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# Zr<sub>61</sub>Ti<sub>2</sub>Cu<sub>25</sub>Al<sub>12</sub> bulk metallic glass: Failure under torsional loading and Mode III fracture toughness

Jian Xu\*<sup>1</sup>, Zhen-Qiang Song, and Evan Ma<sup>2</sup>

<sup>1</sup>Institute of Metal Research, Chinese Academy of Sciences (IMR, CAS) – 72 Wenhua Road, China  
<sup>2</sup>Department of Materials Science and Engineering, The Johns Hopkins University – Baltimore, Maryland 21218, U.S. Virgin Islands

## Abstract

From torsional tests of cylindrical samples, we have determined the torsional properties of high-toughness Zr<sub>61</sub>Ti<sub>2</sub>Cu<sub>25</sub>Al<sub>12</sub> (ZT1) bulk metallic glass (BMG), including its shear yield strength,  $\sigma_y=950$  MPa, its shear elastic strain limits,  $\gamma_C=3.0\%$ , and its shear modulus,  $G=31.5$  GPa. Under torsional loading, the BMG fails via a major shear band, without obvious macroscopic plasticity on the specimen surface. The shear band maintained stable propagation by a distance of  $\sim 300$   $\mu\text{m}$  ( $\sim 20\%$  of cylinder radius) before final catastrophic failure, owing to the constraint of stress gradient along the radial direction. The intrinsic mode III fracture initiation toughness is measured for the Zr<sub>61</sub>Ti<sub>2</sub>Cu<sub>25</sub>Al<sub>12</sub> BMG, which is known to have a high mode I fracture toughness ( $K_{IC}$ ). The plastic strain intensity factor  $G_{III}$  was used as a measure of the fracture resistance under elastic-plastic conditions. The intrinsic mode III fracture initiation toughness of ZT1 BMG,  $G_{IIIc}$ , is found to be  $29 \mu\text{m}$ , equivalent to a  $K_{IIIc}$  of  $51 \text{ MPa}\sqrt{\text{m}}$ . The corresponding fracture energy release rate is similar to or higher than that of conventional engineering metals such as high-strength aluminum alloys and some steels. The subcritical crack growth in ZT1 prior to catastrophic fracture is characterized by an extension of a microscopically zig-zag crack front. ZT1 exhibits a relatively low ratio of  $K_{IIIc}/K_{IC}$  of  $\sim 0.39$ , indicating that the material is more susceptible to mode III fracture. In engineering design with BMGs, the mode III fracture toughness is thus a useful baseline to ensure the reliability of structural components.

**Keywords:** Metallic glass, Fracture toughness, Torsion, Shear band, Zirconium

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\*Speaker