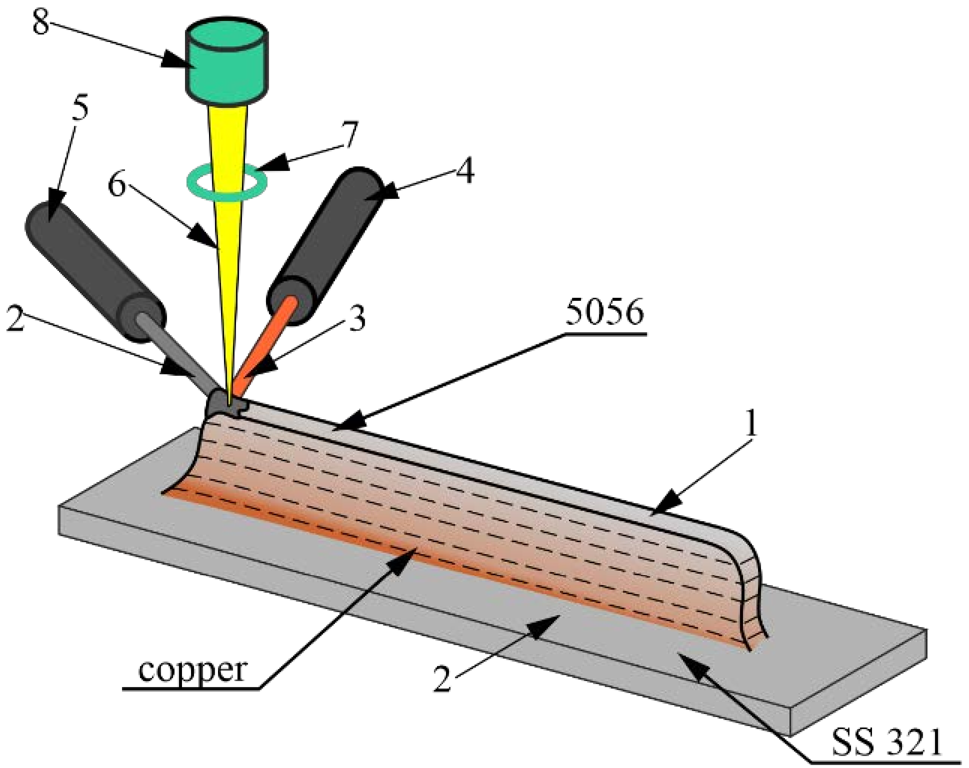
The structure organization and defect formation of Cu-Al system polymetallic materials produced by the electron-beam additive technology

Andrey Chumaevskii (tch7av@gmail.com), Tatiana Kalashnikova, Anastasiya Gusarova, Evgeny Knjazhev, Kirill Kalashnikov and Aleksandr Panfilov
Institute of Strength Physics and Materials Science of Siberian Branch Russian Academy of Sciences (ISPMS SB RAS)
2/4 Academichesky Ave., 634055, Tomsk, Russia

Introduction

- In the work, regularities of the structure formation of polymetallic samples from a copper and an aluminum alloy produced by the electron-beam additive technology were studied. The basic types of defects were defined and conditions of their formation were identified. Structural features of a gradient transition zone from copper to the zone of a solid solution of aluminum in copper, and to the zone of intermetallic phases formation have been investigated. The complex and heterogeneous structure of the gradient zone was revealed. It was found that at the formation of large intermetallic zones even in modes with optimal values of parameters, the formation of cracks with different sizes occurs.

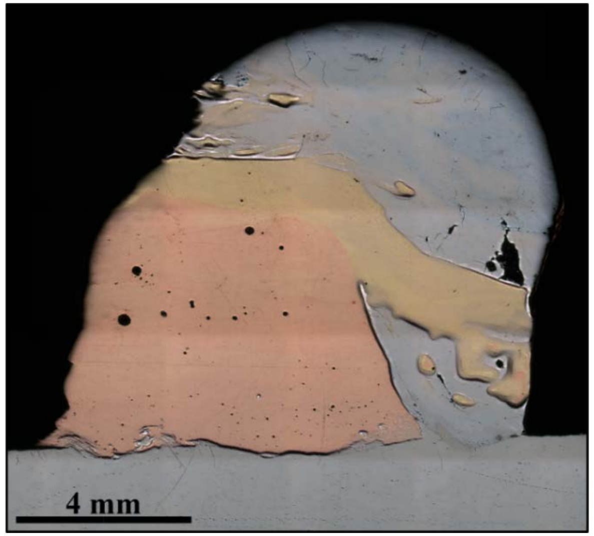
Experimental Setup



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

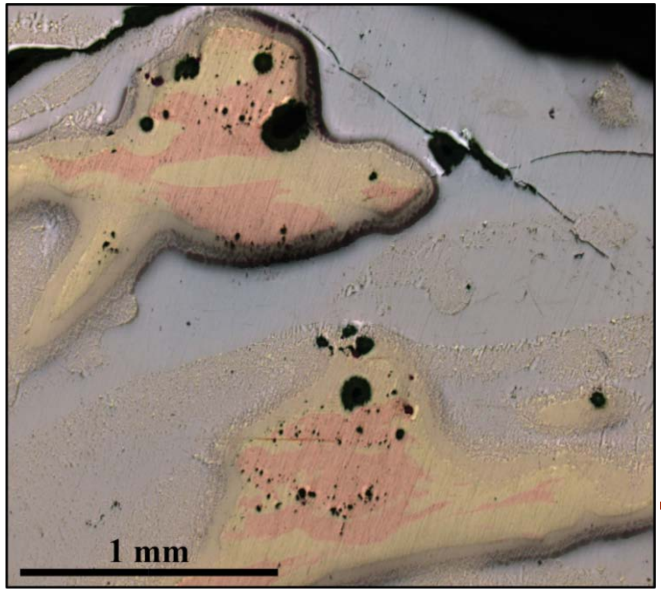
- Samples with a gradient structure from C11000 copper and AA5056 aluminum alloy (1) were produced on a 321 stainless steel substrate (2). The printing was carried out with two filaments (5) and (6) with a smoothly varying feeding rate from 100% copper to 100% aluminum alloy. Filaments were fed from the drums through nozzles (4) and (5) to the printing zone, where they were melted by an electron beam (6) that was directed to the printing zone through the magnetic focusing system (7) from the source (8).

Results and discussion



- The sample appearance with the macrogeometry failure caused by the "flowing" of the printing zone material

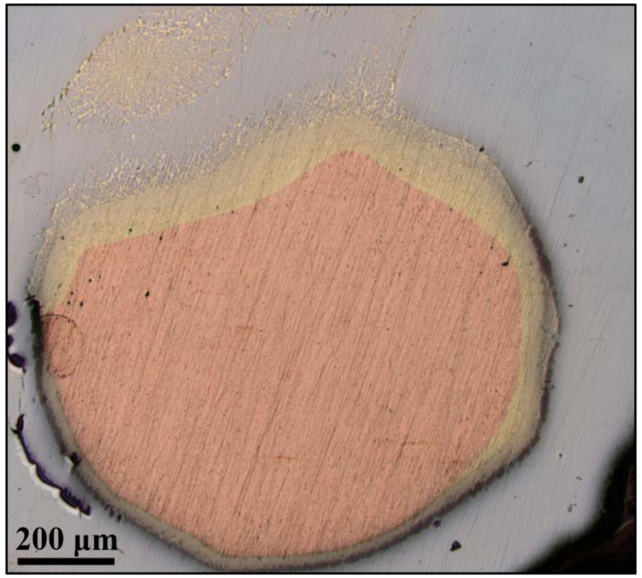
- The sample appearance with the macrogeometry failure caused by the filament feeding irregularity and with the cracking and stratification in the upper part



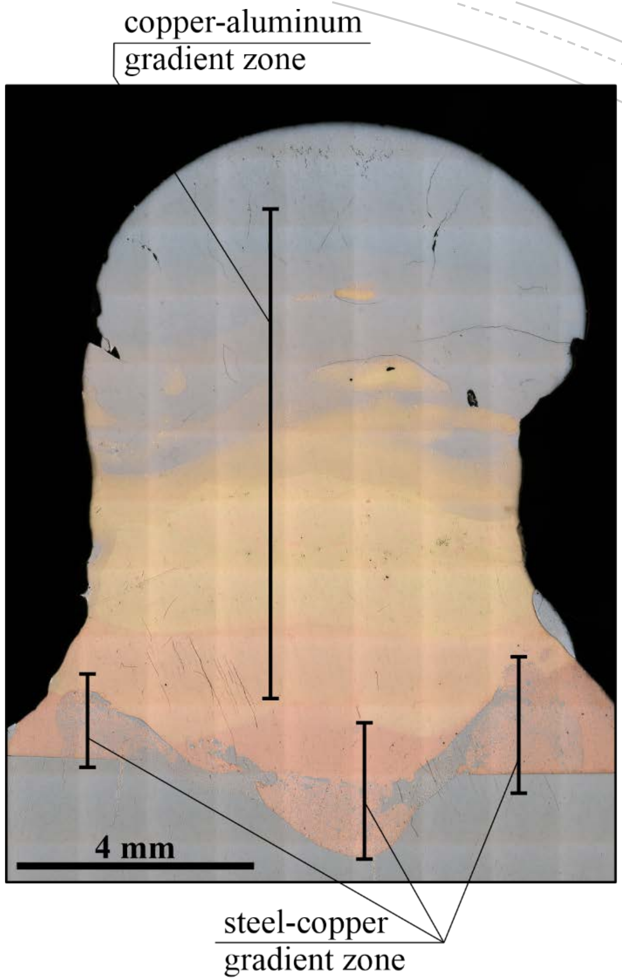
- Irregularities in the distribution of structure components, and the formation of pores and cracks in the gradient zone

During the printing with the use of materials with a high tendency to the mutual diffusion of components there are a number of processes that contribute to the formation of certain types of structures or defects. One of such processes is the formation of low-melting phases, which in the printing zone temperature conditions, causing the melting of filaments, are characterized by a greater castability in comparison with the surrounding material. Such effect can lead to the "flowing" of a material from the printing zone on a lateral edge of the sample with formation of infusions and a macrogeometry failure as a whole.

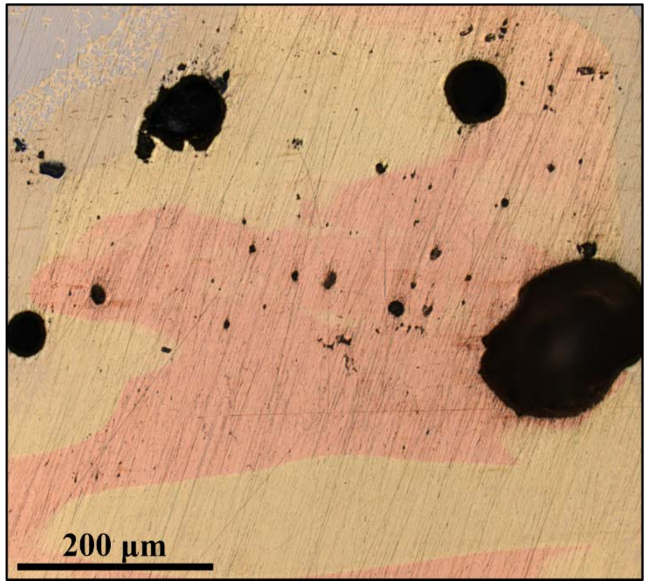
Results and discussion



- Unmelted copper filament residues in the structural gradient zone



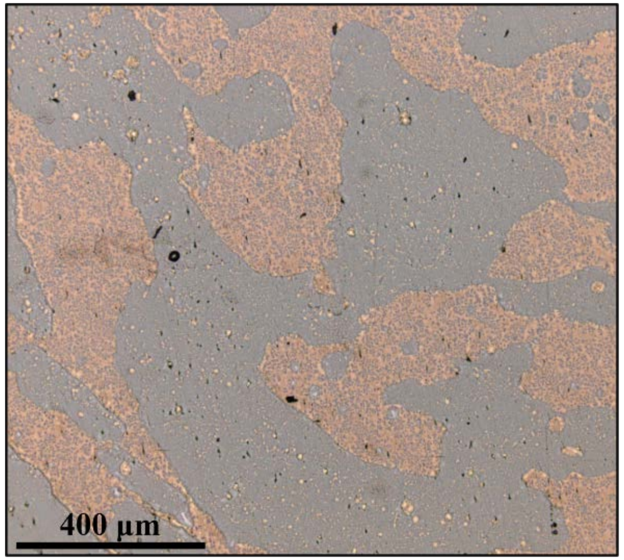
- The appearance of the sample without significant failures in macrogeometry



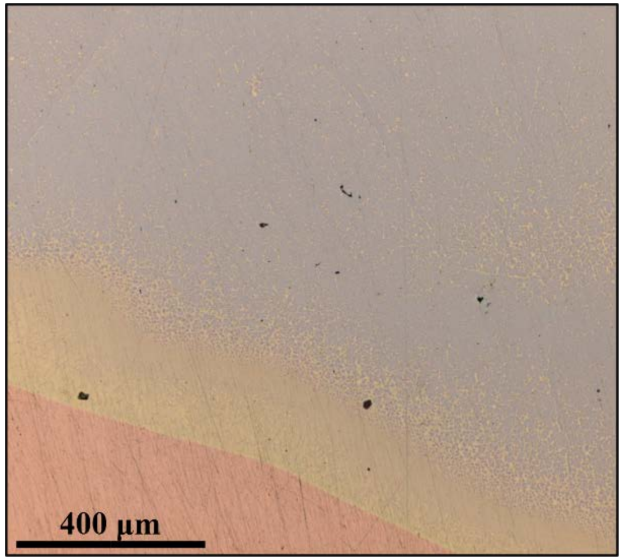
- Irregularities in the structure and pores of different scale levels

In turn, un-melted areas of copper filament fed into the molten bath, which are formed due to irregularities in the filament feeding, result in additional defects as cracks or stratifications in the area of their location (Fig. 5). Due to the high rate of mutual diffusion of copper and aluminum, the copper sections themselves have extensive gradient zones between them. A separate defect in the structural gradient zone is the pores, caused by the evaporation of alloying elements or impurities in alloys during printing in the vacuum (Fig. 6). In polymetallic materials, which differ from monometallic ones by a large difference in melting temperatures of components introduced into the molten bath in the liquid state, the formation of pores is additionally initiated by a reaction between metals.

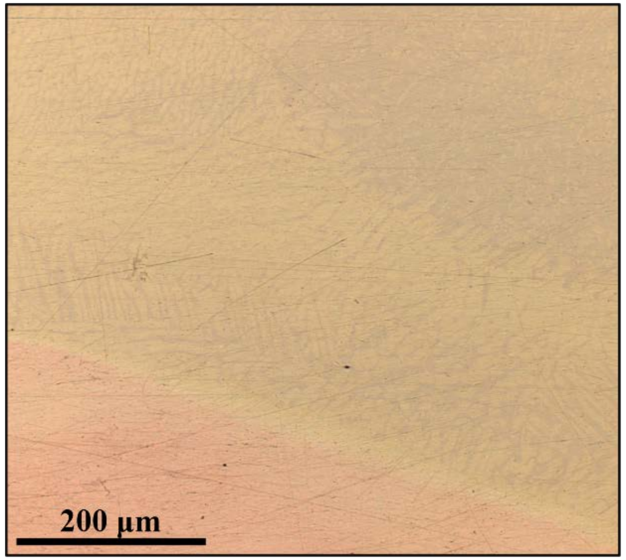
Results and discussion



- The structural gradient zone from the steel substrate to the copper part of the sample



- The boundary between the copper and the predominantly solid-solution area



- The structural gradient zone from copper to the area containing large intermetallic phase fragments and solid solutions

In samples with a defect-free or low defect structure, the structural gradient zone is characterized by a smooth transition from copper to aluminum alloy through the zone of solid solutions and intermetallic phases. The longer the transition zone is, the more stable and defect-free can be the structure of polymetallic samples with the presence of structural gradient. In this case, even in the presented sample a number of structural irregularities are formed, which indicates the necessity of a more stable filament feeding into the molten bath. In addition to the gradient transition zone from copper to aluminum alloy, the structural gradient zone from austenitic steel to copper is formed in the sample due to a severe melting of the substrate when the first copper layers were deposited.

Conclusion

- The carried out studies of the structure of Cu-Al system polymetallic samples produced by the electron-beam additive technology show that when defect-free samples are produced, it is possible to form a polymetal with a sufficiently smoothly changing gradient structure from the copper to the aluminum alloy. Defects formed in the structure of samples can be caused as a mismatch of beam power parameters, wire feeding rate and the printing speed, as well as at deviations from the optimal values of the beam parameters. The most significant defects determining the disturbance of macro-geometry of samples are formed when there is a significant mismatch of filament supply geometry in the melt bath, as well as when insufficient account is taken of structural-phase changes in the printing process of heterogeneous materials of Cu-Al system. The adjustment of electron beam parameters and an optimization of filament feeding geometry allow to achieve the elimination of defects.

Acknowledgment

- The work on the determination of optimal parameters for the sample production was performed according to the Government research assignment for ISPMS SB RAS, project No. III.23.2.11, structural studies were performed within the framework of the Russian Science Foundation, project 19-79-00136.