Chapter 6

Summary and Future Directions

Summary

This thesis has been concerned with the study of the mechanical properties of amorphous metallic cellular structures. Based on the record of amorphous metal foams with high strength [36] and large plastic deformability [30], one of the goals of this work was to create amorphous metallic periodic cellular structures that would be able to outperform periodic structures made from crystalline metals. In this work periodic structures made from metallic glass and metallic glass matrix composite have been shown to inherit the impressive mechanical properties of the parent materials, and exceed them in the ability to absorb large amounts of energy while deforming to high strains without failing catastrophically. These structures also outperform the current state-of-the-art stainless steel structures of the same general geometry in strength and energy absorption.

Amorphous metal foams produced by a powder metallurgy route have been investigated, showing high yield strengths corresponding to plastic yielding of cell walls and energy absorption higher than other metallic glass foams. Another type of amorphous metal foam known to yield by elastic buckling of cell walls [35] was tested under two disparate strain rates and a change in the yield mechanism was observed upon a drastic increase in strain rate. This mechanism change has been explained as the result of the rate of the mechanical test approaching or even eclipsing the speed of elastic waves in the material.

Future Direction in BMG and MGMC Honeycombs

The strength capabilities and energy absorption capabilities of metallic glass and metallic glass matrix composite honeycombs have been shown here. In future work, it would be useful to devise a method or an apparatus that could produce periodic sheets of MGMC with higher porosity to fill in the lack of low relative density data points for these structures. Thinner struts would be one way to do this which might result in these MGMC structures deforming to densification with fewer collapse events. Another way to reduce the density is to change the geometry of the structure to a less dense one. One example of a more porous structure is the egg-box structure which was investigated in chapter 3. Other more porous structures that could be made from these materials are the three-dimensional structures that are made from connected columns and not connected plates of the parent material. Two examples of this type of structure are the textile and the truss, examples of which are shown in Fig. 6.1.

Two major issues with these structures are bonding and uniformity of cellular elements. Cellular structures are commonly used as the core of sandwich panels, and the cores must be bonded to the face sheets of the sandwich and to each other in the case of corrugated sheets used to make a honeycomb. Metallic glasses are difficult to bond together without risking crystallization, but several methods have been studied. Among these methods are laser weld-

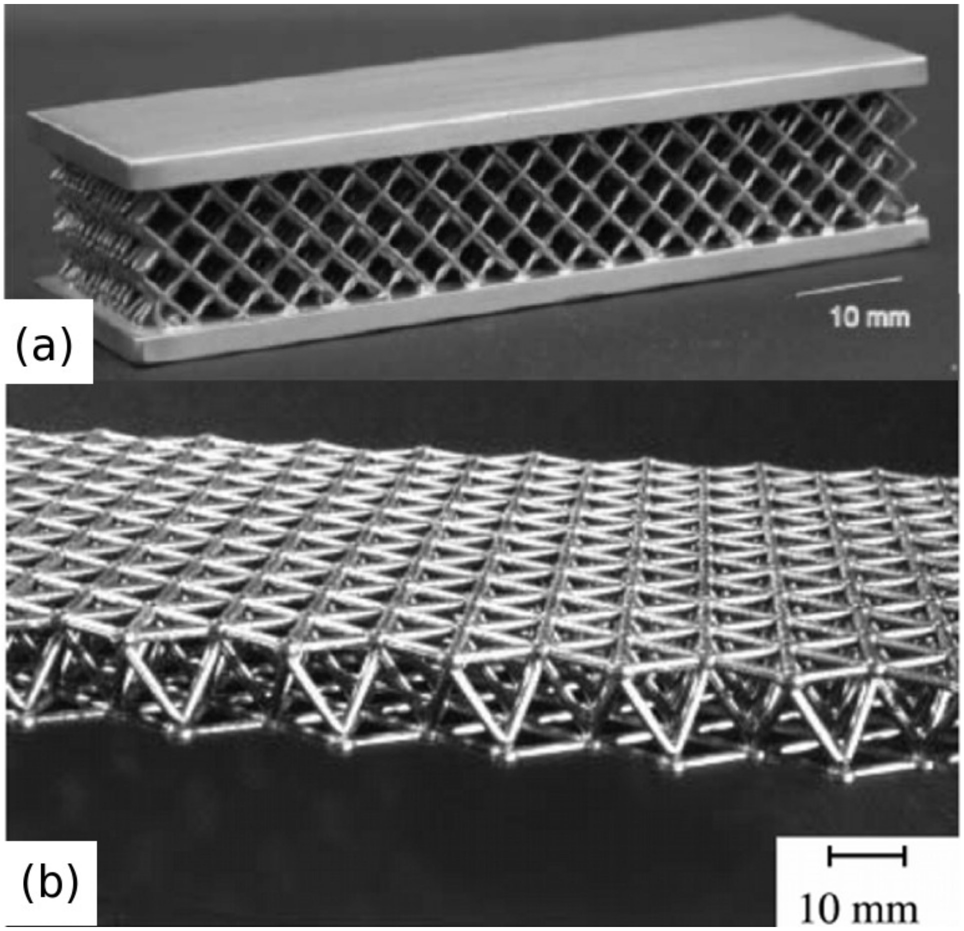

Figure 6.1: Examples of crystalline metal (a) textile and (b) truss.

ing [69, 70], consolidation using electrical discharge welding [71], and adhesive bonding using a cured sol gel layer between metallic glass and epoxy [72]. This final method is interesting because it uses the chemistry of the cured sol gel layer and not local heating of the material to make the bond. Any of these methods could be quite promising for both BMG and MGMC structures if joining can occur without harming the amorphous nature of the material and the bond is strong enough to remain intact as the material around it yields. When the elements of the cellular structure are not uniform, the stochasticity of the structure affects its strength and energy absorbing capabilities as thinner elements may yield early in the deformation plastically or by buckling, and thicker elements may have limited plastic deformability ending in fracture causing a collapse event in the structure. Ideally, the elements of a structure should be uniformly thin.

For any of these structures, it would be desirable to be able to make them in a shorter amount of time so that the sample heating and forming have as small an effect as possible on the amorphous nature of the glass-forming alloy. Containerless processing would also be desirable as the glassy liquid is quite reactive at elevated temperatures. For MGMC structures, the current method involves induction heating in an argon atmosphere, which is basically containerless, but only heats the skin of the sample directly and the rest of the sample is heated by thermal conduction. Forging is currently done manually by the operator plunging the top die into the semi-solid material. An automated system may be able to heat the composite more quickly and uniformly and would definitely produce more uniform parts with thinner struts. For the BMG sheets, it is desirable to process in the supercooled liquid region. A method involving rapid heating from the amorphous state followed by rapid forming and quenching is in development in the Johnson group. This method involves the heating of a metallic glass using the discharge of capacitors and forming in a matter of milliseconds. At these heating, forming, and cooling rates, the glass will not have time to crystallize or react with its surroundings before it has been quenched to room temperature.

The true laboratory test of any energy absorbing structure is a dynamic impact test. Future research on metallic glass and metallic glass matrix composites should include dynamic impact testing of some type. It would be quite interesting to find out whether the phenomenon of elastic buckling suppression observed in chapter 5 is present in very porous periodic honeycomb or egg-box structures.

Conclusion

Amorphous metallic cellular structures have impressive mechanical properties that can surpass those for structures made of crystalline metals despite some non-optimized aspects. The structures tested in this thesis are not completely optimized for strength or energy absorption as a multi-level structure or as sandwich panels because of the lack of reliable bonding and non-uniformity of the structural elements. There are ways to fix these problems, though, and ideal structures made from metallic glasses and metallic glass matrix composites could be even more impressive than those exhibited in this thesis.

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