Thermoplastic processing-induced changes in serrated flow behavior and plastic deformation mechanisms of bulk metallic glasses

This project proposal focuses on exploring the effects of thermoplastic processing on the behavior of bulk metallic glasses (BMGs). BMGs are an advanced and unique class of materials of increasing significance in modern automotive, aerospace, and biomedical industry. They possess exceptional mechanical properties due to their amorphous structure, which lacks the long-range atomic ordering found in traditional crystalline materials. The absence of crystal defects, such as dislocations and stacking faults, which are carriers of deformation under load, means that BMGs deform differently than their crystalline counterparts.

There are two recognized types of plastic deformation in BMGs. At low temperatures, BMGs undergo a process called inhomogeneous deformation, where the material forms localized bands of intense shearing, known as shear bands. This type of deformation results in a characteristic serrated flow pattern under load and can lead to limited plasticity and premature failure due to shear localization. This type of deformation can be described by shear transformations zones (STZ) theory. These STZs are small groups of atoms that work together to accommodate applied stress by undergoing unique, non-affine motions – they are fundamental units of deformation in BMGs. When the stress reaches a critical point, the STZs activate, leading to the formation and propagation of shear bands what is observable as serrated flow. In contrast, at high temperatures above the glass transition temperature, BMGs exhibit homogeneous deformation, where the material flows like a highly viscous liquid (supercooled liquid region). This behavior allows BMGs to be shaped into complex structures through a process called thermoplastic processing, similar to how plastics are molded.

The goal of this project is to investigate how thermoplastic processing, which involves deforming BMGs in their viscous state, affects their subsequent low-temperature deformation behavior. This research is crucial because BMGs are increasingly being used in structural applications and as machine parts, where thermoplastic processing is often employed to create complex shapes. However, the exact impact of this processing on the low-temperature deformation mechanisms of BMGs and therefore their properties is not well understood.

To shed light on this issue, we will study the differences in the serrated flow and deformation mechanisms of BMGs before and after thermoplastic processing, considering various processing parameters such as strain and temperature. We hypothesize that the deformation of BMGs during thermoplastic processing leads to changes in the way shear bands form and propagate at low temperatures, due to alterations in the material's atomic structure.

To achieve these research goals, our research will involve producing BMG samples from three different model alloy groups using rapid cooling techniques and characterizing their amorphous nature, supercooled liquid region, and time required for crystallization at specific temperatures. The primary investigation involves conducting nano- and microindentation measurements to analyze the serrated flow and plastic deformation mechanisms before and after thermoplastic processing by thermoplastic compression. During thermoplastic compression, the samples will be subjected to strain and temperature variations as significant factors influencing the process.

During the indentations, the load-displacement curves will be registered. Through statistical analysis of the first shear band activation (visible on the curves as characteristic “pop-in”), we will determine key parameters that describe the shear transformation zones (STZs). These parameters include activation volume, activation energy, STZ volume, and STZ size. Additionally, we will also assess the instrumented hardness, elastic modulus, and the share of plastic strain energy in total deformation energy together with hardness strain-rate sensitivity. The size and distribution of registered shear band activations will be utilized to create a statistical description of the serrated flow. Furthermore, since the mentioned properties of BMGs are known to be temperature-dependent, we will investigate how thermoplastic processing affects this temperature sensitivity by conducting indentation tests at elevated temperatures.

Ultimately, we will compare the results obtained before and after thermoplastic processing to analyze any changes in the deformation behavior of BMGs and assess their significance for future applications. The findings from this project will provide valuable insights into the effects of thermoplastic processing on the plastic deformation mechanisms of BMGs. It will contribute to a deeper understanding of low-temperature plasticity of this fascinating group of materials guiding the development of processable BMGs with improved mechanical properties more capable of fulfilling the requirements of modern high-tech industry.