# DEVELOPING AND CHARACTERIZING BULK METALLIC GLASSES FOR EXTREME APPLICATIONS

THESIS BY

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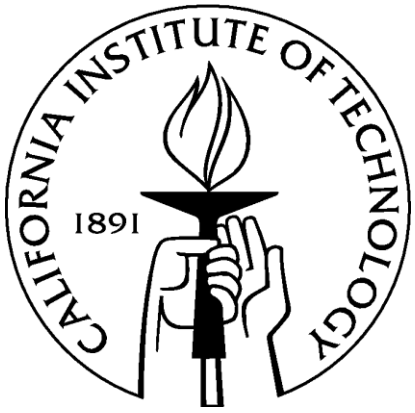


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NOTHING IS TOO SMALL...

PUT DOWN IN RECORD EVEN YOUR DOUBTS AND SURMISES...

WE LEARN FROM FAILURE,

NOT FROM SUCCESS!

ABRAHAM VAN HELSING, M.D., D.PH., D.LITT., ETC.

## ABSTRACT

Metallic glasses have typically been treated as a “one size fits all” type of material. Every alloy is considered to have high strength, high hardness, large elastic limits, corrosion resistance, etc. However, similar to traditional crystalline materials, properties are strongly dependent upon the constituent elements, how it was processed, and the conditions under which it will be used. An important distinction which can be made is between metallic glasses and their composites. Charpy impact toughness measurements are performed to determine the effect processing and microstructure have on bulk metallic glass matrix composites (BMGMCs). Samples are suction cast, machined from commercial plates, and semi-solidly forged (SSF). The SSF specimens have been found to have the highest impact toughness due to the coarsening of the dendrites, which occurs during the semi-solid processing stages. Ductile to brittle transition (DTBT) temperatures are measured for a BMGMC. While at room temperature the BMGMC is highly toughened compared to a fully glassy alloy, it undergoes a DTBT by 250 K. At this point, its impact toughness mirrors that of the constituent glassy matrix. In the following chapter, BMGMCs are shown to have the capability of being capacitively welded to form single, monolithic structures. Shear measurements are performed across welded samples, and, at sufficient weld energies, are found to retain the strength of the parent alloy. Cross-sections are inspected via SEM and no visible crystallization of the matrix occurs.

Next, metallic glasses and BMGMCs are formed into sheets and eggbox structures are tested in hypervelocity impacts. Metallic glasses are ideal candidates for protection against micrometeorite orbital debris due to their high hardness and relatively low density. A flat single layer, flat BMG is compared to a BMGMC eggbox and the latter creates a more diffuse projectile cloud after penetration. A three tiered eggbox structure is also tested by firing a 3.17 mm

aluminum sphere at 2.7 km/s at it. The projectile penetrates the first two layers, but is successfully contained by the third.

A large series of metallic glass alloys are created and their wear loss is measured in a pin on disk test. Wear is found to vary dramatically among different metallic glasses, with some considerably outperforming the current state-of-the-art crystalline material (most notably $Cu_{43}Zr_{43}Al_7Be_7$). Others, on the other hand, suffered extensive wear loss. Commercially available Vitreloy 1 lost nearly three times as much mass in wear as alloy prepared in a laboratory setting. No conclusive correlations can be found between any set of mechanical properties (hardness, density, elastic, bulk, or shear modulus, Poisson's ratio, frictional force, and run in time) and wear loss. Heat treatments are performed on Vitreloy 1 and $Cu_{43}Zr_{43}Al_7Be_7$. Anneals near the glass transition temperature are found to increase hardness slightly, but decrease wear loss significantly. Crystallization of both alloys leads to dramatic increases in wear resistance. Finally, wear tests under vacuum are performed on the two alloys above. Vitreloy 1 experiences a dramatic decrease in wear loss, while $Cu_{43}Zr_{43}Al_7Be_7$ has a moderate increase. Meanwhile, gears are fabricated through three techniques: electrical discharge machining of 1 cm by 3 mm cylinders, semisolid forging, and copper mold suction casting. Initial testing finds the pin on disk test to be an accurate predictor of wear performance in gears.

The final chapter explores an exciting technique in the field of additive manufacturing. Laser engineered net shaping (LENS) is a method whereby small amounts of metallic powders are melted by a laser such that shapes and designs can be built layer by layer into a final part. The technique is extended to mixing different powders during melting, so that compositional gradients can be created across a manufactured part. Two compositional gradients are fabricated and characterized. Ti-6Al-4V to pure vanadium was chosen for its combination of high

strength and light weight on one end, and high melting point on the other. It was inspected by cross-sectional x-ray diffraction, and only the anticipated phases were present. 304L stainless steel to Invar 36 was created in both pillar and as a radial gradient. It combines strength and weldability along with a zero coefficient of thermal expansion material. Only the austenite phase is found to be present via x-ray diffraction. Coefficient of thermal expansion is measured for four compositions, and it is found to be tunable depending on composition.

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