Mechanics of thin film coated Bulk Metallic Glass(BMG) composites

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Introduction

Bulk Metallic glasses are amorphous alloys of recent origin. These are amorphous alloys of metals like Zirconium (Zr), Titanium (Ti), Copper (Cu), Nickel (Ni), Beryllium (Be), Aluminum (Al) etc. Metallic glasses are super-cooled alloys and prepared by cooling metallic liquid with very high rate of cooling to avoid crystallization and atoms have no time to arrange into crystalline structure[1].

Metallic glasses show very good mechanical properties such as high strength(2GPa), high yield strain about 2% and high corrosion resistance which are mainly because of lack of crystalline structure due to which there are no crystal defects i.e. point defects, line defects etc. resulting in very high strength, toughness and elasticity.

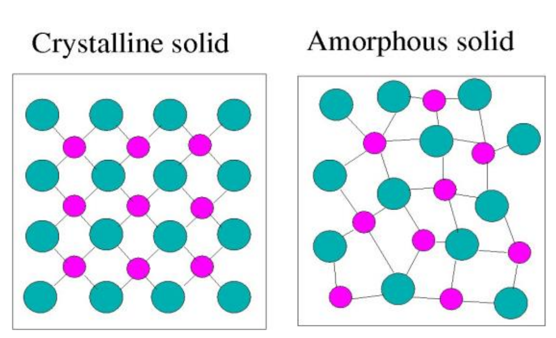

Fig1. Crystal structure of BMG

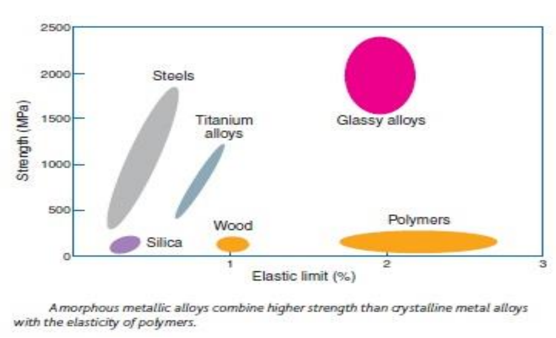

Fig2. Mechanical properties of BMG

Objective

The objective of the project is to numerically investigate the mechanical behavior of BMG composites through finite element simulations using the commercial software package ABAQUS.

Having superior mechanical properties than many other engineering materials their use is limited as structural material because they lack ductility in uniaxial tension and respond in a quasi-brittle manner. This has motivated the synthesis of BMG matrix composites which improve the ductility in uniaxial tension without compromising on the tensile strength.

The project focuses on the comparison of monolithic BMG matrix and coated BMG matrix to qualitatively match the stress-strain response under uniaxial tension and compression tests.

Methods

The methodology of the project involves modeling of CAE models of the test specimen for simulation in ABAQUS. The models simulated are with Vit1[2]and Vit105[3] BMG. The simulation requires 1] Input file which includes the mesh and boundary condition information 2]User subroutine which has the Fortran code written by Prof. Parag Tandaiya[2].

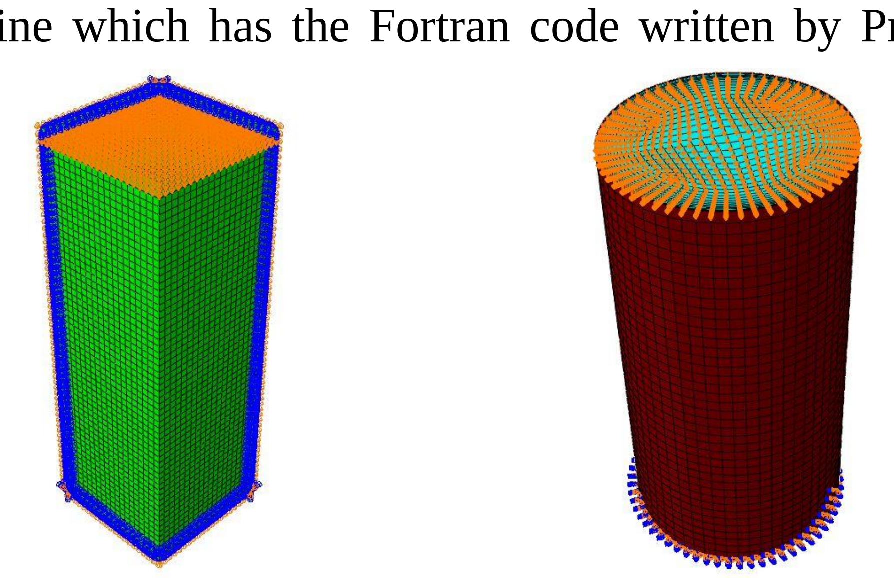

Fig3. Figure shows the applied boundary conditions for prismatic bar and 3D coated cylinder model under compression

Results

1]Prismatic box under compression without damage

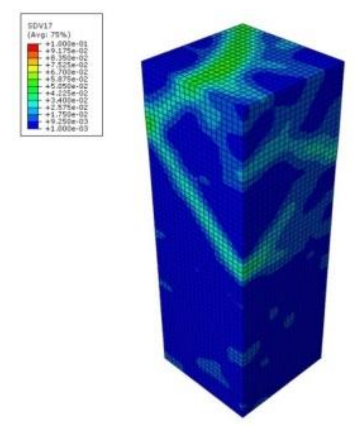

Fig4. $\ln \lambda_1^P$ at 3% strain

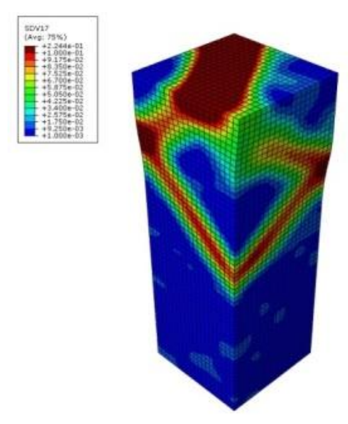

Fig5. $\ln \lambda_1^P$ at 5% strain

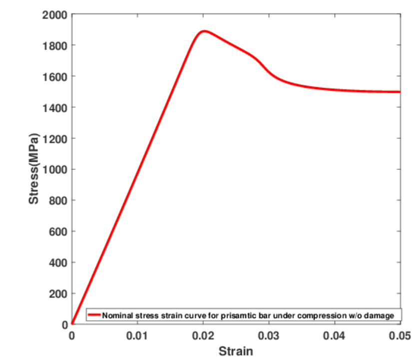

Fig6. Engineering stress-strain curve

2] Slab under uniaxial tension with damage

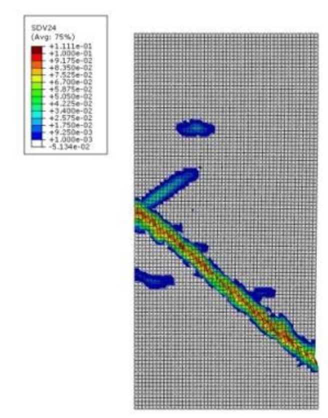

Fig7. $\ln \lambda_1^P$ at 3% strain

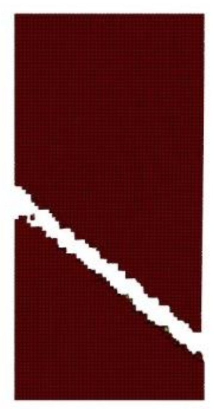

Fig8. Damage plot at 3%strain

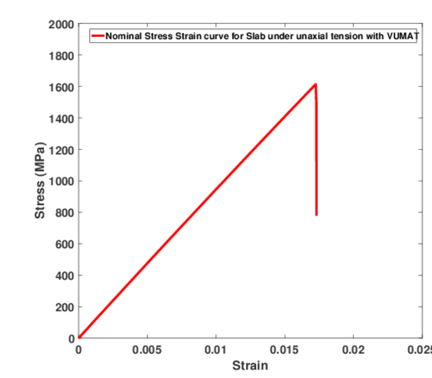

Fig9. Engineering stress-strain curve

3] Axisymmetric cylinder models (100μm Coating)

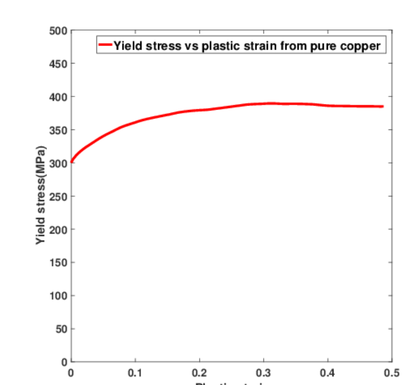

Fig10. Stress-Strain curve for pure copper

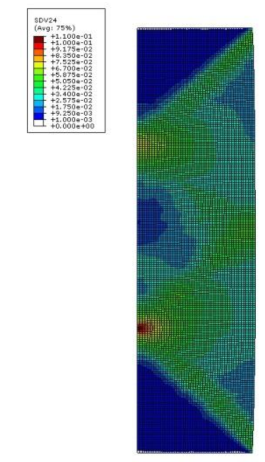

Fig11.Uncoated cyl. $\ln \lambda_1^P$ at 6% strain

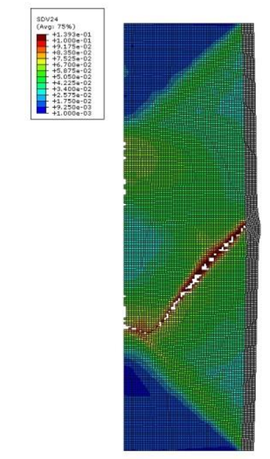

Fig12. Coated cyl. $\ln \lambda_1^P$ at 8% strain

Experimental Observations

The data of uniaxial compression tests and the Engineering stress -strain curve is obtained for cylindrical specimen is referred from research paper available. The coating of 20μm on the cylindrical specimen of 2mm diameter gives the enhancement of 8% strain in ductility[4].

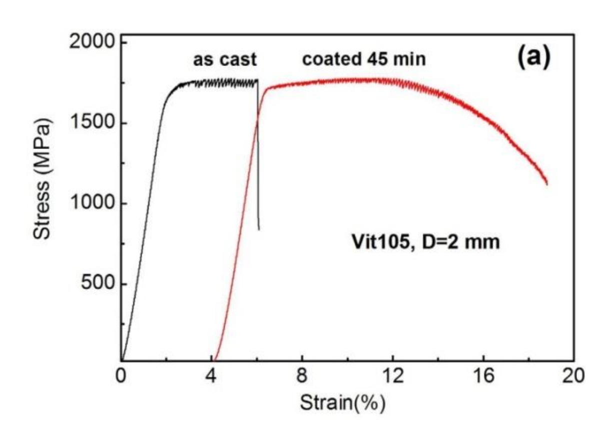

Fig.13 Engineering stress-strain Curve of Vit105 from experiment

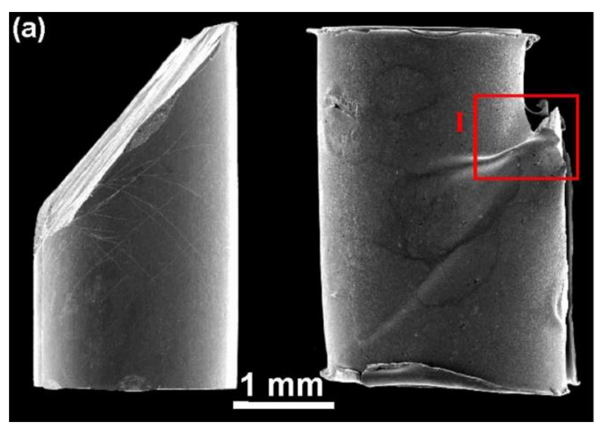

Fig14. As cast and Coated sample (right) after failure

$\ln \lambda_1^P$ is Maximum principle logarithmic plastic strain

Simulation results

The simulation include the axisymmetric uncoated cylinder of 2mm diameter and coated cylinder with same diameter with copper coating of thickness 100μm is simulated. All the base nodes are fixed and strain is applied to top face with an engineering strain rate of $5 \times 10^{-4} s^{-1}$.

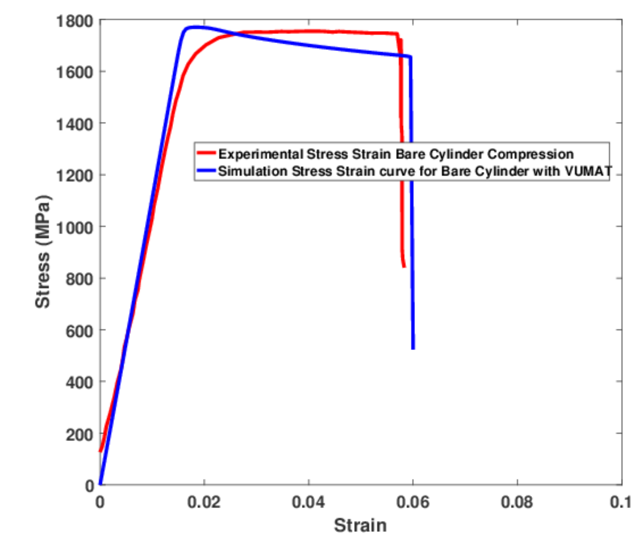

Fig. 15

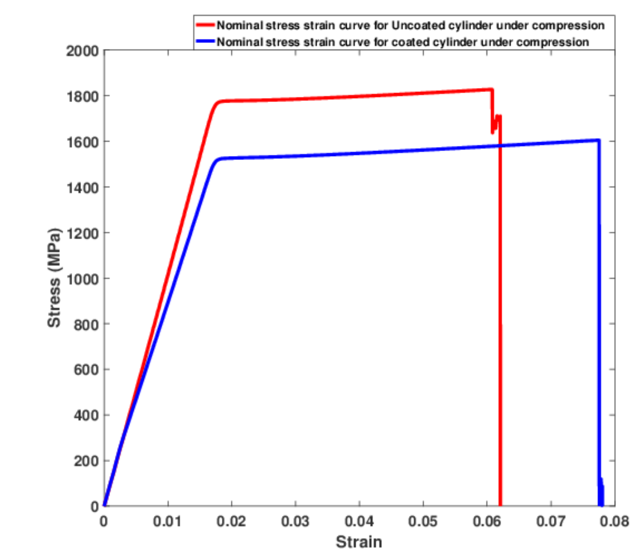

Fig. 16

Fig15 shows comparison of experimental nominal stress-strain curve with simulation nominal stress-strain for uncoated cylinder 3D model

Fig16 shows comparison plot of nominal stress-strain curve from the simulation for uncoated and coated cylinder from axisymmetric model

Conclusion

The BMGs being amorphous they don't show yielding by necking or by ductile deformation. BMGs are more likely to fail by shearing.

BMGs have more yield strength in compression than in tension which is property of pressure sensitive materials[5].

The formation for shear bands at an angle of 45°in the plane of maximum shear initiates the damage in the BMG matrix

Formation of dominant shear band which results in fracture by shear. The shear band has to be traversed through the entire cross section of the model which confirms the fracture of the specimen.

Fig11 and Fig12 shows copper coating resists the formation of dominant shear band at an angle of 45°.

It can be seen from the comparison plots that thin coating of copper enhances the ductility of BMG.

References

[1] Greer, A. L. (2009). Metallic glasses...on the threshold. Materials Today, 12(1-2), 14-22.doi:10.1016/S1369-7021(09)70037-9

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[4] B.A.Sun,S.H.Chen(2016) Origin of shear stability and compressive ductility enhancement of Metallics glasses by metal coating

[5] Plasticity for structural engineers (2007) Fah Chen Da Jian Han Ross