1.semester report by

Mukhtarova Kamilla (kamilla551@gmail.com)

PhD Program: Materials science and solid state physics

Supervisor: Gubicza Jenő

Ph.D. Thesis title: Defect structure and mechanical performance of advanced metals processed by additive manufacturing

Introduction:

One of the most important tasks of the science is the improvement of the quality of human life without additional loading on the environment. The achievement of this goal requires the development of new materials and novel processing technologies. Recently, a new way of materials processing was initiated which is called as additive manufacturing (AM). This technique is a specific three-dimensional (3D) printing process in which the component material is built up layer by layer from material supplied in powder form. The most important advantage of this methodology is the flexible net shape production of parts with full density. In addition, using AM techniques the waste of production is minimized. The good mechanical performance of additively manufactured materials is a prerequisite for their applications. The plastic properties are significantly influenced by the lattice defects, such as grain boundaries, stacking faults and dislocations. Therefore, the characterization of the defect structure immediately after AM processing and during subsequent plastic deformation is very important from the point of view of the practical application of these materials. Moreover, the defect structure can be tailored by changing the conditions of AM and applying post-processing heat treatment and/or hot isostatic pressing (HIP). With an appropriate selection of the manufacturing conditions, the mechanical properties of AM-processed materials can be improved in order to achieve a combination of high strength and good ductility. In the frame of the planned project, the correlation between the lattice defect structure (grain boundaries, planar faults and dislocations) and the mechanical performance of novel metallic materials produced by AM techniques will be studied.

Description of research work carried out in current semester:

We investigated the four-point bending fatigue features in the high-cycle domain of Ti-6Al-4V alloy reinforced with 1 wt.% nano-yttria-stabilized zirconia melted by laser powder bed fusion technology. A particular attention was paid to the crack initiation mechanism of such novel metal matrix composites fabricated via AM technology. The stress-relieved (heat-treated, HT) composite material exhibited similar or slightly lower fatigue strength than its annealed unreinforced AMed Ti-6Al-4V counterparts due to early fatigue crack nucleation at lack-of-fusion flaws. On the other hand, HIP post-processed composite material (HT+HIP) showed an elevated fatigue endurance level (σ_{max} = 844 MPa), which strongly suggests an improvement of the fatigue endurance in respect to its unreinforced AMed Ti-6Al-4V counterparts. Such an endurance value also suggests similar fatigue resistance of HT+HIP material to conventional wrought Ti-6Al-4V, at least. Furthermore, a clear crack nucleation mechanism governed by plastic slip was observed for AMed Ti-6Al-4V without cleavage facets. In a way similar to forged lamellar Ti-6Al-4V, this phenomenon is promoted by the elongated α-grain colonies, which potentially generate long slip distances if the activated systems are approximately parallel with the geometrical orientation of the long-length α layers. Combined with its high static strength compared to unreinforced AMed Ti-6Al-4V, this singular crack nucleation mechanism is thought to be the main reason for the high fatigue strength. Moreover, the occurrence of this nucleation mechanism implies that a limitation of the maximum plastic slip distance by the reduction of the α-grains length should consist in an effective way to reach even higher fatigue strength. Both HIP processing and fatigue loading have no considerable effects on the overall dislocation density, regardless of the applied stress level. Furthermore, most dislocation had <a>-type

Burgers vector and prismatic or pyramidal glide planes. Consequently, nano-zirconia reinforced Ti-6Al-4V subjected to adapted post-treatment presents promising characteristics for actual applications as a structural material from its fatigue characteristic viewpoint.

Furthermore, a 316L stainless steel produced by AM technique was studied. Two laser powers (LP1: Laser scan speed: 275 mm/s, Laser Power: 700 W. LP2: Laser scan speed: 235 mm/s, Laser Power: 750 W) were used for preparing the samples. Then, the samples were processed by HPT at 6 GPa and 1 rpm for ½, 5 and 10 turns. The specimens were investigated before and after HPT-processing. In addition, samples compressed in the HPT facility without torsion were also studied. The X-ray line profile analysis (XLPA) measurements were performed at the centers and edges of the HPT-processed discs, as well as on the as-processed and as-compressed samples. The XPLA measurements revealed that the crystallite size is large for as processed samples, the twin fault probability was negligibly small for both as-received specimens. HPT processing led to a significant refinement of the crystallite size to about 20-30 nm even after ½ turn of HPT. Regarding the lattice defects, their density was enhanced with increasing number of turns for both laser powers. In addition, the thermal stability of the microstructures was examined using differential scanning calorimetry (DSC).

In addition to my doctoral topic, 5083-Al samples processed by Equal Channel Angular Pressing (ECAP) or Dual Equal Channel Lateral Extrusion (DECLE) were studied by XRD. XLPA measurements were also performed on these samples. The lattice constant of the FCC Al matrix was determined from the XRD peak positions using the Nelson-Riley method.

Publications:

1. B. Guennec, A. Hattal, A. Hocini, K. Mukhtarova, T. Kinoshita, N. Horikawa, J. Gubicza, M. Djemaï, G. Dirras. Fatigue performance of zirconia-reinforced Ti-6Al-4V nanocomposite processed by laser powder bed fusion: An improvement by hot isostatic pressing. International Journal of Fatigue, Volume 164, 2022, 107129. https://doi.org/10.1016/j.ijfatigue.2022.107129.

Studies in current semester:

Subject code	Subject name	Lecturer	Credits	Requirements	Class per week	Grades
FIZ/1/024	Lattice defects I.	Gubicza Jenő	6	exam	2	5 (Excellent)
FIZ/1/038E	Diffraction methods in Materials Science I.	Gubicza Jenő	6	exam	2	5 (Excellent)

Teaching in the current semester:

Subject code	Subject name	Course type	Class per week
applphysf17lm	Methods of Applied Physics Laboratory	Laboratory	4