CRYSTALLIZATION KINETICS AND MECHANICAL PROPERTIES OF RAPIDLY QUENCHED Zr\textsubscript{50}Ti\textsubscript{5}Cu\textsubscript{10}Ni\textsubscript{10}Be\textsubscript{25} ALLOY FOR ADDITIVE MANUFACTURING

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ABSTRACT

AFM/LFM topography examination, crystallization kinetics and mechanical properties of the rapidly quenched Zr\textsubscript{50}Ti\textsubscript{5}Cu\textsubscript{10}Ni\textsubscript{10}Be\textsubscript{25} alloy for additive manufacturing is studied. The investigated sample in the as-cast state produced in form of rod was fully amorphous. The supercooled liquid region $\Delta T = 117$ °C, enhanced mechanical properties and good thermoplastic properties below the crystallization temperature of the produced alloy indicate that proposed material is a promising candidate for use in fused filament fabrication process.

Keywords: bulk metallic glass, glass forming ability, mechanical properties, FFF process.

INTRODUCTION

The developing industry is looking for new ways to efficiently process materials to form more and more complex geometries. Additive manufacturing is one of the possible answers to this demand. However, in the case of higher strength parameters, which usually implies the use of metallic materials, the complexity of devices and their costs increases simultaneously [1,2]. Developing the material and adapting the existing simple, cheap and well-known fused filament fabrication (FFF) technology to manufacture metallic objects are interesting issues and have implementation potential due to the possibility of producing complicated items with much better mechanical characteristics at low costs.

RESULTS AND CONCLUSIONS

Ingots of the alloy with the nominal composition Zr\textsubscript{50}Ti\textsubscript{5}Cu\textsubscript{10}Ni\textsubscript{10}Be\textsubscript{25} alloy (at. %) were remelted several times in a furnace under Air atmosphere in order to receive homogenous material. Amorphous rod 3 mm in diameter and 100 mm in length was obtained by a suction casting method. The amorphous nature of the produced sample was confirmed by DSC/TG investigations. The mechanical properties such as hardness, elastic modulus as well as elastic, plastic and total deformation energies were performed with the help of NHT\textsuperscript{2} Nanoindentation Tester with respect to the Oliver-Pharr procedure [3]. The crystallization kinetics for the investigated alloy is shown in Figure 1(a). The DSC thermal analysis curve recorded with a heating rate of 20 K/min in N\textsubscript{2} atmosphere is typical for amorphous Zr-based alloys. The glass transition temperature ($T_g$) and onset primary crystallization temperature ($T_{x1}$) are visible at 336 °C and 453 °C, respectively. The wide supercooled liquid region (defined as $\Delta T = T_{x1} - T_g$) equals $\Delta T = 117$ °C together with good thermoplastic properties makes this material interesting for additive manufacturing, which enables 3D printing of complex forms through fused filament
fabrication process. It is worth noting that the melting point of the investigated sample appears at 744 °C. The amorphicity of the Zr$_{50}$Ti$_5$Cu$_{10}$Ni$_{10}$Be$_{25}$ alloy was also confirmed by AFM/LFM investigations of the polished surface sample performed in contact mode. For the scanning area from 0.5 μm × 0.5 μm to 45 μm × 45 μm the presence any grains was not observed. The roughness parameters obtained for scanning area 5 μm × 5 μm equal $R_q = 0.509$ nm (root-mean-squared roughness), $R_a = 0.392$ nm (the average roughness) and $R_z = 2.255$ nm (the ten point average roughness). These results are typical for amorphous structures. The observation of sample’s surface under optical microscope with polarized light and magnification of ×5, ×20, ×50 and ×100 also did not show any grains/phases or heterogeneous structures.

Figure 2(b) shows the results of the grid nanoindentation array (2D map) obtained for the as-quenched Zr$_{50}$Ti$_5$Cu$_{10}$Ni$_{10}$Be$_{25}$ sample. The calculated hardness ($H_{IT}$), elastic modulus ($E_{IT}$), and elastic ($W_{el}$), plastic ($W_{pl}$) and total ($W_{tot}$) deformation energy are characterized by single mode distribution, which is typical for single phased material (amorphous state). The average value of $H_{IT} = 760$ HV (8.2 GPa), $E_{IT} = 107.6$ GPa, $W_{el} = 35.5$ nJ, $W_{pl} = 60.4$ nJ and $W_{tot} = 95.9$ nJ show enhanced mechanical properties of the produced material in comparison to typical crystalline metallic materials. Moreover, the good thermoplastics properties below the crystallization temperature (close to 453 °C) show that the Zr$_{50}$Ti$_5$Cu$_{10}$Ni$_{10}$Be$_{25}$ alloy is suitable material for extrusion in FFF processes. The first tests of the investigated rod (3 mm in diameter) performed at temperature range 445 - 450 °C show that our material can be easily compressed (without structural and mechanical parameters changes) into a plate with a thickness of 1.2 mm.

REFERENCES

