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Microstructure evolution and segregation behavior of thixoformed Al−Cu−Mg−Mn alloy

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Abstract: A commercial wrought Al−Cu−Mg−Mn alloy (2024) was thixoformed based on the recrystallization and partial melting (RAP) route, and the microstructure evolution and segregation behavior during the indirect thixoforming process were studied. The results show that fine spheroidal microstructures can be obtained by partial remelting of commercial extruded 2024 alloys without additional thermomechanical processing. During the indirect thixoforming, the stress distribution can be optimized by increasing the thickness of base region. Under three-dimensional compression stress state, the microstructures are homogeneous among different regions with no evidence of liquid segregation and micro-porosities, and the grains in the columns are deformed plastically. The distribution of tensile mechanical properties is consistent with the microstructures. Moreover, the distribution of deformation mechanism was discussed, and a technical method for improving the stress distribution was proposed.

Key words: aluminum alloy; semi-solid; thixoforming; segregation; microstructure

1 Introduction

Semi-solid processing (SSP) is a novel technology for forming alloys in the semi-solid state to near net shaped products. In comparison with conventional forming technologies, SSP has many advantages, such as lower forming force, less product defects and longer die life [1]. Thixoforming is a semi-solid metal processing route, which involves reheating suitable material into the semi-solid state and then forming it to near net shaped components [2−4]. The materials must have an appreciable melting range, and the microstructures must consist of solid metal spheroids in a liquid matrix before thixoforming [5−9]. Thixoforming can be classified into two types: direct forming and indirect forming [10,11]. For direct thixoforming, the semi-solid alloy is placed into opened dies and then deformed by the upper punch, and the deformation process is similar to open-die forging. The indirect thixoforming system consists of upper and lower dies and a punch, and the semi-solid alloy is forced into the previously closed dies and then deformed by the punch. The former type is suitable for forming components with simple or axial symmetric shapes, while the latter one could fabricate components with relatively complex shapes.

Thixoforming can provide high mechanical properties which are close to wrought target. Commercial thixoformed components are almost made from conventional casting alloys, which have high fluidity and castability [12−14]. However, the thixoforming of wrought aluminum alloys was limited due to some general difficulties which were summarized by LIU et al [15], such as wide freezing range (results in higher hot tearing sensitivity) and steep slope in liquid fraction versus temperature curves (leads to a small processing window). In recent years, increasing attention has been given to the thixoforming of wrought aluminum alloys, such as Al−Zn−Mg−Cu and Al−Cu−Mg series.

Some commercial wrought aluminum alloys are

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supplied in the extruded state. It is consistent with the recrystallization and partial melting (RAP) route, which involves warm working and partial remelting. During reheating, recrystallisation occurs in the extruded materials, and as liquid forms, it penetrates the recrystallised boundaries to form spheroids surrounded by liquid [16]. Therefore, it will be significant to obtain spheroidal microstructures directly from commercial extruded alloys without additional thermomechanical processing. JIANG et al [17] studied the microstructure evolution and coarsening by reheating the as-received 7005 aluminum alloy to the semi-solid state. They obtained spheroidal microstructures which are suitable for semi-solid processing. BIROL [18] studied the thixoformability of AA6082 aluminum alloy reheated from the as-cast and extruded states, respectively. KANG et al [10,19,20] have done much work on the microstructures and mechanical properties of thixoformed aluminum alloys.

Although many researches have been conducted on the thixoforming of wrought aluminum alloys and liquid segregation during semi-solid casting or rheoforming, little work has been done on the segregation behavior of indirectly thixoformed wrought aluminum alloys. The present work aims to study the segregation behavior of a thixoformed Al−Cu−Mg−Mn alloy. Moreover, the microstructure evolution and mechanical properties of the components thixoformed under different mechanical conditions were presented.

2 Experimental

The commercial wrought 2024 aluminum alloy was supplied by Northeast Light Alloy Co., Ltd., China, in the form of extruded rods with 45 mm in diameter with extrusion ratio of 1:17. The composition of the starting material is given in Table 1. Differential scanning calorimetry (DSC) was used to determine the solidification interval and the liquid fraction−temperature relationship. About 30 mg samples with 3 mm in diameter were heated to 700 °C at 10 °C/min and cooled to room temperature at the same rate. The change in liquid fraction with temperature was obtained from the heat flow versus temperature curve, as shown in Fig. 1.

Table 1 Composition of 2024 aluminum alloy (mass fraction, %)

Cu	Mg	Mn	Fe	Si	Ni	Zn	Ti	Al
3.8−4.9	1.2−1.8	0.3−0.9	0.5	0.5	0.10	0.30	0.15	Bal.

In order to investigate the microstructure evolution of the commercial wrought 2024 aluminum alloy during partial remelting, some samples with a diameter of 8 mm and a length of 12 mm were cut from the as-received rods. The samples were then reheated in an electrical resistance furnace into the semi-solid state, and isothermally held at 620 °C for different time and quenched in water to room temperature. A thermocouple was placed in a hole with 2 mm in diameter and 4 mm in depth in the center of the sample to ensure accurate temperature measurement and feedback control. According to the DSC results, the liquid fraction (φ_L) of 2024 alloy is 38.8 % at 620 °C.

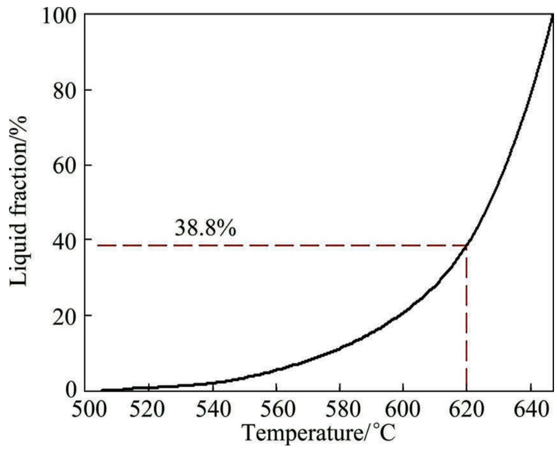

Fig. 1 Change in liquid fraction with temperature of 2024 aluminum alloy

A series of complex shaped components were designed and thixoformed. The components have four columns with different sizes in order to make distinct segregation during the thixoforming process. Figure 2 shows the schematic diagram of indirect thixoforming. As shown in Fig. 2(a), the indirect thixoforming dies consist of upper and lower dies and a punch. The four columns, from the largest one to the least one, are indicated as 1, 2, 3 and 4, respectively, and the base is indicated as 5.

The thixoforming process was carried out using a double-action hydraulic press, which could provide the maximum load of 5000 kN for locking the dies and 1000 kN for the punch. The as-received rods were machined to cylinder-shaped slugs with a diameter of 42 mm and heights of 48 and 56 mm, respectively, so as to thixoform the components with different base thicknesses (3 and 10 mm, respectively). The slugs were rapidly reheated to 620 °C using an electrical resistance furnace. The heating process was monitored by a K-type thermocouple, located at a depth of 10 mm from the top center of slug, which were quickly removed prior to actual thixoforming. During the thixoforming process, the pressure exerted on the slug was increased rapidly to a pre-determined level. The loading velocity and dwelling time were 150 mm/s and 30 s, respectively.

The thixoformed components were then subjected to standard heat treatment T6 (solution treatment at