A Review on Bulk Metallic Glasses for Bio Medical Applications

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Abstract – *Bulk metallic glasses is one of the emerging bio-compactable bio materials. It is formed at very low critical cooling rates. They have so many unique properties which are high fracture toughness, high elastic strain limit, lower Young modulus and biocompatibility. Bulk metallic glasses are non-crystalline solids and so they lack grain boundary and also they have better corrosion resistance. And also they are bio degradable as like magnesium based biomaterial.*

Key Words: Fracture toughness, Biocompatibility, Corrosion resistance, Cooling rate, Young modulus

1. INTRODUCTION

With increasing knowledge of the materials science of bulk metallic glasses (BMGs) and improvements in their properties and processing, they have started to become candidate materials for biomedical devices. Medical devices made from metallic alloys are in widespread use, and a process of continuous metallurgical improvement has led to

Enhanced biomechanical and biocompatible performance of these materials a dichotomy in the types of medical applications has also emerged, in which some families of BMGs are being developed for permanent devices whilst another family – of Mg-based alloys – is showing promise in bio absorbable implants. The current status of these metallurgical and technological developments is summarized. Bulk metallic glasses (BMGs) are a relatively new class of metallic materials developed over the past three decades. Whereas conventional alloys have a crystalline structure, BMGs exhibit no long-range atomic order, appearing instead as an atomically frozen liquid. The created foam showed 88% porosity, and exhibited excellent matching with the properties of calcium bone, in terms of stiffness and compressive strength. In all cases the applications will rely on the unique properties of amorphous metals, but significant scientific and engineering challenges need to be overcome before the successful clinical applications of most of the relevant medical devices[2,3].

1.1 Bulk metallic glasses in medical implants

Biomedical materials can improve the life quality of a number of people each year. The range of applications includes such as joint and limb replacements, artificial arteries and skin, contact lenses, and dentures. So far the accepted biomaterials include metals, ceramics and polymers[2]. The metallic biomaterials mainly contain stainless steel, Co-Cr alloys, Titanium and Ti-6Al-4V. Recently, bulk metallic glasses as novel materials have been rapidly developed for the past two decades in Mg-, Ln-, Zr-, Fe-, Ti-, Pd-, Cu-, Ni-based alloy systems because of their unique physical, chemical, magnetic and mechanical properties compared with conventional crystalline alloys. As above-mentioned, Nano-crystalline structure is formed in the Ti-Zr-Cu-Pd bulk metallic glass subjected to an optimum annealing treatments. The crystallized structure changes seriously the mechanical properties and fracture morphology[5].

2. A review on bulk metallic glasses for biomedical application.

Takeshi et al. [1]: In this paper it was found that the ductility of a $Pd_{40}Cu_{30}Ni_{10}P_{20}$ bulk glassy alloy increased even by homogeneous dispersion of spherical pores into glassy matrix. In addition to the increase in ductility, the porous bulk glassy alloys exhibited the decreases in specific weight, Young's modulus and strength as well as the increase in absorption energy required up to fracture. The porous bulk glassy alloys containing spherical pores with sizes from 15 to 33 µm in a wide volume fraction range from 2 to 70% can be formed by use of significant difference in solubility limit of hydrogen between super cooled liquid and glassy solid. Porous bulk glassy alloys have been also produced by the precompaction and sintering method , by the sequent processes of homogeneous mixing of bulk glassy alloy powder and sodium chloride, followed by dissolution of sodium chloride with water , and by the formation of immiscible type glassy alloy, followed by dissolution of less-noble glassy phase field with some acids.

A.Inoue et al. [2]: This paper deals with the recent development in various casting techniques of molten alloy to produce bulk glassy alloys with desired outer shapes have been developed to full fill their engineering needs. As a result, we can utilize glassy alloy rods with diameters of 3 to 5 mm and a length of about 1 m, glassy alloy sheets with dimensions of 0.3-2x125x200 mm and spherical glassy alloy balls with diameters of 3-10 mm. The combination effect of unique Properties, these use- full forms and simple net-shape production process is expected to open up much wider application fields.

Chunling Qin et al. [3]: This paper mainly focused on alloying elements by adding special elements leading to the deviation from the three component rule to bulk glassy alloys, we can produce bulk glassy alloys containing Nano-crystalline nanoquasicrystalline micrometer-scale dendrite crystalline phase in number of alloy systems such as Zr, Cu, Ni, Pd, Ti, and Fe bases.

Yixuan Wu et al. [4]: In this paper encourage the use of BMG for automobile parts, it have been succeeded in producing high torque geared motors with outer diameters of 1.5 and 2.4 mm which are composed of sun- carrier, planet-type gears, gear axis and bearing made of Zr-, Cu-, Ni-, and Fe-based glassy alloys [18]. When the endurance time of these gears is measured in comparison with conventional tool steel (SK4), it is noticed that the time is much longer than that of SK4 and the difference reaches 32 times for Zr-based alloys, 107 times for Cu-based alloys and over 1000 times for Ni-based alloys. As an ex-ample, shows the durability of Ni-based glassy alloy gears used in the geared motor with an outer diameter of 2.4 mm in comparison with SK4.

Jan Schroers et al. [5]: For the purpose of developing biodegradable magnesium alloys with suitable properties for biomedical applications, Mg–Zn–Ca–Ag metallic glasses (MGs) were synthesized by copper-mold casting and melt spinning. The effects of Ag addition on the glass formation, thermal stability, micro hardness, hydrogen evolution, corrosion resistance, and cytocompatibility of the Mg-based glassy alloys were studied in vitro. The corrosion resistance and the capability of suppressing the hydrogen evolution are enhanced for the Ag-containing alloys, in comparison to the Mg–Zn–Ca MG, though the incorporation of Ag decreases the glass forming ability but influences insignificantly on micro hardness.[2]The higher cellular viability of the Ag-containing alloys than that of the Ag-free alloy was also revealed by direct cell-culture experiments. Thus, Mg–Zn–Ca–Ag MGs possess the potential to be employed as biodegradable materials.

Muhammad et al.[6]: This paper mainly focused on Crystalline materials, such as 316L stainless steel (316L SS), Co-Cr alloys, shape memory alloys, and Ti-based alloys, are being used extensively as different biomedical devices or implants, however, low corrosion resistance releases toxic ions inside the human body. Moreover, elastic modulus mismatch with bone restricts their applications as functional biomaterials. This limitation is amplified because of a complex fabrication method, which restrains the desired formability needed for materials used in biomedical implants. BMGs have great potential in biomedical applications ranging from orthopedic, cardiovascular to dental implants and fillers. Biomedical implants, such as articulating surfaces, artificial prostheses and dental implants, which are needed to serve a long time in the severe human body environment as they will degrade gradually in human body after completing their temporary mission (would dissolve completely upon fulfilling the mission of fixing or supporting) during which arterial/bone remodeling and healing would occur.

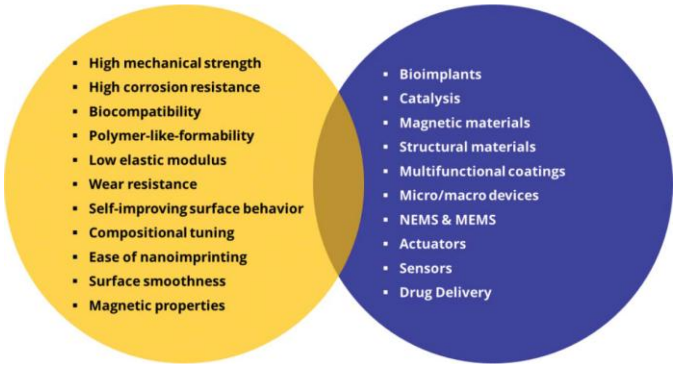

Fig -1: Some remarkable features exhibited by different BMG systems and their potential applications in various fields. (Muhammad et al. [2017])

Gideon et al. [7]: This paper focused on bulk metallic glasses used in cardiovascular applications by using BMG it is very much bio compactable and its toxic effect is less. The latter (structural integrity), which poses certain requirements on the mechanical properties of biomaterials, addresses concerns regarding the complex physiological loading by surrounding tissues, blood vessel walls, and bones during the operational life of any implantable medical device especially during different disease conditions[7].In the paper they compare the biocompatibility and effect of BMG and nitinol. The feasibility of using BMGs as stent material for self-expandable stent applications. Stent deployment, which is an important process that decides the outcome of the surgical process, was considered here in this paper.[7]

Gideon et al. [8]: As paper focused on bio compactable self-expandable stent made up of BMG. They contact many simulations such as FEA and MD to investigate and understanding the feasibility of using self-expandable stunt for cardiovascular applications. They find out that BMG would be a promising material for cardiovascular stent applications.

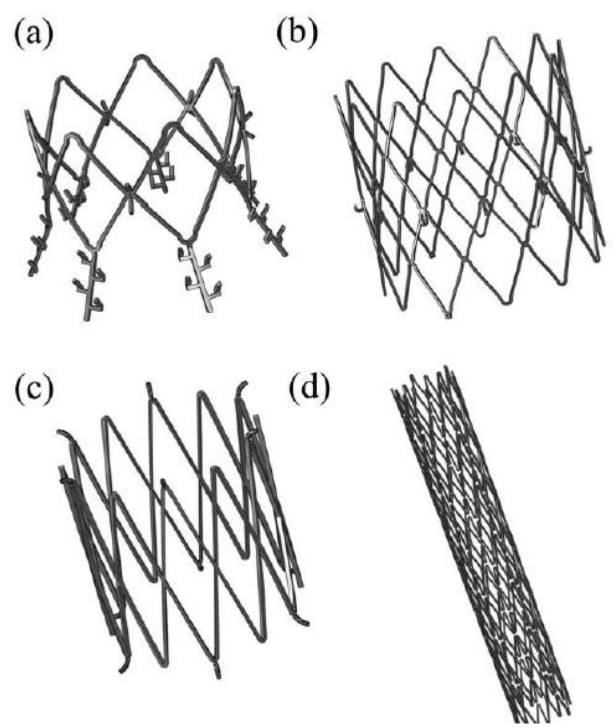

Fig -2: Stent designs used in this study. (a) Geometry A-Mitral stent; (b) Geometry B- Caval stent; (c) Geometry C-Aortic stent; (d)Protege stent.(Gideon et al.[2016]).

Mehdi et al.[9]:In this review paper they almost cover all the important applications of bulk metallic glass and they also through a light in the area of BMG especially in cardiovascular applications they also took some of the excellent journals that cover latest development of BMG. Paper also focus the mechanical and biocompatibility property of BMG.

WEI HE etal. [10]: A part from cardiovascular applications. BMG are also used in orthopedic applications. This paper focused on the use of BMG in orthopedic applications for their study they use Zr based bulk metallic glasses. The bone cell osteoblast response to Zr-based bulk metallic glasses (BMGs), an emerging class of materials that offers an attractive combination of properties, such as high strength and low moduli, has-been investigated. [10].They also find out that Low modulus BMG study have a lots of scope in near future.

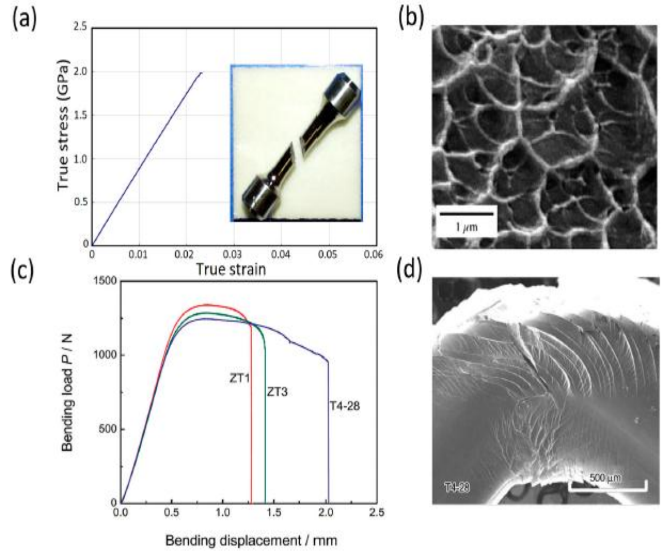

Fig -3: Ductility and failure of MGs under different loading conditions at room temperature (far below Tg). (a) A typical tensile fracture in which the plastic deformation is severely localized within an arrow single band and the MG exhibit almost no tensile ductility. Approximately 2% of the elastic

Elongation is observed. The inset shows the result of catastrophic failure of an MG sample upon tensile loading via the formation of a single shear band aligned at about 45° with respect to the loading direction; (b) in contrast with the brittle-like style of stress-strain curve shown in (a); the fracture surfaces of MGs display a typical vein morphology typical of "ductile" fractures; (c) bending loading test of MG samples, showing extensive bending ductility for different compositions; and (d) a prototypical Zr-based BMG sample could exhibit an extensive plastic deformation via multiple

Shear banding in bending tests. Regardless of overall observed ductility in (c); the plastic deformation in this case is still severely inhomogeneous (Adapted with permission [9]). Figure 5. Ductility and failure of MGs under different loading conditions at room temperature (far below Tg). (a) A typical tensile fracture in which the plastic deformation is severely localized within a narrow single band and the MG exhibit almost no tensile ductility. Approximately 2% of the

Elastic elongation is observed. The inset shows the result of catastrophic failure of an MG sample upon tensile loading via the formation of a single shear band aligned at about 45◦ with respect to the loading direction; (b) in contrast with the brittle-like style of stress-strain curve shown in (a); the fracture surfaces of MGs display a typical vein morphology typical of "ductile" fractures; (c) bending loading test of MG samples, showing extensive bending ductility for different compositions; and (d) a prototypical Zr-based BMG sample could exhibit an extensive plastic deformation via multiple shear banding in bending tests. Regardless of overall observed ductility in (c); the plastic deformation in this case is still severely inhomogeneous (Adapted with permission [9]). (Mehdi et al.[2018]).

3. CONCLUSIONS

As the review paper is more focused on the effect and study of BMG in cardio vascular applications and most of the paper finds out that the use of BMG would be a promising material for stunt based applications. And also we also go through the use of BMG in orthopedic applications. Most of the paper done various simulations for finding out the biocompatibility of BMG and most of them gives out promising outcomes. BMG of Zr based alloys found a good biocompatibility especially for cardiovascular applications. Nano crystalline structure formed in BMG also have high mechanical property and they enhance fracture resistance property in selected BMG.

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