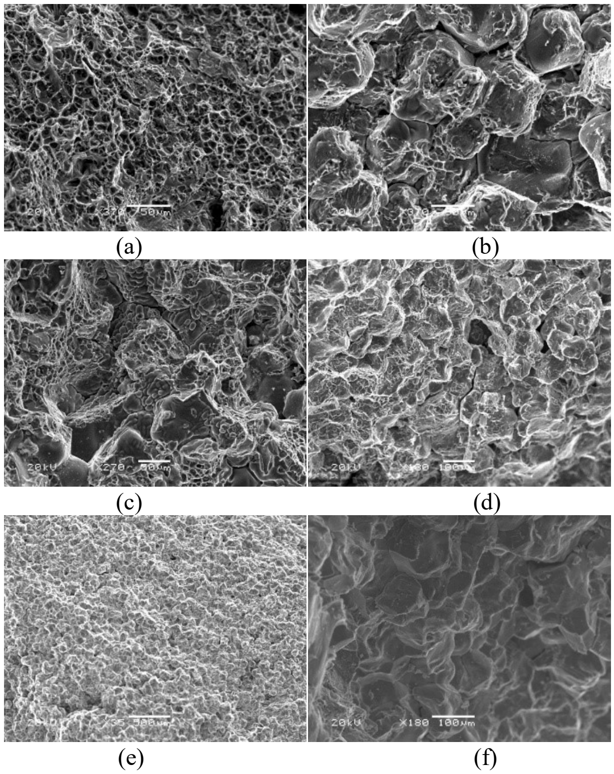

Fig. 7. SEM images on the fracture surface of tensile samples. (a) ductile fracture surface; (b-c-d) mix fracture surface; (e-f) pore initiated, hot tear look-alike transgranular fracture surface

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