

# Bulk Metallic Glasses: Design, Composites, and Plasticity

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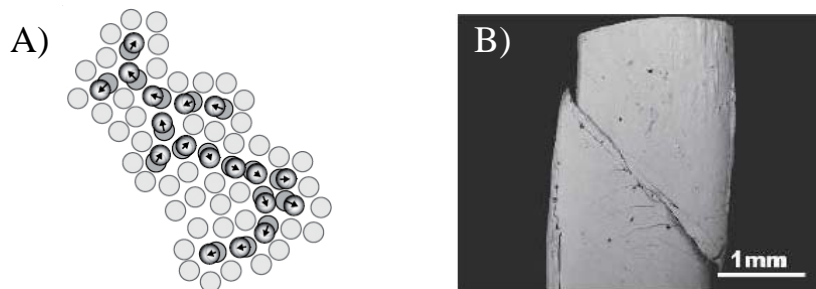
Literature Seminar

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Bulk metallic glasses (BMGs) have many attractive intrinsic properties that stem largely from their amorphous atomic structure.<sup>1,2</sup> Due to the absence of crystallographic slip planes, many BMGs have strengths that approach theoretical limits and hardness values that easily surpass conventional alloy materials.<sup>1,3</sup> Past technological applications of BMGs have typically exploited their outstanding corrosion resistance and soft magnetism.<sup>4</sup> However, due to their extraordinary mechanical properties, BMGs are also attractive for structural applications. BMGs have already found use in applications such as micromotors and sporting equipment, but have not yet been utilized as building materials. One primary reason for this is the tendency of BMGs to fail catastrophically under applied stress with almost zero plastic deformation.<sup>5</sup> In order for metallic glass to become a widespread structural material, mechanisms for improving plasticity must be developed.

Several factors must be considered when designing bulk metallic glasses. As size and valence differences between component atoms increase, electronegativity differences increase as well. These differences lead to high negative heats of mixing and thus favor the formation of stable intermetallic compound phases.<sup>6</sup> The number of components involved in the system also plays a role in determining how the glass will form. Generally, the more components present, the more crystallization will be suppressed, improving the glass forming ability of the system.<sup>6</sup> Other issues such as near-eutectic composition and the location of the glass transition temperature relative to other crystalline phases can also prove important in BMG formation.<sup>7</sup>

Brittleness in BMGs is the result of the localization of applied stress into a few highly plastic regions of the material that eventually lead to catastrophic failure.<sup>3</sup> Under stress, atoms in these regions move more freely and become nucleation sites for thin bands of high atomic mobility.<sup>8</sup> These areas of increased plasticity and high mobility, with a greater fraction of open volume<sup>9</sup> compared to the rest of the material, are termed shear bands. Thin shear bands merge to form larger shear bands that lead to strain softening and the ultimate failure of the material.



**Figure 1:** (A) Schematic of atomic movement due to open volume within an amorphous material.<sup>10</sup> (B) Scanning electron micrograph of a fracture in a  $\text{Zr}_{65}\text{Al}_8\text{Ni}_{10}\text{Cu}_{17}$  bulk metallic glass.<sup>11</sup>

One of the most popular methods in recent years for improving plasticity in BMGs is the formation of composite glasses.<sup>12-14</sup> Composite BMGs typically consist of a glassy matrix in which small crystals or foreign particles reside. These inhomogeneous areas lead to the nucleation and evolution of multiple shear bands, which delocalize the applied stress, and allow the material to deform plastically.<sup>15</sup> For instance, the inclusion of nanocrystalline phases in a series of zirconium-based BMGs increases the strain limit to roughly 12% versus 2% for conventional BMGs.<sup>16</sup> A similar phenomenon has been observed in a copper-based BMG/graphite composite in which strain values reached as high as 17%.<sup>17</sup>

## References

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