STRUCTURAL FEATURES AND MECHANICAL PROPERTIES OF RAPIDLY SOLIDIFIED AlSi ALLOYS

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Abstract

Nowadays, manufacturing of materials with unique properties is in the centre of attention of materials engineering. Aluminum and aluminum alloys are widely applied in variety of industries due to their high specific strength and in the following years they will become even more important. Construction elements made from aluminum and its alloys are produced mainly by casting or plastic working processes. In order to obtain the highest mechanical properties in afore mentioned materials their microstructure must be characterized by grain size on the level of sub- or nanoscale. This goal can be achieved on several ways including SPD methods or by applying more unconventional methods such as rapid solidification. In this paper mechanical properties and results of microstructure observations of AlSi5 and AlSi10 has been presented. Materials were obtained by two different methods. At first traditional casting followed by hot extrusion at the temperature of 400 °C was applied. The second manufacturing method was rapid solidification. In this case melted aluminum was casted on cold, fast rotating cooper wheel followed by plastic consolidation by hot extrusion. From obtained rods samples were cut for tensile test as well as microstructure observations which were performed both with a use of light and electron microscopy. Microstructure examination results and mechanical properties confirmed that rapid solidification significantly increases mechanical properties by structure refinement.

Keywords: Rapid solidification, plastic consolidation, aluminum alloys, shape factor

1. INTRODUCTION

One of the most effective way to improve mechanical properties in metals and alloys is grain refinement, obtained for example in mechanical synthesis process or plastic consolidation of metal powders, quickly crystallized tapes, flakes, etc. [1-10]. In Al-Si alloys during traditional casting, hard, large and brittle Si particles may form which in result leads to material cracking during plastic forming. Rapid solidification (RS) processes allow to obtain material with a very fine grain size and highly fragmented Si particles, which increases their plastic workability during forming processes [11,13]. Proper distribution of fine precipitates and oxide phase enables effective blocking of grain boundaries movement, which contributes to the high stability of the structure at elevated temperatures [3]. In Al-Si alloys after plastic consolidation (e.g. RS442, AlSi12.5Fe5Cu3.5Mg1)) microstructure can characterize by highly fragmentation level with a matrix grain below 1 µm and high mechanical properties maintained even after annealing at 450 °C [11-13]. Rapid solidification process of hypereutectic 6061 alloy (with 26 wt.% Si addition) combined with KOBO extrusion (λ = 19) leads to fragmentation of silicon precipitates and sub-micron matrix grains. Despite the high Si content (26 wt.%), highly fragmented structure significantly increases the plasticity of the material [14].

2. EXPERIMENT PROCEDURE

Materials used for the tests were AlSi alloys with Si addition of 5 wt.% and 10 wt.% (IM-ingot material, RS-rapid solidification material). Alloys were prepared by mixing silicon with AA1050 aluminum which chemical composition presents **Table 1**. Materials used in the research were prepared by conventional casting process and rapid solidification method with a use of melt spinner. The materials production schematic is shown in **Figure 1**. Before the material was subjected to the RS process, it was inductively melted at 700 °C in the protective gas shield. Melted metal was subsequently cast through a hole in a crucible (with a diameter of 0.5 mm), onto a fast-spinning copper wheel (with a diameter of 148). The wheel speed was 2800 rpm. The end results of this process were 3 mm wide and 10 to 40 µm thick ribbons. The next step was compacting of the obtained ribbons at ambient temperature on a vertical press under load of 240 MPa. As a result, round compacts were obtained, with a diameter of 38 mm and a height of 10 mm. The last stage of the production process was hot extrusion of solid ingots and compacted RS briquettes. Both materials in a form of 200 g weight charge were extruded at 400 °C with a ram speed of 3 mm/s to form a rods with a diameter of 8 mm. Micro-structured samples were taken from longitudinal sections and were examined using the HITACHI SU-70 scanning electron microscope. The mechanical properties were determined in uniaxial tensile test.

Table 1 Chemical composition of AA1050 alloy

Element	Al	Cu	Fe	Mg	Mn	Si	Ti	V	Zn	Others
weight %	99.5	0-0.05	0-0.4	0-0.05	0-0.05	0-0.25	0-0.03	0-0.05	0-0.05	0.03

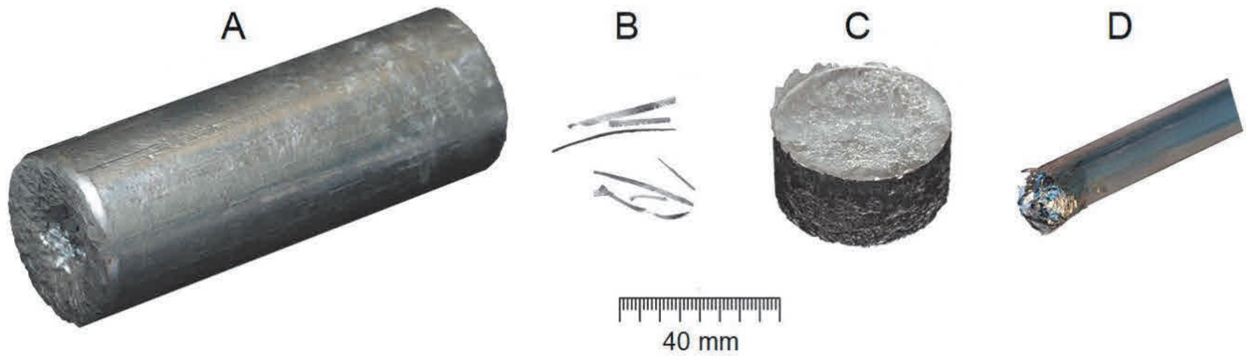

Figure 1 Materials used in the experiment: a) ingot, b) ribbons, c) briquette, d) extruded rod

3. RESULTS AND DISCUSSION

In **Figure 2** microstructure on the longitudinal section in as extruded rods has been presented. Both **Figures 2a** and **2b** present solid material microstructure, with a Si content of 5 wt.% and 10 wt.% respectively. In both examined rods brittle silicon particles with various morphology and average area of 2 µm^2 were observed. In addition brittle, intermetallic phases of AlFeSi are also visible in the structure in the form of white precipitates. These phases are characterized by higher level of fragmentation than Si particles. Both Si and AlFeSi phases were distributed evenly in the entire volume of the observed rods. **Figures 2c** and **2d** show the microstructure of rods obtained from a RS material with a silicon content of 5 wt.% and 10 wt.%. Compared to the microstructure of rods extruded from solid material, finer silicon phase are observed, with an average surface area of 0.13 µm^2. Rapid solidification resulted in fragmentation of both silicon particles (by 15 times) as well as intermetallic AlFeSi phases. Inhibition of silicon growth is most likely caused by limitation of diffusion processes during rapid solidification. Differences size of Si and AlFeSi phase sizes are confirmed by elements distribution map shown in **Figure 3** for solid material and in **Figure 4** for the material obtained from rapidly solidified ribbons.

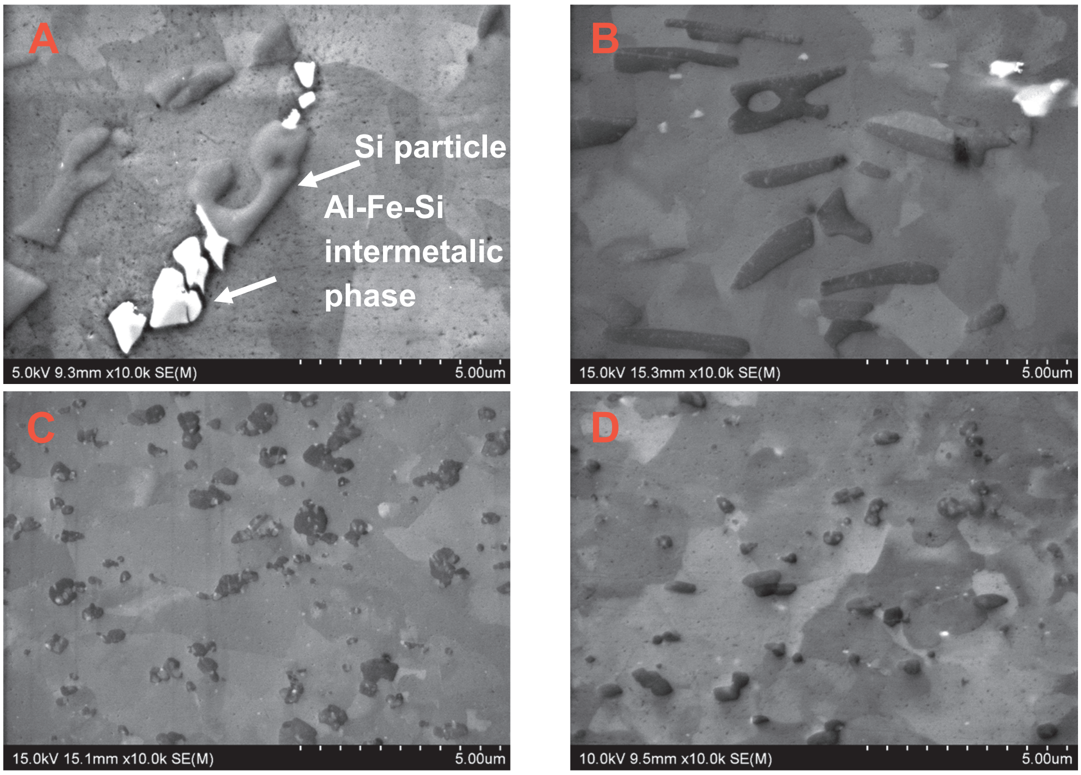

Figure 2 Microstructure of as-extruded rods: a) AlSi5 IM, b) AlSi10 IM, c) AlSi5 RS, d) AlSi10 RS

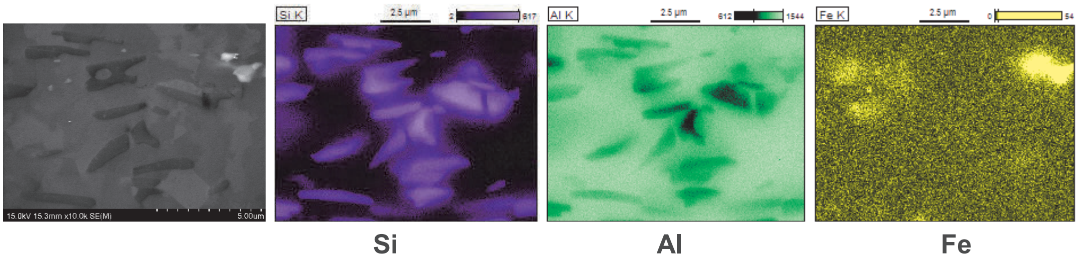

Figure 3 Elements distribution maps for AlSi10 IM (SEM/EDX)

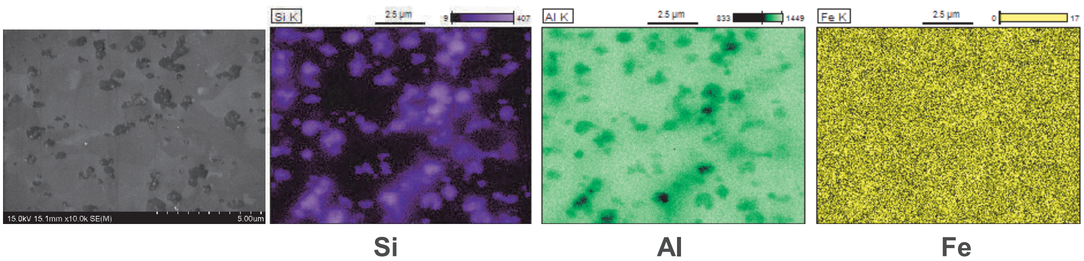

Figure 4 Elements distribution maps for AlSi10 RS (SEM/EDX)

By analyzing the microstructure of the obtained rods by hot extrusion process, a significant change in morphology of silicon particles was observed depending on the method of obtaining the material. In addition to size change, shape of Si particles also changed. In order to examine these variations, shape factor of the silicon precipitates was determined with a use of ImageJ software. By determining Si shape factor level of particle surface development can be measured. The lower the value of the coefficient, the more developed area of the analyzed particle [15]. For each extruded rod microstructure analysis was performed with a use of 10 photos. **Figure 5** shows the percentage of individual shape factor ranges. Similar distribution graphs can be observed for the material obtaining by the same method regardless of Si content. However, when comparing alloys obtained by different methods, percentage contribution of individual shape factor ranges differ significantly. In the case of rods obtained from solid material, approximately 90% of all particles remain in shape factor range from 0 to 0.6. In the case of material obtained from RS ribbons, this tendency is reversed and about 90% of all particles remain in the range of 0.5 in the above.

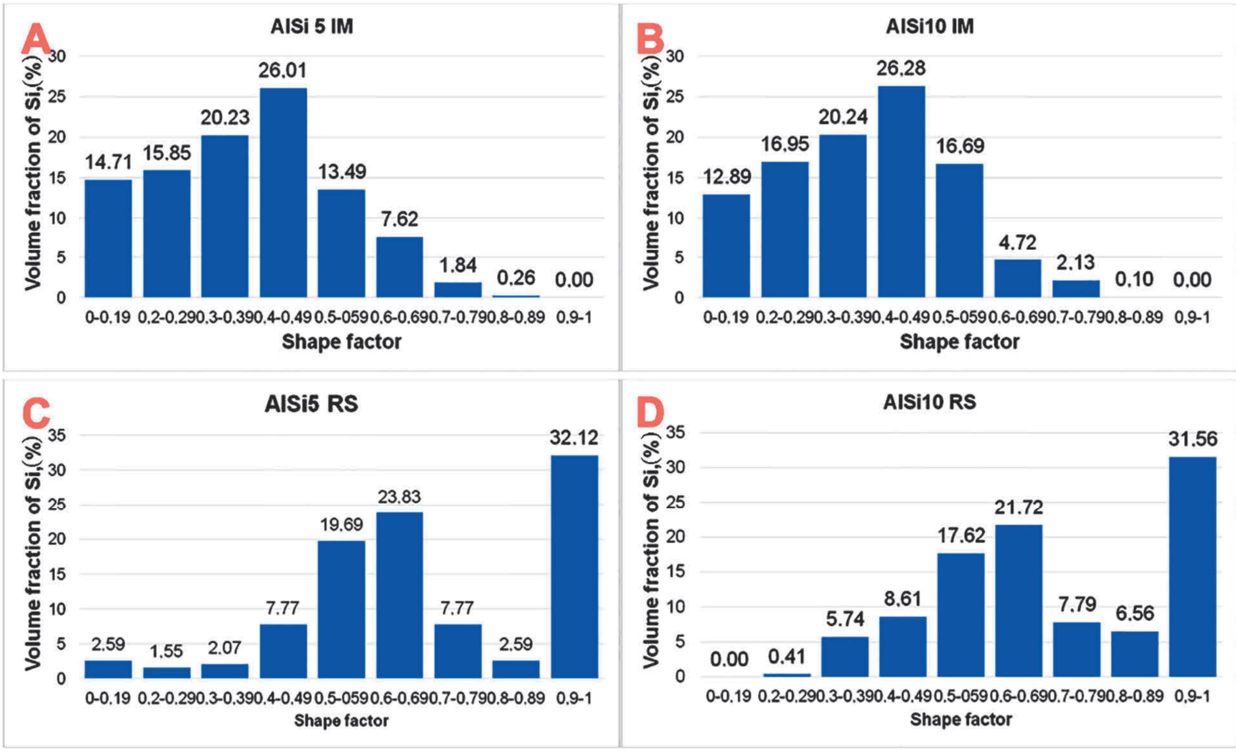

Figure 5 Shape factor distributions of Si particles in samples: a) AlSi5 IM, b) AlSi10 IM, c) AlSi5 RS, d) AlSi10 RS

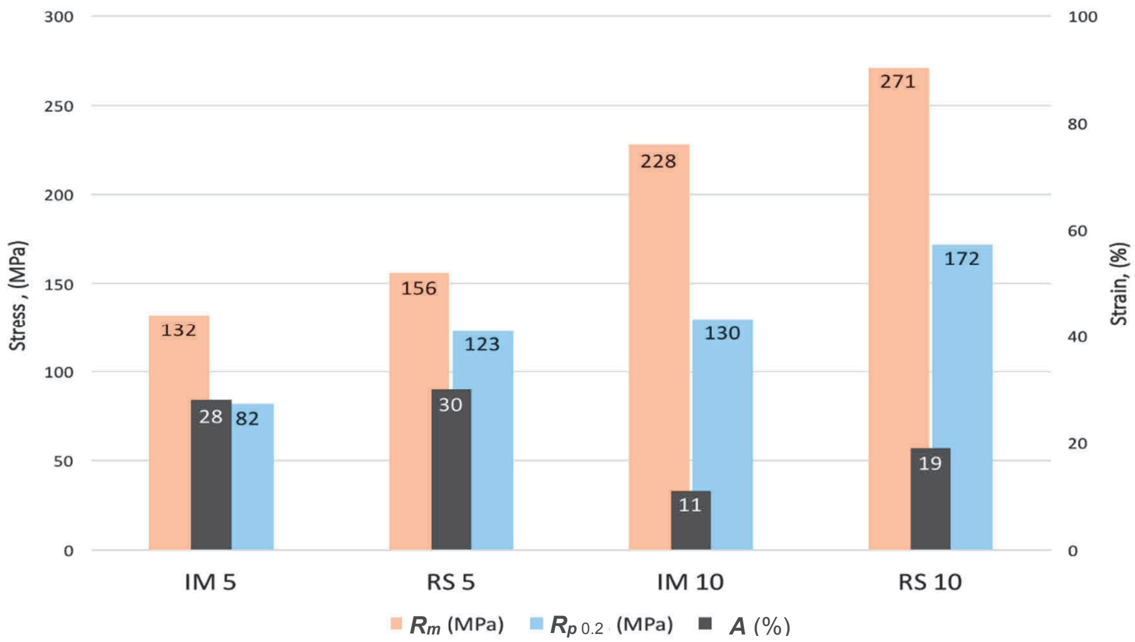

Figure 6 Comparison of mechanical properties obtained from uniaxial tensile test

Figure 6 presents the results of tensile tests carried out at ambient temperature. In case of traditionally cast materials, increasing Si content in alloys from 5 wt.% to 10 wt.% resulted in almost double increase in UTS value from 132 MPa for AlSi5 IM to 228 MPa for AlSi10 IM. Additionally significant increase in the yield strength with simultaneous reduce of total elongation to 11% was observed. Rapidly solidified AlSi5 RS samples were characterized by higher UTS value of 156 MPa in comparison to traditionally cast reference material AlSi5 IM. At the same time, the increase in elongation is only 2%. In the case of RS alloy with 10 wt.% of Si addition, was observed further increase in strength properties (both R_m and $R_{p\,0.2}$). It is worth emphasizing that the total elongation for RS alloy with 10 wt.% Si is almost two times higher than AlSi10 IM.

4. CONCLUSIONS

1) Raising the silicon content to 10 wt.% resulted in an increase of mechanical properties by about 70% compared to rods with 5 wt. of Si addition.
2) Rapid solidification process resulted in material strength increase by about 20%, and in the case of rods with Si content of 10 wt.% significant improvement in total elongation (from 11% for AlSi10 IM to 19% for AlSi10 RS).
3) The combination of rapid solidification and plastic consolidation influenced both on size and morphology of AlFeSi and silicon phases. In comparison to the conventionally cast alloys, RS materials possessed finer silicon particles (15 times smaller) with less surface development.

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