Study of crystallization in Zr-based bulk metallic glasses in Laser Powder Bed Fusion

SCIENTIFIC PROJECT: Zr-BMGs in LPBF

The interest in bulk metallic glasses (BMGs) emerges from the augmented properties this material exhibits thanks to its amorphous nature. These properties are difficult to master with conventional manufacturing methods, but the high cooling rates reachable in additive manufacturing (AM) opened the door for improvement, with furthermore no strict limitation on the parts dimensions.

BMGs are non-crystalline metallic alloys with an atomic structure lacking long-range order. A fully amorphous microstructure can be achieved when the exerted cooling rate from the melt is high enough to impede the ordered arrangement of atoms. Such a high cooling rate can be achieved via AM processes such as laser powder bed fusion (LPBF). However, even if rapid cooling is achieved in the melt pool, the thermal cycles undergone by the heat-affected zone below the melt pool may lead to crystallization of the microstructure (Figure 1). The presence of impurities such as oxygen can act as a preferential site for nucleation of metastable quasicrystals. Nanocrystals can also be present in the powder itself, and act as nucleation sites if they were not completely melted in the melt pool.

This work aims to study Zirconium-based BMGs, and more specifically Zr-Cu-Al systems. This system containing mainly transition metals has a good glass-forming ability and a low critical cooling rate. Based on the work of Sohrabi et al., the two main regimes that are present in Zr-BMGs are the conduction mode characterized by the amorphous state, and the keyhole mode where crystallization occurs. It was shown that a relatively low amount of nanocrystals is not detrimental to mechanical properties, but to a certain extent crystallization induces cracking, particularly at low power.

As part of a project for developing a data base on acoustic signatures linked to statistical defects and transformations taking place during LPBF of different metallic alloys, a high interest rises for the detection of crystallization and cracking in Zr-BMGs. One of the main advantages of acoustic emission is that it can easily be implemented into industrial processes, suppressing the need for time-consuming post mortem analysis. But first, the parameters for crystallization and cracking need to be unambiguously identified. For now, a parameter window for creating amorphous and crystalline samples in an industrial LPBF machine with the 3 different powders has been successfully identified. However, these parameters need to be translated into a different machine which allows the implementation of acoustic sensors.

The focus will mainly be on two new powders with a low oxygen content. The first powder is a Zr-Cu-Al-Nb system with a melting point of 920°C and the second powder is a Zr-Cu-Al-Ni-Ti system with a melting point of 830°C. An industrial grade AMZ4 powder with higher oxygen content, but same composition as the first powder, will also be used to study the influence of oxygen.
STUDENT PROGRAM:
The project can be built on the following listed research questions:

- How to translate the process parameters for an amorphous structure, crystallization and cracking of Zr-BMGs in a machine with higher laser spot size?
- What is the effect of composition and melting point on the process window?
- What is the effect of oxygen on crystallization and cracking?
- Can these events be detected by acoustic emission acquisition?

THE STUDENT WILL BE ASKED TO:

- Do a literature review
- Design of an experimental plan to answer a problematic
- Carry out experimental work:
  - Printing samples with an LPBF system,
  - Preparing samples (metallography: resin embedding, polishing, etching) for Scanning Electron Microscopy to observe the melt pools
  - Differential Scanning Calorimetry to measure crystalline content
  - Implementing acoustic sensors
  - Measuring temperature using thermocouples to calibrate simulations, etc.
- Work in a team
- Discuss the results with critical approach
- Write a scientific report and present the results orally

Contact: Claire Navarre
Laboratory of Thermomechanical Metallurgy – EPFL Microcity (Neuchâtel)

claire.navarre@epfl.ch

Sources