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Microstructure evolution during semi-solid powder rolling and post-treatment of 7050 aluminum alloy strips

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ABSTRACT

Semi-solid powder rolling (SSPR) combines semi-solid rolling with powder rolling to prepare high-performance metallic strips. Semi-solid powders were prepared under an inert atmosphere and subsequently rolled by a powder rolling machine. Conductive cooling between the pre-heated rollers and semi-solid powders results in a rapid solidification effect that is able to process alloys with a broad freezing range. The liquid in the semi-solid powders plays an important role in the microstructure evolution, which can improve the strength of strips. The 7050 aluminum alloy strips were obtained and used to evaluate the processing parameters and strip qualities for strips up to 100 mm wide and 1.5–2 mm thick. The process of semi-solid powder rolling was described and microstructure evolution during rolling and post-treatment was analyzed. The combination mechanism of semi-solid powders during rolling was also discussed. The results show that the best liquid fraction to prepare a strip ranges from 45 to 65%. Flowing and filling of liquid (>10%), densification by rolling and recrystallization (<10%) are the three combination mechanisms of the semi-solid powders during rolling. In addition, semi-solid powder rolled strips can be processed subsequently by hot rolling with the improved micro-hardness and relative density.

1. Introduction

High strength aluminum alloys such as AA7050 were used extensively for aerospace applications stated in the study by Lang et al. (2011). Flat or strip products are usually manufactured by conventional ingot metallurgy (I/M) process. Subsequently, the materials are further processed (e.g. heat treatment, hot rolling, cold rolling, etc.) to meet the required properties as shown in the study by Deshpande et al. (1998). So, the production run is long and energy wasting. In the 1970s, semi-solid forming proposed by Flemings (1991) can obtain a homogeneous defects-free globular microstructure based on the special properties of semi-solid slurry. Kang et al. (1999) stated that semi-solid forming was mainly used to produce the low melting point alloys such as aluminum alloys. Later, Kiuchi and Kopp (2002) demonstrated that semi-solid rolling consisting of thixo-rolling and rheo-rolling was used to prepare metallic plates and strips at a laboratory scale. At present, rheo-rolling is not applied to industrial production because of the difficulty in slurry preparation on the production line, liquid-segregation and surface cracking as discussed by Govender and Moller (2008). Kang et al. (1997) stated that rheo-die castings were more into having surface crackings and Masuku et al. (2010) said that liquid segregation is easily formed during forming. These flaws have a negative effect on the mechanical properties as shown in Kim et al. (2007). Schaffer et al. (2001) stated that powder rolling can be used to make aluminum alloy strips. However, most green strips prepared by powder rolling have high porosity and need sintering or further processing to get dense materials. In addition, lubricant and binder are necessary for preparing the compacts. Then Zu and Luo (2001) studied semi-solid powder forming (SPF) and Wu et al. (2010a) discussed various processing routes. In general, here needs pre-compaction before heating in SPF as stated in Wu et al. (2010b). And it is mainly applied in the extrusion and compaction. In 2003, McHugh et al. (2004) proposed spray rolling which appeared to include the advantages of energy saving and high production rate while improving quality with a uniform fine-grain equiaxed microstructure. But this new strip/sheet manufacturing process needs dedicated and expensive apparatus, which leads to high costs.

Therefore, a novel strip manufacturing process, termed “semi-solid powder rolling”, is proposed by the authors. The general concept of semi-solid powder rolling is from the possible combination of semi-solid forming and powder rolling. Semi-solid powder rolling (SSPR) consists of semi-solid powder preparation under an inert atmosphere, semi-solid powder rolling at a relatively stable temperature, and post-treatment procedures if necessary. This new process is mainly used to prepare strips with high quality,

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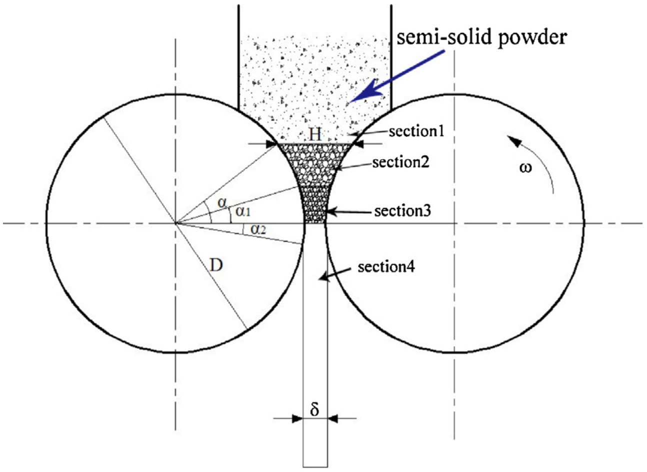

Fig. 1. Schematic of semi-solid powder rolling process.

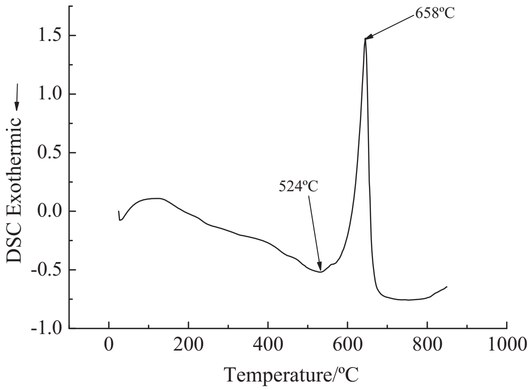

Fig. 2. DSC curve of 7050 aluminum alloy powders.

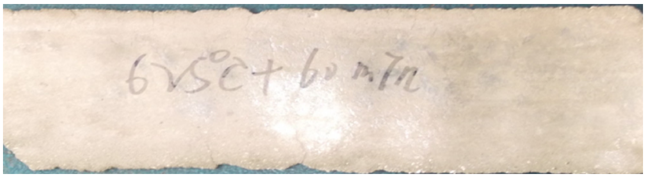

Fig. 3. A strip prepared by semi-solid powder rolling (heated at 625 °C and held for 60 min).

especially for alloys that have a wide freezing range and low melting point such as aluminum alloy (AA7050, 2124, etc.). While still in the early stage of development, semi-solid powder rolling shows a promise for reducing strip manufacturing costs and saving energy while improving the qualities. The inherent rapid solidification, easily controllable process conditions and solid solubility extension may provide an interesting avenue for the development of alloys. The objective of this study is to analyze the best parameters to prepare strips and provide an insight into the mechanisms that govern the microstructure evolution during semi-solid powder rolling. The combination mechanism of semi-solid powders and the effect of liquid fraction on the microstructure evolution are emphasized.

2. Experimental procedures

A schematic of the approach is shown in Fig. 1. The powders used in this work are the gas atomized 7050 aluminum alloy powders with a nearly spherical morphology (the mean particle size is about 75 μm). The chemical composition of raw materials is summarized in Table 1. The experiments were carried out on a powder rolling machine with rollers pre-heated to 300 °C so as to maintain the rolling temperature. The diameter of roller is 150 mm with a width of 100 mm, a rolling gap of 0.1 mm and a rotating speed of 0.4 rad/s.

Firstly, in order to obtain the semi-solid powders, the gas atomized 7050 aluminum alloy powders were heated to the semi-solid temperature range and held for different time under an inert atmosphere (the actual freezing range of 7050 aluminum alloy powders is 524–658 °C analyzed by DSC as shown in Fig. 2). Then, the semi-solid powders were fed into the gap between pre-heated rollers and consolidated into dense strips. In order to analyze the effect of liquid fraction on microstructure evolution during rolling, the representative values of liquid fraction at each stage were selected as the processing parameters to prepare the strip (low liquid fraction, intermediate liquid fraction and high liquid fraction). Thus, the following parameters were selected: (1) heated at 555 °C, held for 30 min, (2) heated at 585 °C, held for 60 min, (3) heated at 625 °C, held for 60 min, (4) heated at 640 °C, held for 20 min, (5) heated at 650 °C, held for 40 min and (6) heated at 650 °C, held for 50 min. The strips up to 100 mm wide and 1.5–2.0 mm thick were obtained with a good formability and a smooth surface as shown in Fig. 3. Subsequently, the semi-solid powder rolled strips were hot rolled at 471 °C with 30% thickness reduction by using a laboratory rolling mill with a loading capacity of 240 t. All the hot rolled strips were treated with air cooling after hot rolling. Samples were discontinuously selected from the central zone along to the rolling direction. Finally, the relative density of each specimen was tested by using the Archimedes' principle. The microstructures of the polished and etched samples were observed with an optical microscope (LcicaDMI500M). The phase identification was carried out by X-ray diffraction (XRD) analysis using D8 ADVANCE (Bruker, Germany) Cu (Kα1 + Kα2) radiation (the diffraction angle 2θ is 10–90°, scan speed is 17.7 s/step). The micro-hardness was tested at HVs-100 Vickers, and the loading force was 1.96 N. For each sample, the micro-hardness was measured randomly at 6 different points, and then the mean value of micro-hardness as well as standard deviation were calculated and reported. The grain size was determined by using the linear intercept. Scanning electron micrograph (SEM) observation was carried out at NovaNanoSEM430 for identifying the morphology and distribution of second phase particles.

Table 1
Chemical composition of 7050 aluminum (wt%).

Zn	Mg	Cu	Zr	Ti	Fe	Si	Al
6.43	2.26	2.02	0.13	0.03	0.11	0.07	Bal

3. Results and discussion

3.1. Effect of liquid fraction on microstructure during semi-solid powder rolling

Fig. 4 shows the microstructure of semi-solid powders prepared under different conditions and the corresponding liquid fraction is summarized in Table 2.

Table 2
liquid fraction at different temperatures.

Temperature(°C)	555	585	625	640	650
Liquid fraction (%)	1.38	13.8	44.2	65.09	83.2