Hardening of aluminium alloy 5556 and copper C11000 produced by the additive electron-beam method with the following friction stir processing

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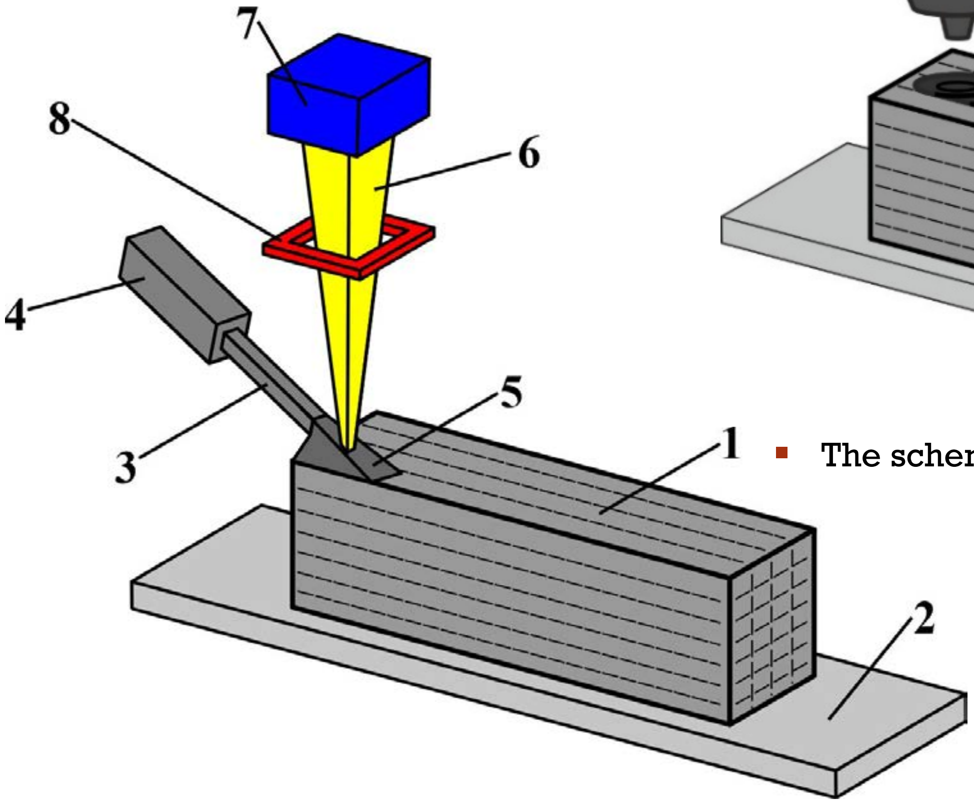
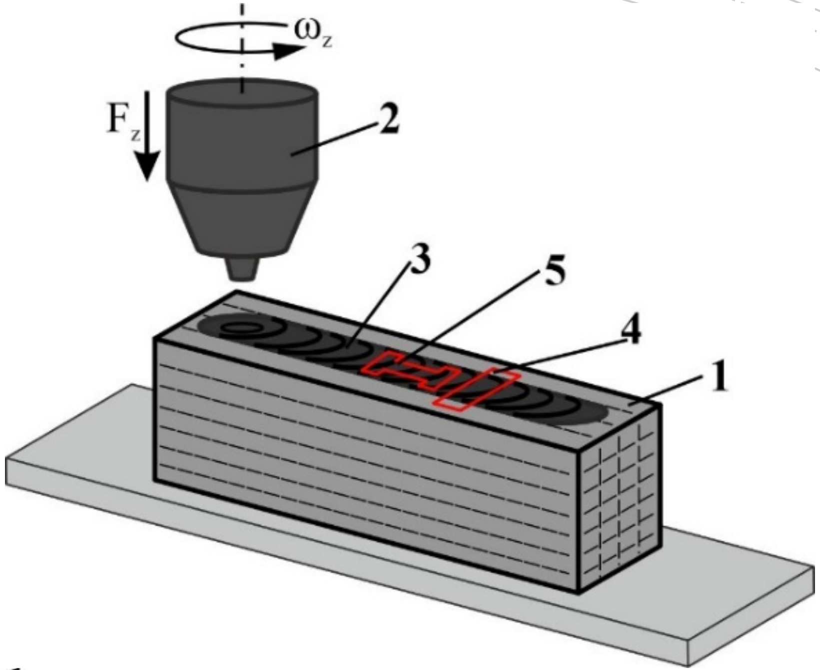
Introduction

- The results of the work show that a hardened layer with almost complete absence of pores and delaminations and increased mechanical properties occurs in the surface layer at the processing depth. The structure of the surface layer is similar to that obtained by friction stir processing of flat rolled products. Mechanical tensile testing of the gradient zone between processed and unprocessed material shows that fracture occurs mainly along the boundary between the processing zone and the additively manufactured material. Thus, the combination of wire-feed electron-beam additive technology and friction stir processing makes it possible to obtain components with a hardened surface layer of the finished product.

Experimental Setup



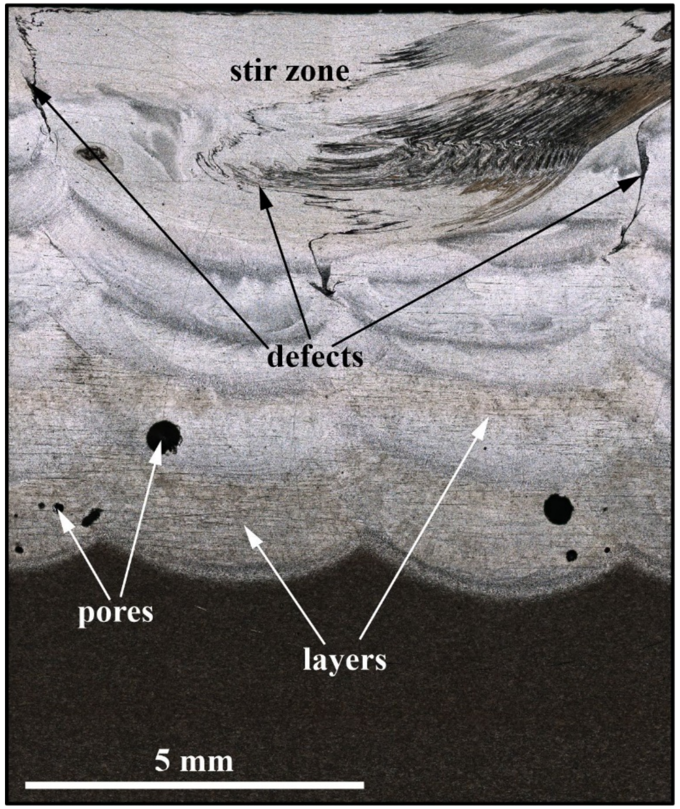
- The scheme of the electron-beam 3D-printing process



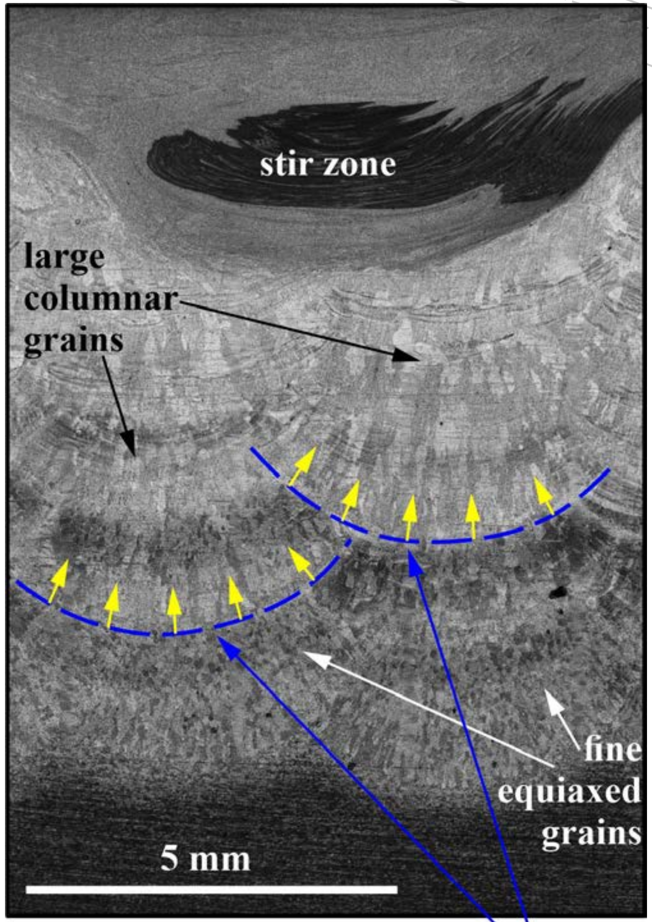
- The scheme of the friction stir processing

- Samples were produced by the additive electron-beam technology on the equipment of ISPMS SB RAS. The process of printing is schematically shown in Fig. 1. Samples of C11000 copper and AA5556 aluminium alloy (1) were obtained on a substrate (2) from an identical material by melting the filament (3), fed through a nozzle (4) and forming a molten pool (5). Melting of the filament was carried out by an electron beam (6) from the heat source (7), directed to the molten pool through the magnetic focusing system (8).

Results and discussion



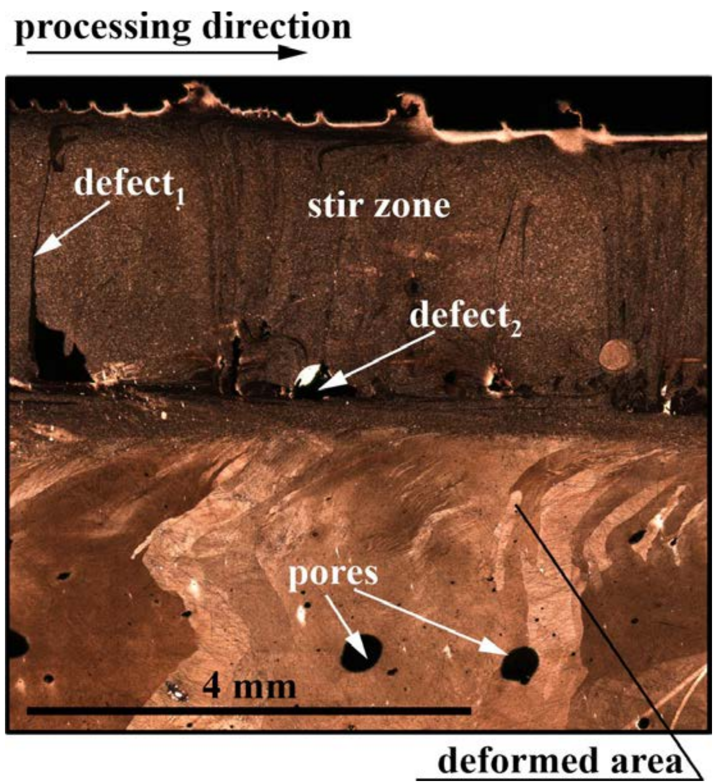
- Structure of the 5556 alloy sample with large macrodefects produced by the additive 3D-printing and friction stir processing



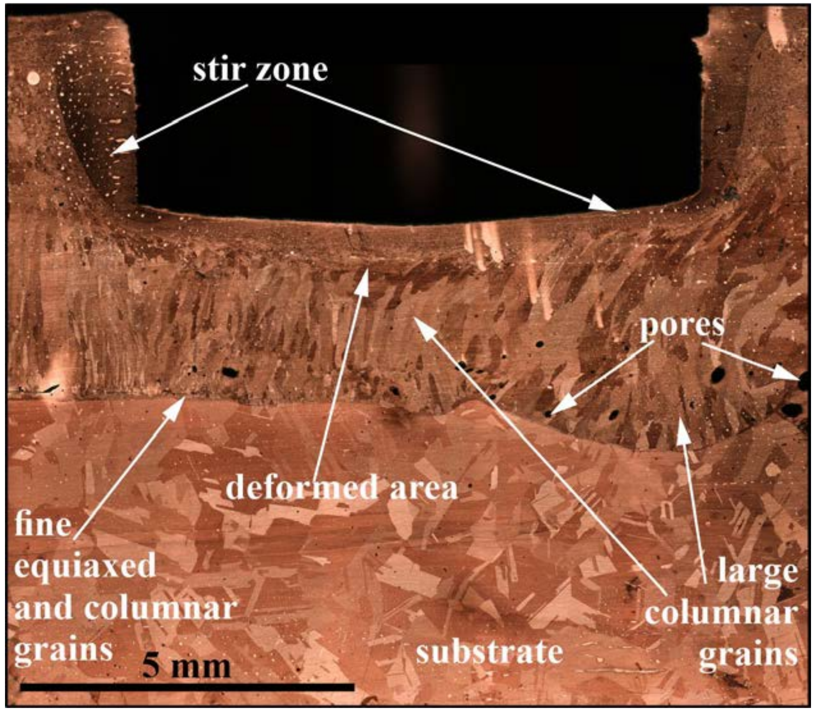
- The structure of the AA5556 alloy sample produced by the additive 3D-printing and friction stir processing without initial macrodefects

Carried out researches show that in the samples of the 5556 alloy produced by the electron-beam method both small defects eliminated by the friction stir processing and large discontinuities that cannot be eliminated by a post-treatment are formed.For example, shows the macrostructure of a sample obtained by forming large discontinuities between adjacent columns and small pores of a round cross-section. Pore defects occur only in the additive material. In the processing zone, the pores are compacted and stirred, and as a result, their negative impact on mechanical properties is leveled out. Defects in the form of discontinuities, located in the vertical direction in the additive material, after the friction stir processing are compacted and partially eliminated in the processing zone and its edges. However, this position is obviously not sufficient to obtain an adequate strength of the material and defects in the form of large discontinuities can be considered completely unrecoverable in the area around the stir zone and partially recoverable in the SZ itself. In this case, in the stir zone, it is possible to have a defect in the central part, in the place where there was a large-sized discontinuity similar to the defect of the joint line type observed in the friction stir welding and which is one of the most dangerous in terms of its impact on mechanical properties. In the area of a joint line formation, the strength of the material when tested across the processing zone can drop to almost zero.

Results and discussion



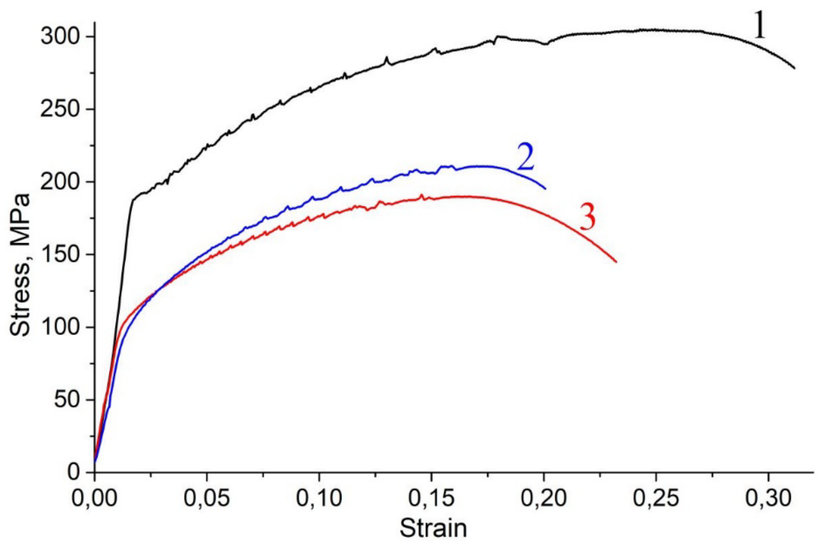
- The formation of a defective structure in the stir zone of a copper sample in the longitudinal section



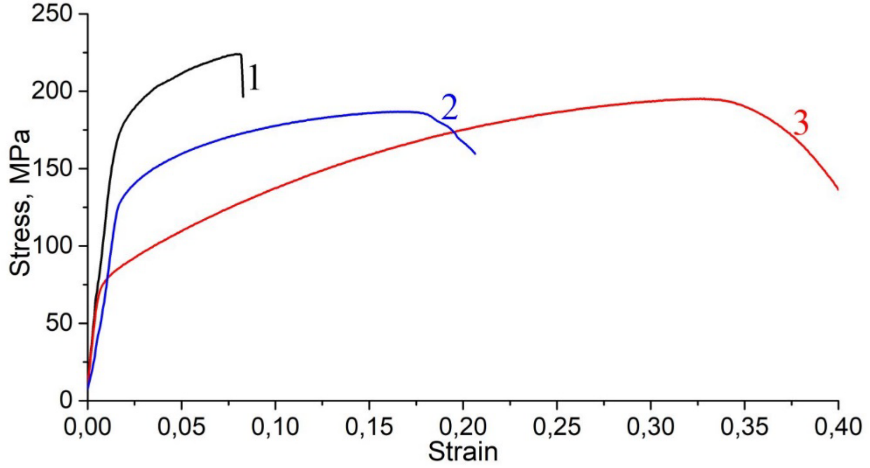
- The structure of the friction stir processing tool outlet area

In contrast to the aluminum alloy, for which the influence of processing parameters on the process of structure formation is significant, but also provides a fairly wide range of control process parameters, allowing to produce defect-free samples with an ultrafine dispersed structure. Copper produced by the additive method has a fairly limited range of control parameters, with a slight deviation from which the formation of fragmented and highly defective structure in the material occurs (fig. 5). The figure shows the image of the processing zone in the longitudinal section. The formation of vertically oriented defects (defect1) is closely related to the physical nature of the friction stir processing. During the processing the main mechanism is the formation of a fine tribological layer due to the friction of the tool against the sample material, and its movement from the leading edge of the tool to the trailing edge of the tool. When the heat is quickly removed from the friction zone due to the high thermal conductivity of copper, especially in the coarse crystalline state, the formation of such layer becomes more complicated, and the tool is resting on the unheated material, after which there is an abrupt movement of the tool along the processing line with alternating periods of resting and failures of the tool. During this process, when the tool moves in the unheated material, defects of the first type are formed.

Results and discussion



- Mechanical properties of AA5556 alloy samples: the FSP stir zone (1), the 3D-printed material (2), and the substrate (3) after thermal effects from the layer to be deposited



- Mechanical properties of C11000 copper samples the FSP stir zone (1), the 3D-printed material (2), and the substrate (3) after thermal effects from the layer to be deposited

Structural changes in the stir zone directly affect the mechanical properties of materials produced during printing followed by processing. In aluminium alloy AA5556, the sample material that has been cut out from the substrate and subjected to repeated thermal effects during printing has the lowest strength. The strength of the 3D-printed material is slightly different. The highest values of a strength and ductility are characteristic for samples cut out from a stir zone. In the additively produced copper the thermal effect on the substrate material is practically not effective, and the substrate has an average strength and sufficiently high ductility. The additively produced material has a slightly lower ultimate tensile strength and a twice lower ductility. The material obtained by additive method and processed by FSP has a high strength, but the lowest ductility.

Conclusion

- The carried out studies show that the material of aluminium alloy 5556 and copper C11000 during the electron-beam 3D-printing inevitably contains defects in the form of pores or, at an essential deviation of the printing process macro-geometry, large discontinuities. Removal of such defects in the structure of samples using the friction stir processing method allows to increase the strength and ductility of the aluminum alloy, and in the case of copper leads to a decrease in the ductility and an increase in the strength. This may be due to the need for a finer selection of copper processing parameters, especially with large crystalline structures after the 3D-printing process, due to the high thermal conductivity, resulting in a rapid heat dissipation from the processing zone and the disruption of the process smoothness. At the electron-beam additive manufacturing such properties of copper lead to the formation of a large number of pores in the structure of samples, which is due to the need for more intense heating of the molten pool at printing, leading to an intense evaporation of various impurities from the material, which solidifies in the structure during the rapid cooling as bubbles or pores. Thus, the electron-beam additive manufacturing can be supplemented with the post-treatment by the FSP method to harden the material and align the surface structure of large parts of both aluminum alloy 5556 and copper.

Acknowledgment

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