Fall 10-4-2015

Deformation behavior of bulk metallic glasses produced via Severe Plastic Deformation and the influence of a second phase

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Recommended Citation

[1] Krämer, L.; Kormout, K.S.; Setman, D.; Champion, Y.; Pippan, R. Production of Bulk Metallic Glasses by Severe Plastic Deformation. Metals 2015, 5, 720-729.

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Over the last years bulk metallic glasses (BMG) have been strongly investigated as their mechanical properties are very promising especially in terms of their high yield strength and high elastic strain. However, a major drawback is their complicated production depending strongly on dimensions and chemistry. A promising technique to overcome these drawbacks is using a severe plastic deformation process, e.g. high pressure torsion (HPT), where the production can be started with metallic glass powders, which are generally much easier to fabricate.

For this route, the powder is consolidated and then the powder particles are welded together by applying a high shear deformation. The produced specimen remain fully amorphous and no porosity is detectable after sufficient deformation [1]. To improve the mechanical properties of the BMG, the used Zr-based metallic glass powder is mixed with a crystalline Cu-powder or a Ni-based metallic glass powder to achieve a metal/metallic glass composite or a metallic glass/ metallic glass composite, respectively.

Due to the small amounts of produced material, conventional macroscopic characterization methods, like compression or tension tests can hardly be used to analyze the overall mechanical properties. Therefore, in this work different micromechanical testing methods, such as nanoindentation, *in-situ* SEM micropillar compression, and finally *in situ* TEM picoindentation were carried out to investigate the deformation behavior under ambient but also non-ambient conditions. Using nanoindentation, the hardness and the Young's Modulus was determined for two HPT-deformed BMGs with different composition. Additionally, high temperature nanoindentation experiments up to 350 °C were conducted to determine not only the temperature dependent hardness and the Young's modulus but also to study the change in thermally activated processes during deformation via nanoindentation strain rate jump tests. It was found, that nanoindentation hardness is in good accordance to the macroscopic Vickers results. Increasing the temperature, hardness decreases slightly, while the modulus increases. The shear band formation is also dependent on the deformation temperature, since the extent of stair case formation in the load-displacement curves changes. Overcoming 300°C, the material becomes extremely ductile showing a strong strain rate sensitivity.

Further, the uniaxial mechanical response of Zr-based BMG was examined *in-situ* in SEM using FIB prepared micropillars. The microcompression experiments revealed a strength of more than 2 GPa. Steps in the stress-strain curve suggest shear band formation, which could also be confirmed by the *in-situ* recorded SEM images

Finally the influence of the second materials phase was investigated via TEM in-situ picoindentation, where a wedge shaped indenter was pressed in a TEM lamella. The load-displacement curve show a similar stair case behavior as seen during nanoindention and microcompression, indicating shear band formation. The shear band formation could be also observed in the TEM micrographs.

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