Intrinsic and Extrinsic Toughening of Metallic Glasses

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ABSTRACT

Amorphous alloys were first developed over 40 years ago and found applications as magnetic cores or reinforcements added to other materials. The recent ability to process Bulk Metallic Glasses (BMGs) with a minimum diameter of 10 mm and unique combinations of strength, corrosion resistance, and damage tolerance, made BMGs promising candidates for engineering applications. Applications range from micro- electromechanical systems (MEMS) through large aerospace structures. In this work, one of the most important mechanical characteristics of various BMG systems, fracture toughness, is investigated and compared to oxide glasses. Metallic glasses exhibit toughness values ranging from those approaching ideally brittle solids (i.e. 1 J m^{-2}) to those of tough steels (i.e. >10,000 J m^{-2}) while possessing near theoretical strength. The factors affecting the intrinsic plasticity or brittleness of different metallic glass alloys as well as annealing-induced embrittlement are reviewed. Extrinsic toughening approaches are also summarized.

BACKGROUND

- Some Metallic Glasses are Tough

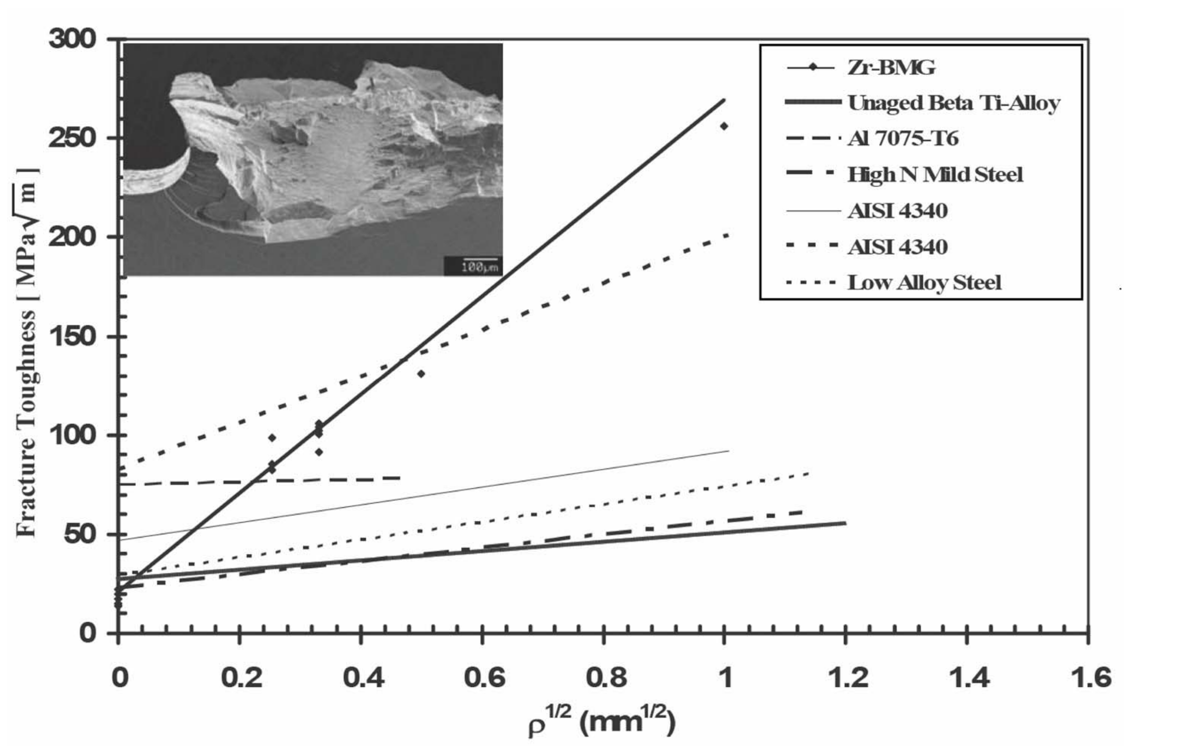


Figure1-Fracture toughness, Kc vs the square root of notch radius for Zr-BMG ($Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$) in comparison to various crystalline structural materials.

- Some Metallic Glasses are Brittle
- Need Prediction of Brittle vs. Tough Behavior
- Need Toughening Approaches For Brittle Glasses

PREDICTION OF INTRINSICALLY BRITTLE VS. TOUGH

- Bulk Metallic Glasses Are Elastically Isotropic
- Examine Competition Between Flow And Fracture
  - Flow Controlled By Shear Modulus, μ
  - Fracture Related To Bulk Modulus, *B* (i.e. Resistance To Dilation)
  - Does Ratio μ/B Control Brittle vs. Tough Behavior?
    - Does Low μ/B Produce Tough BMG?
    - Does High μ/B Produce Brittle BMG?
- Experimentally Evaluate Fracture Energy, $G = \frac{K^2(1-\nu^2)}{E}$, and Plot G vs. μ/B

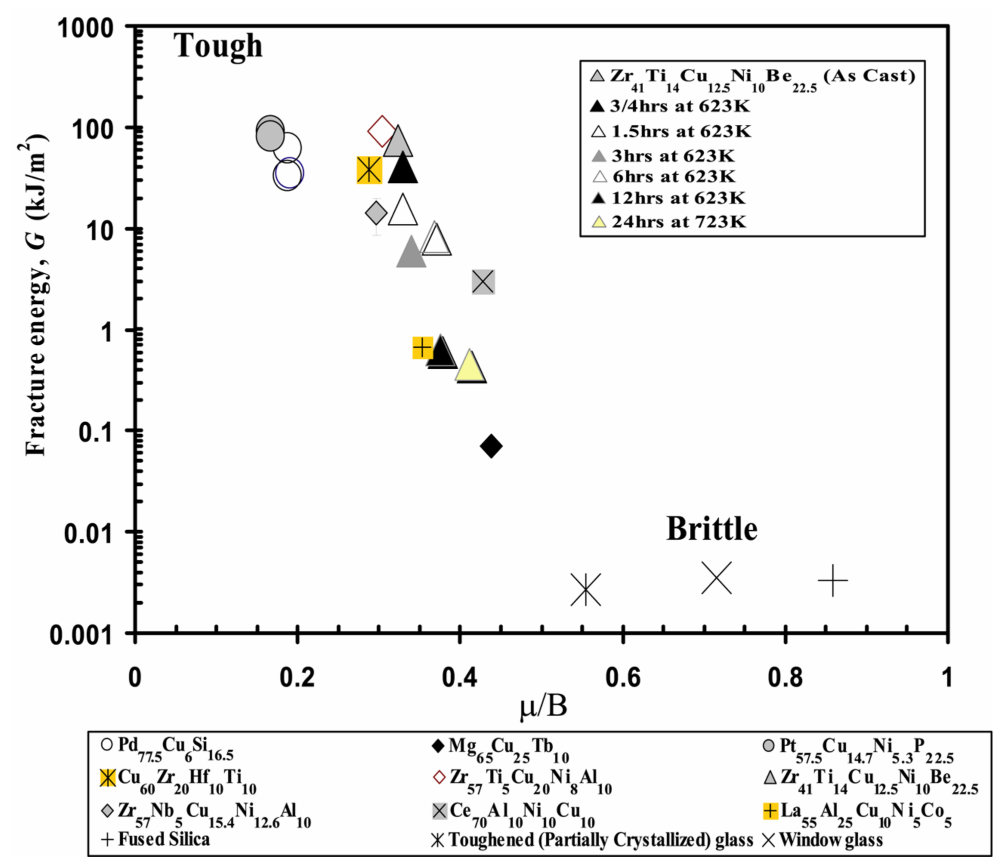


Figure 2- The correlation of fracture energy G with ratio μ/B

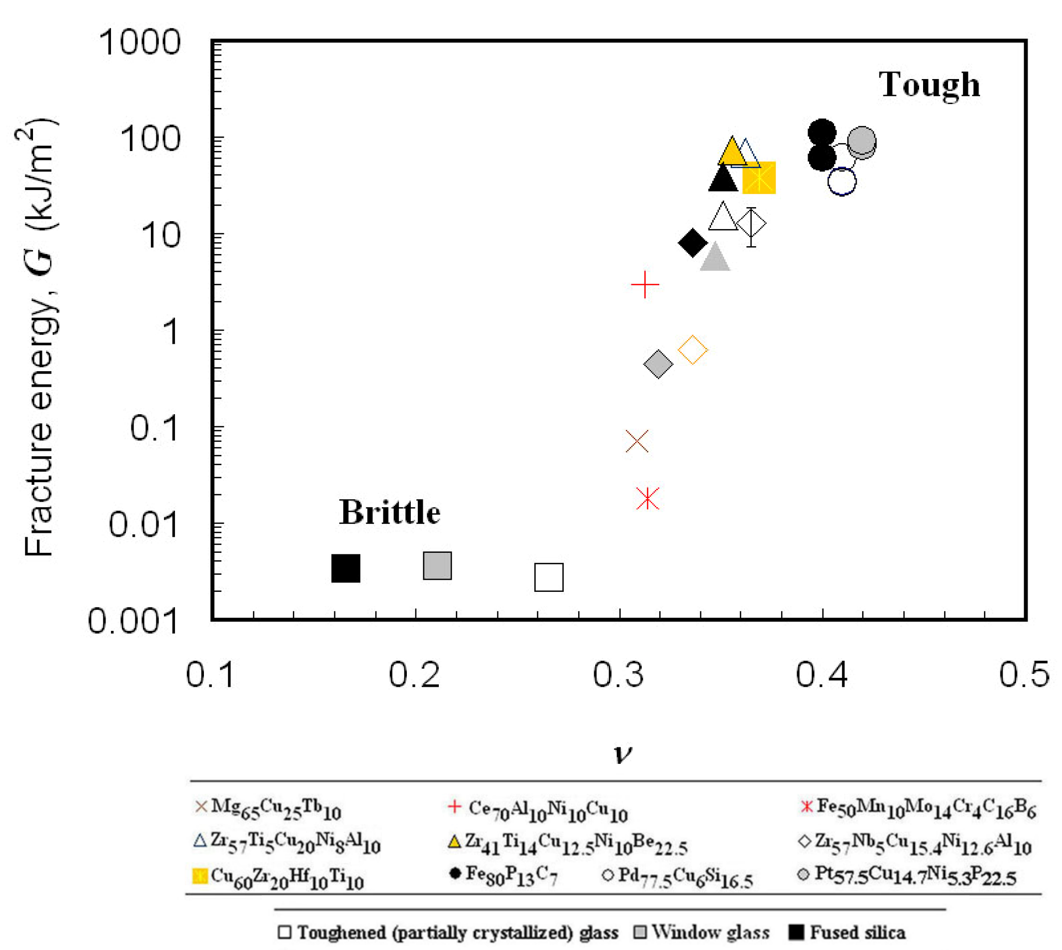


Figure 3- The correlation of fracture energy G with Poisson's ratio ν

EXTRINSIC TOUGHENING OF METALLIC GLASSES

- Needs
  - Multiplicity of Shear Banding
  - Reduce Magnitude of Shear Offset
  - Introduce Energy Absorbing Phase(s)

APPROACH

- Produce In-Situ Composites via Controlled Devitrification

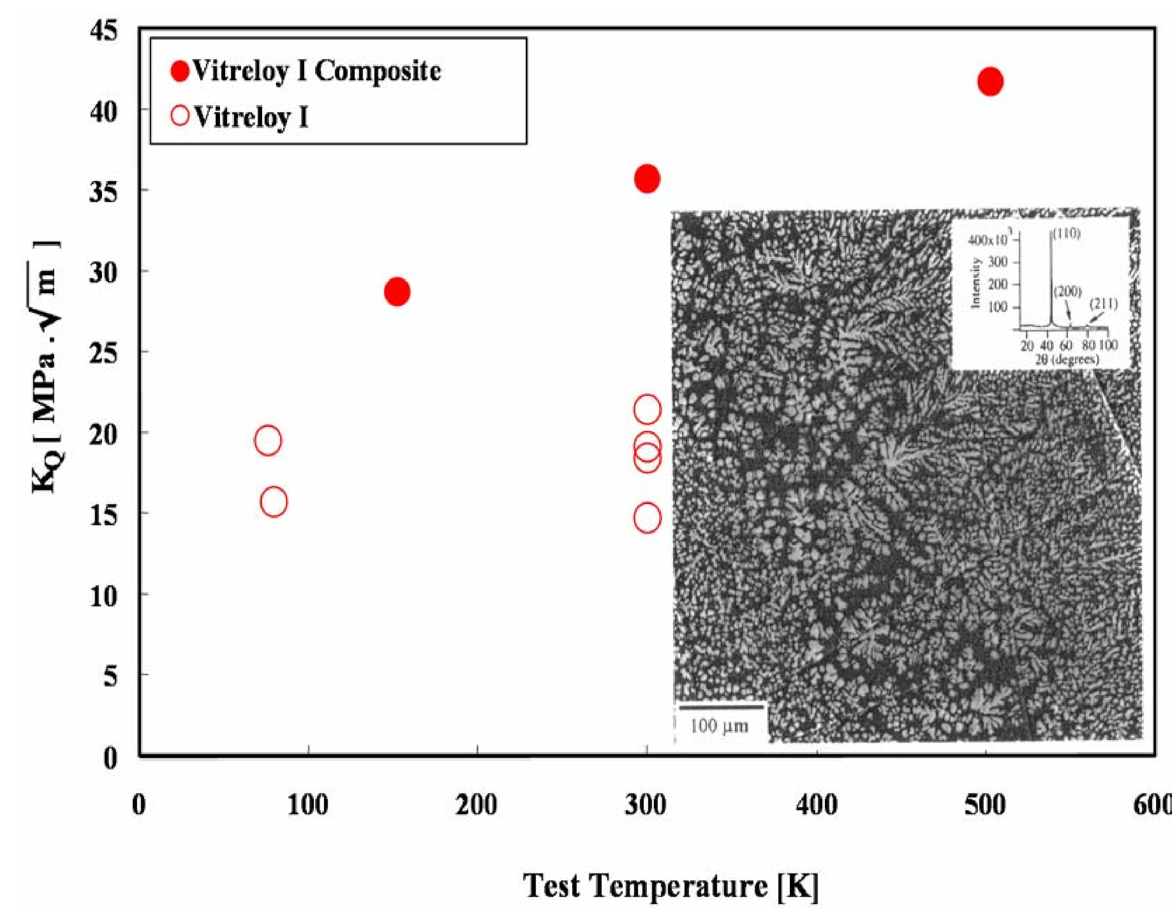


Figure 4- Metallic Glass Composite (Inset) Exhibits Higher Toughness Than Metallic Glass

ALTERNATE APPROACH

- Utilize Novel Deformation Characteristics Near Glass Transition Temperature, T_g
  - Significant Strength Reduction Near T_g

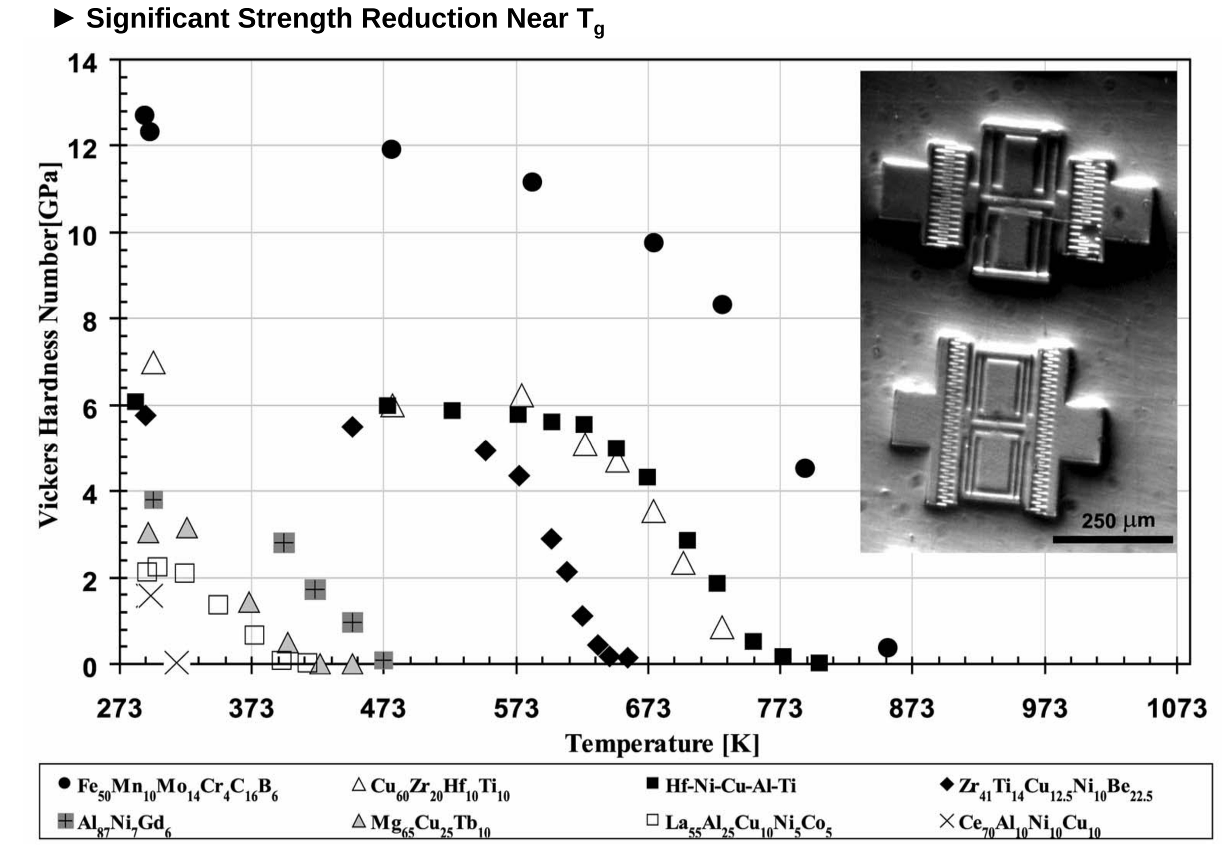
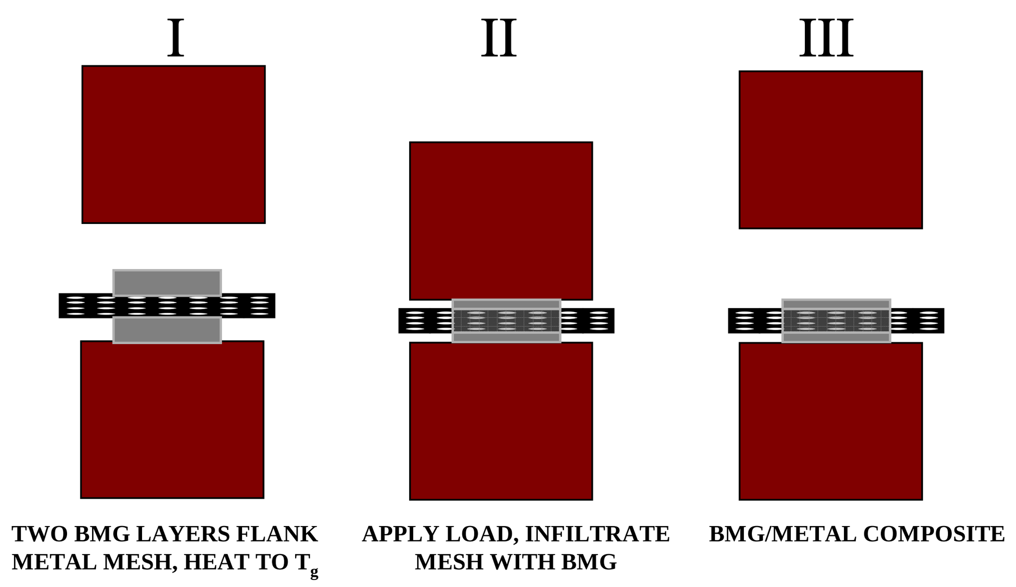


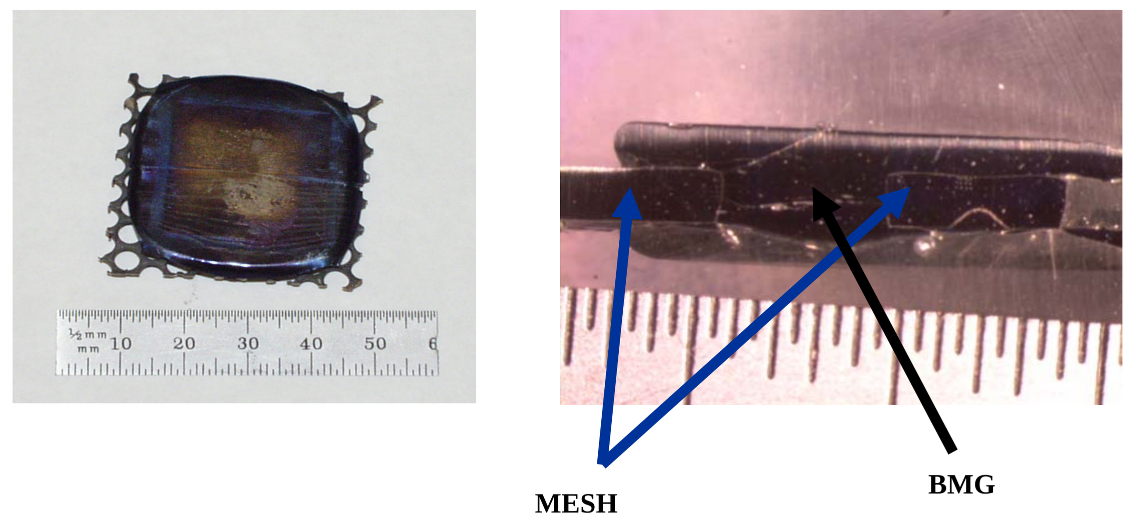
Figure 5- Vickers microhardness vs temperature for a variety of amorphous metals. Inset illustrates replication of MEMs devices obtained via warm pressing of Si-based MEMs devices into $Zr_{41}Ti_{14}Cu_{12.5}Ni_{10}Be_{22.5}$

- Creation of Layered / Laminated Bulk Metallic Glasses (BMGs) Via Deformation Processing

BMG/METAL MACRO-COMPOSITE



BMG/METAL MESH MACRO-COMPOSITE



CONCLUSIONS

- Brittle vs. Tough Behavior of Metallic Glasses Can Be Predicted
  - μ/B < 0.41- 0.43 *"Brittle"*
  - ν > 0.31- 0.32 *"Tough"*
- Extrinsic Toughening of Metallic Glasses is Possible via
  - In-Situ Devitrification
  - Layered/Laminated Processing

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