Cellular Amorphous Metal Composites for Energy Absorption

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Introduction

Building structures resistant to impact damage, such as that resulting from improvised explosive devices (IEDs) is of high interest to the Department of Defense (DoD). The ability of cellular structures to absorb impact energy is a function of their yield strength and relative density. Metallic glasses are attractive materials for this application because of their high yield strengths (~2 GPa), large elastic limits and relatively low density [1]. The purpose of the current study is to determine the feasibility of using cellular metallic glass structures in energy absorption applications. This report discusses methods of fabrication energy absorbing cellular structures and compares mechanical test results of these structures to cellular structures made of stainless steel and aluminum.

Experimental

Fabrication

Cellular amorphous composites were fabricated from monolithic bulk metallic glass (BMG), dendritic metallic glass composites [2], amorphous BMG ribbon, and Metglas® ribbon.

Monolithic BMG ($Zr_{35}Ti_{30}Be_{29}Co_6$) and dendritically toughened metallic glass composites [3] ($Zr_{36.6}Ti_{31.4}Nb_7Cu_{5.9}Be_{19.1}$) were thermo-plastically formed in a press by heating a metallic glass to the supercooled liquid region followed by pressing over the corrugated shape, producing a "potato chip" of amorphous alloy [4]. As shown in Figure 1, by forming the supercooled liquid at elevated temperature followed by quenching to room temperature, virtually any shape may be constructed.

Two methods were used to fabricate cellular structures of melt spun ribbons of Vitreloy 101 ($Cu_{47}Ti_{34}Zr_{11}Ni_8$) and Metglas® 2826 ribbon. In one, Vitreloy 101 ribbons were periodically slit using electro discharge machining (EDM), assembled into a cellular structure and soldered in place, as shown in Figure 2. In the second method, corrugated ribbons of Vitreloy 101 and Metglas 2826 were thermoplastically formed, then assembled into out-of-plane cellular structures using adhesive joining or soldering. Aluminum skins were then adhesively attached to the cellular structures.

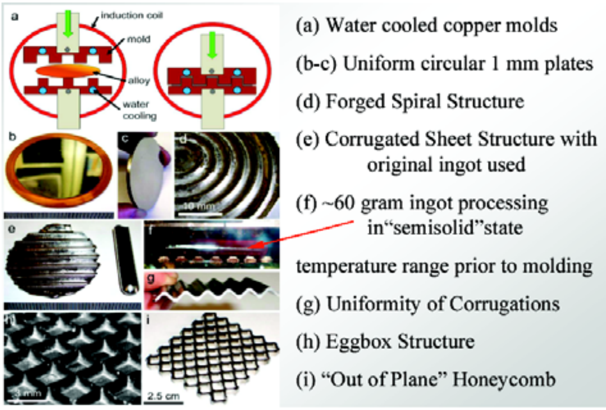

Figure 1 Wide variety of shapes that can be fabricated using semi-solid processing techniques.

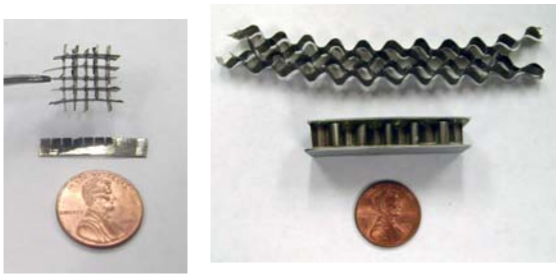

Figure 2 Out-of-plane cellular structures formed from (left) Vitreloy 101 melt-spun ribbon and (right) corrugated ribbons of Vitreloy 101 and Metglas 2826.

Results and Discussion

Corrugated structures made of bulk metallic glass and metallic glass composites of various relative density were tested in both in-plane and out-of-plane loadings. Figures 3 shows peak stress results for in-plane and out-of-plane monolithic BMG and BMG composites compared to steel and aluminum structures. These curves illustrate the high yield strength of the metallic glass cellular fabrications with respect to the relative density. The amorphous metals outperform crystalline metals for all the relative densities tested.

Figure 4 compares in-plane stress-strain performance of BMG and BMG dendritic composite cellular structures with that of steel core structures. Yield strength of the metallic glass structures is roughly three times that of the steel fabrications at nominally the same relative density. Further, the flow strength of the BMG composite is double that of the steel throughout the working strain. In both cases, this translates into significantly higher energy absorption than with traditional crystalline metal cellular materials.

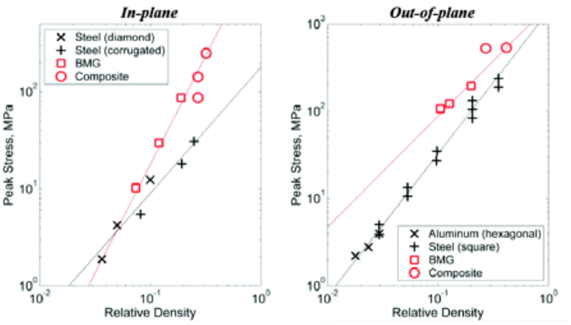

Figure 3 In-plane (left) and out-of-plane (right) peak load vs. relative density for aluminum, steel, and cellular amorphous [5,6] metals.

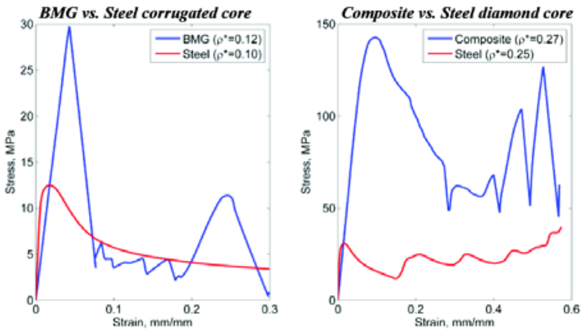

Figure 4 In-plane cellular composite performance of monolithic BMG (left) and dendritically toughened composite (right) to that of steel [5].

Figure 5 shows the results for cellular structures made of Vitreloy 101 ribbons at 7.3% relative density, compared to 304 stainless steel at 10% relative density. As with corrugated structures formed by thermoplastic or semi-solid processing methods, these structures show twice the yield strength of steel structures of 33% higher relative density.

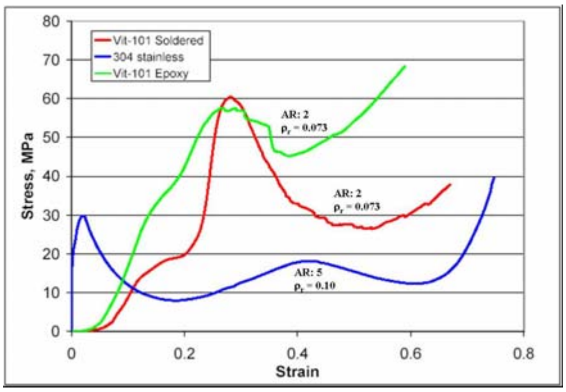

Figure 5 Out-of-plane stress vs. strain for cellular structures made from Vitreloy 101 ribbon and joined using solder or epoxy, and 304 stainless steel steel [5].

Conclusion

Periodic Cellular Amorphous Metal (PCAM) structures were designed and fabricated from monolithic Zr-Ti-based BMGs, highly toughened Ti-based BMG composites, and ribbons of Zr-based BMG and Fe-based Metglas®. Mechanical tests have demonstrated enhanced energy absorbing capabilities of amorphous corrugated layers under both in-plane and out-of-plane loading when compared to conventional metals. The high specific strength and fracture toughness of BMG's and ductile phase toughened BMG composites make these superior materials for the design of efficient energy absorbing structures.

References

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