Friction Stir Processing Regularities of Cast Aluminum Alloy AlSi12

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Abstract. The paper studies the structure and morphology of the treating zone surface of cast aluminum alloy AlSi12 after 1-4 passes with a friction stir tool. The studies show that after all four passes, the surface of the tool exit zone has traces of material tearing out along the edge of the pin, but the overall appearance of the machining surface improves. The structure after four passes with the tool is dominated by smaller and more rounded particles, while after one pass there is a large number of elongated particles. Friction stir processing leads to improvement of material plasticity by up to 2.5 times and ultimate tensile strength value by 9-10%.

1. Introduction
Friction stir processing of aluminum alloys has been used for a long time to harden and modify the structure in order to improve the mechanical and performance characteristics of the finished products [1-3]. It is possible to modify the structure of magnesium, aluminum, copper, titanium alloys, steels, high entropy alloys, etc. by friction stir processing. Potentially, this type of processing has broad prospects for the formation of wear-resistant surface structures and obtaining lightweight tribotechnical parts. One of the most preferable for use as materials for tribological purposes in such a case are cast aluminum-silicon alloys, for which there are currently a number of studies in the field of friction stir processing [4,5]. Additional modification by powder particles based on metals, oxides, carbides, allows increasing the wear resistance of alloys, strength or other performance characteristics. For the most optimal ratio of structure and properties of the obtained products, the friction stir process is carried out in several passes (mainly 3-4 passes). This situation is caused by the mechanics of the machining process which leads to the formation of large agglomerations of powder material in the stir zone after 1-2 passes with the tool. In this case, a large number of passes with the tool along the machining line for AlSi12 aluminum-silicon alloy can potentially lead to the formation of defects in the structure and a decrease in properties. Moreover, at the present time, literature sources contain insufficient information on the regularities of influence on the structure and properties of aluminum-silicon alloys by multipass friction stir processing. Based on the above, the purpose of the present work is to conduct preliminary studies of the structure formation of aluminum-silicon alloy AlSi12 subjected to multi-pass friction stir processing.

2. Materials and methods
The samples were obtained by friction stir processing with a screw-pin tool on the experimental setup at the Institute of Strength Physics and Materials Science. The machining was carried out at a tool
rotation speed of 700-750 rpm and a feed rate of 90 mm/min. The clamping force of the tool to the workpiece material was 750 kg. The machining depth was 3 mm. The width of the tool arms was 16 mm and the tool pin was 7 mm. Processing was carried out from one to four passes with the tool on the same area. The structure was studied by optical microscopy (Altami MET1C microscope). Mechanical tests were carried out on a universal testing machine UTS110-M.

3. Results and discussions
The surface layers obtained after processing has a different structure depending on the number of passes (figure 1). In the area of the tool exit hole there are traces of material tearing off at the boundary of the tool shoulders and pins (figure 1). With each pass of the tool along the machining line, the surface of the treated material is smoothed. The surface of the machining area is significantly smoother after 4 passes with the tool as compared to the first pass.

![Figure 1. Surface appearance in the processing area after 1-4 passes with the tool](image)

In the structure of the treated material it can be distinguished the stir zone (SZ in figure 2) and the thermomechanical affected zone (TMAZ in figure 2), differently organized on the retreating (RS in figure 2) and advancing (AS in figure 2) sides. In the material of the stir zone, it can be distinguished the absence of pores found in large numbers in the base metal. The structure of the stir zone and neighboring zones does not reveal the presence of defects of stir friction processing in the form of wormhole, cracks or delaminations. In contrast to the base metal, represented by the large-dendrite structure of cast aluminum-silicon alloy AK12, there is crushing of large silicon plates in these areas with the formation of the central part of the stir zone structure with almost equal-axis silicon particles after 4 passes by the tool along the processing line (figure 3). In this case, in the structure of the samples after the 1st pass there are more large particles of silicon, including elongated shape. With each new pass the average size of silicon inclusions decreases. And the intensity of structure refinement with each pass of the tool along the processing line decreases. The images in Figure 3 also show a decrease in the volume fraction of silicon particles with increasing number of passes along the treating line, which may be related both to the increase in the number of fine particles and to the general heterogeneity of the AlSi12 aluminum alloy structure before treating.

Determination of the silicon inclusions size shows that before processing the average size of silicon plates in the cross section is 5.70 microns (figure 3, a). After one pass treating, the average particle size of the near-axial particles is 4.75 μm. Then, after the second and third passes, the particle size is reduced with less intensity and it averages is 4.40 μm. In the last stage, after 4 passes, the average particle size decreases to 4.05 μm. It can be assumed that after the initial crushing of elongated silicon plates in the aluminum matrix, the further stages of crushing already close to equiaxial particles are more difficult, because the aluminum matrix has significantly higher ductility and lower hardness compared to the
silicon particles, which simply do not meet sufficient resistance to breakage and are crushed only by local shearing on the surface when stirred.

![Figure 2](image2)

**Figure 2.** Structure of the stir zone after the 1st and 4th passes with the tool (SZ - stir zone, TMAZ - thermomechanical affected zone, AS - advancing side, RS - retreating side)

The regularities of plastic deformation and fracture of AlSi12 alloy in the initial state and after 1-4 passes with the tool are quite similar (figure. 4, b). The deformation has an elastic part, smoothly passing to the stage of plastic flow, and after it, to fracture, occurring mainly one-step after reaching the strength limit. A small stage with smoothly decreasing loading force appears in the samples after 3-4 passes, indicating an increase in plasticity in the material and formation of the neck before fracture. Plasticity increases in the material by up to 2.5 times (figure. 4, c). The ultimate tensile strength increases less intensively, not more than 9-10% compared to the base metal (figure. 4, d). At the analysis of mechanical properties of system it is possible to allocate also, that after 1-2 passes by the tool the ultimate tensile
strength essentially does not change, and plasticity even undergoes some decrease. However, this circumstance does not prevent the application of this technique in the future for obtaining composite materials on the basis of aluminum-silicon alloys of AlSi12 type.

![Figure 4](image)

**Figure 4.** Average particle size of silicon in aluminum matrix (a), patterns of plastic deformation in the initial state and after treating in 1-4 passes (b) and the effect of the number of tool passes along the treating line on the ultimate tensile strength (c) and ductility (d) of the AlSi12 alloy

4. **Conclusions**

As a result of the studies it can be established that the friction stir processing of aluminum-silicon alloy AK12 allows obtaining the material with a refined structure of silicon particles in the aluminum matrix. Increasing the number of passes by the tool from 1 to 4 leads to the formation of a more finely dispersed structure with more equiaxed particles in the stir zone. At the same time defects in the material structure are not revealed. The plasticity of the stir zone in tensile tests increases by 2.5 times, with an average increase in the ultimate tensile strength of 9-10%. Thus, it can be established that the method of multipass friction stir processing of aluminum-silicon alloys has significant applicability for obtaining composite materials with metal matrix.

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