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Evaluation of the Effect of Holding Temperature and Time of SIMA Process on the Microstructure and Mechanical Properties of Aluminum Alloy 2024

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1- Introduction

To produce homogeneous semisolid materials with proper structure, SIMA method is the best option since in this method, the semisolid material is easily accessible in addition to inexpensive equipment. Due to limited research on the impact of SIMA on mechanical properties and microstructure in 2024 aluminum alloys, attempt has been made in this study to address this important issue and examine the effect of semisolid process specifications (temperature and holding time at this stage). The obtained results are compared with mechanical properties resulting from T6 standard operations in order to evaluate the efficiency of the process.

2- Experimental

In this study, SIMA process includes one stage of applying strain followed by one stage of retention at semisolid temperature. To apply strain, the samples were rolled to 40% at ambient temperature. The samples were then placed in a furnace with an argon-controlled atmosphere at different times and temperatures within the temperature range of the semisolid. In this research, 2024 aluminum sheet with a thickness of 4.85 mm and chemical composition stated in Table 1 was used.

Table 1 Chemical composition of 2024 aluminum alloy obtained through emission spectrometry method

Al	Cu	Mg	Mn	Fe	Si
Base	4.8	1.3	0.6	0.30	0.30

To check the hardness of the samples, Vickers microhardness test was employed. To assess the mechanical behavior of the samples, uniaxial tensile test with the strain rate of 2.6×10^{-6} was applied. For metallography, samples were etched in chlorine solution (2 ml of HF (40%) + a3 ml of HCl (38%) + 5 ml of HNO_3 (70%) + 190 ml H_2O). Microstructure images were prepared using optical microscope and scanning electron microscope (SEM) at different magnifications.

3- Results and Discussion

Optical microscope images related to the samples kept for 5 minutes at different temperatures of 575, 595, 610 and 620 °C are presented In Fig. 1. As can be seen, increasing the temperature up to 610 °C caused an increase in the rate of sphericity, but at 620 °C, sphericity slightly decreased. Additionally, with increasing melt fraction, the grain size is reduced up to 610 °C and then increased. At temperatures above 610 °C, in addition to decreasing the shape factor and increasing the grain size, destructive effects including the thickening of the grain boundaries and separation and porosity in the microstructure are observed. The optimal state of microstructure in this section is reported to be obtained at 610 °C.

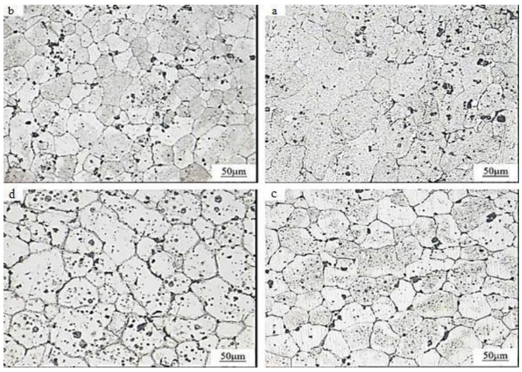

Fig. 1 Optical microscope images related to the microstructure of the samples with 60% strain and time of 5 minutes; a) 575 °C; b) 595 °C; c) 610 °C; and d) 620 °C

To better evaluate the effect of holding time within the semisolid range, four holding times of 5, 10, 15 and 30 minutes were chosen. Optical microscope images of these four different times at 575 °C are presented in Fig. 2. With increasing holding time, the rate of sphericity has dramatically increased. At very high holding times (30 minutes), the rate of sphericity decreased.

Table 2 displays the results of engineering tensile test. As can be observed, with the temperature rise and subsequent increase in the sphericity, tensile strength increases and elongation is first increased and then reduced. On the other hand, toughness decreases with increasing temperature. By increasing the holding time, elongation first increases and then decreases significantly. This indicates the sensible effect of holding time on mechanical properties of 2024 alloy in the SIMA process. Moreover, with increasing holding time, tensile strength is increased and toughness reduced.

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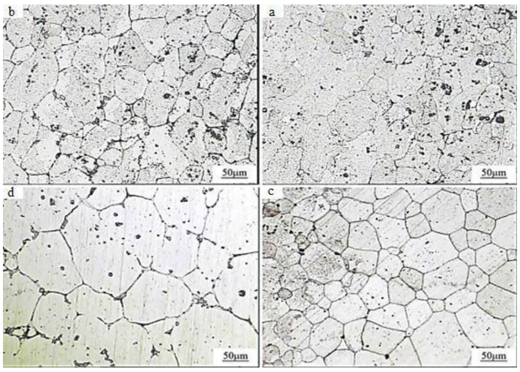

Fig. 2 Optical microscope images related to the microstructure of the samples with 60% strain and temperature of 575 °C; a) 5 min; b) 10 min; c) 15 min; and d) 30 min

Based on the results mentioned in Table 2, we witness a 44% increase in the optimal toughness mode relative to T6 state, which suggests the positive impact of the SIMA process on increased toughness. Although the optimum tensile strength of the alloy in the SIMA process has slightly decreased compared to T6 sample, the significant increase in elongation and toughness also represents the positive effect of the SIMA process on tensile properties of the alloy.

Table 2 Results of SIMA sample tensile test

Sample	Summary of operations	Yield stress (Mpa)	Tensile strength (Mpa)	Elongation percentage	Toughness (Mpa.m$^{1/2}$)
S575-5	40% strain at ambient temp, 5 min of holding at 575° C	280	460	20.7	74.7
S595-5	40% strain at ambient temp, 5 min of holding at 595° C	300	472	26.7	26.2
S610-5	40% strain at ambient temp, 5 min of holding at 610° C	320	485	22.8	23.3
S570-10	40% strain at ambient temp, 10 min of holding at 575° C	265	462	27.5	26.7
S570-15	40% strain at ambient temp, 15 min of holding at 575° C	240	386	5.1	3.3
T6	55 min of solution making at 500°C, quench in cold water, aging at 190°C	450	513	12.7	52

Results of hardness test have been presented in Fig. 3. At a specified temperature, the hardness has increased with increasing holding time or temperature. Thus, regarding the 2024 aluminum alloy, an attempt to spheroidize the microstructure by increasing temperature or time has led to increased hardness.

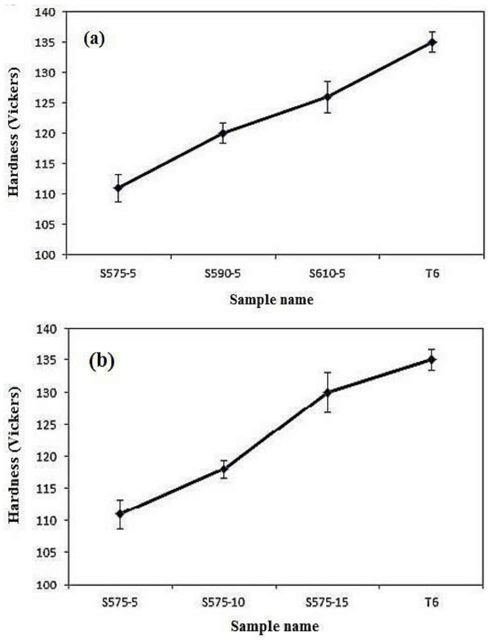

Fig. 3 Hardness chart of SIMA samples: a) In constant strain and time; b) In constant strain and temperature

4- Conclusions

1. With increasing semisolid temperature, sphericity is first increased and then reduced and the grain size first decreased and then increased.
2. With increasing holding time, the grain size showed an increasing regime. By increasing the holding time, the rate of sphericity increased but the grain boundaries became thicker and intermetallic compounds on the grain boundaries became more interconnected. However, after long holding times, the rate of sphericity has decreased.
3. SIMA process has reduced the overall strength but has had a positive effect on elongation and hardness.