Mechanical Properties of Bulk Metallic Glasses and composites

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ABSTRACT

We have studied the mechanical properties of monolithic bulk metallic glasses and composite in the La based alloys. $La_{86-y}Al_{14}(Cu, Ni)_y$ (y=24 to 32) alloy systems was used to cast the in-situ structure and subsequently tested under compression. We found that the ductility of the monolithic is actually poorer than that of the fully crystalline composite.

Keywords: Metallic glass; composite; Compression; Deformation and fracture; Fracture Angle

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I. INTRODUCTION

The limited application of bulk metallic glass as engineering material is its quasi-brittle deformation behavior under loading even though it exhibits superior properties compared to its crystalline counterparts. BMGs are known to have unique mechanical properties, such as high strength, relatively low Young's modulus and perfect elastic behavior [1]. However, they show little global room temperature plasticity and deform by highly localized shear flow [2, 3]. When subjected to a state of uniaxial or plane stress, metallic glasses fail on one dominant shear band and show little overall plasticity, which makes the stress-strain curve appear similar to that of a brittle material. Under constrained geometries (e.g. plane strain), BMGs fail in an elastic, perfectly plastic manner by the generation of multiple shear bands. Multiple shear bands are observed when the plastic instability is constrained mechanically, for example in uniaxial compression, bending, rolling, and under localized indentation.

Attempts to ductilize BMGs have been carried out via introducing ex-situ (ductile metal or refractory ceramic particles) [4, 5] and in-situ (ductile dendrite phases) [4, 6] reinforcements in bulk metallic glass matrix. The resulting microstructure effectively modifies shear band formation and propagation. High density of multiple shear bands evolves upon loading, which results in significant increase in ductility both in tension and compression, toughness, and impact resistance compared to the monolithic glass. It was proposed that the second phase/particles will restrict shear bands propagation thus promoting the generation of multiple shear bands and improve the toughness of the composite [4, 7]. Recently, an in-situ dendritic precipitates in a nanostructured matrix was developed when the authors modified an originally glassy alloy by replacing 40% of the amorphous composition with miscible compounds. This new system exhibits up to 14.5% compressive plastic strain [8].

In this paper a monolithic metallic glass and composites based on $La_{86-y}Al_{14}(Cu, Ni)_y$ (y=24 to 32) system has been chosen to study the influence of crystalline phases in amorphous matrix on compression. The composites are prepared via in situ processing by deviating from the composition of monolithic glass forming alloy.

II. EXPERIMENTAL PROCEDURE

Monolithic $La_{62}Cu_{12}Ni_{12}Al_{14}$ amorphous alloy and $La_{86-y}Al_{14}(Cu, Ni)_y$ (y=24 to 32) alloy composites were prepared by arc-melting a mixture of La (99.9 %), Al (99.9 %), Ni (99.98 %) and Cu (99.999 %) in a argon atmosphere. The BMG alloy and its composites were prepared by remelting the master ingots at a temperature of 973 K in an argon atmosphere and cast into copper mould with a 5 mm diameter cavity. Cross sections of the rods were examined by X-ray diffraction. The glass transition and crystallization of all the samples were studied with a differential scanning calorimeter at a heating rate of 20 K/min. The Image Analyzer was used to determine the volume fraction of dendrites in the composites. Analysis of as-cast microstructures and fracture surfaces were characterized by scanning electron microscopy (SEM). An Instron 5500R load frame was used to test three specimens of each type at room-temperature under uniaxial compression loading. The compression test specimens were 10 mm in length and 5 mm in diameter and polished plan parallel to an accuracy of less than 10 μm. The compression samples were sandwiched between two WC platens in a loading fixture designed to the guarantee axial loading. The ends of the compression samples were lubricated to prevent ‘barreling’ of the samples. Strain gages (TML) glued on the surface of the specimen’s gage section were used to obtain one-dimensional surface strains. All compression tests were conducted using constant strain rates of 10^{-4} s^{-1}.

III. RESULTS AND DISCUSSION

Materials Characterization

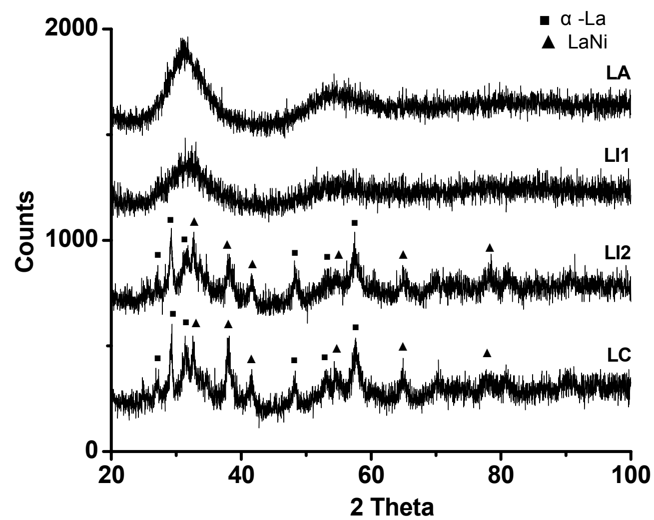

Figure 1: XRD scan of as-cast La-based bulk amorphous alloy and composites

In Figure 1, the X-ray diffraction patterns of the monolithic amorphous alloy and composites were compared. Sample LA were fully amorphous as is verified by the absence of crystalline peaks. Some small peaks corresponding to crystalline phases can be seen for the diffraction pattern of the LI1 composite. More intense crystalline peaks were observed when the LI2 and LC samples were scanned. The corresponding microstructures of the samples are shown in Figure 2. While the polished and etched microstructure of

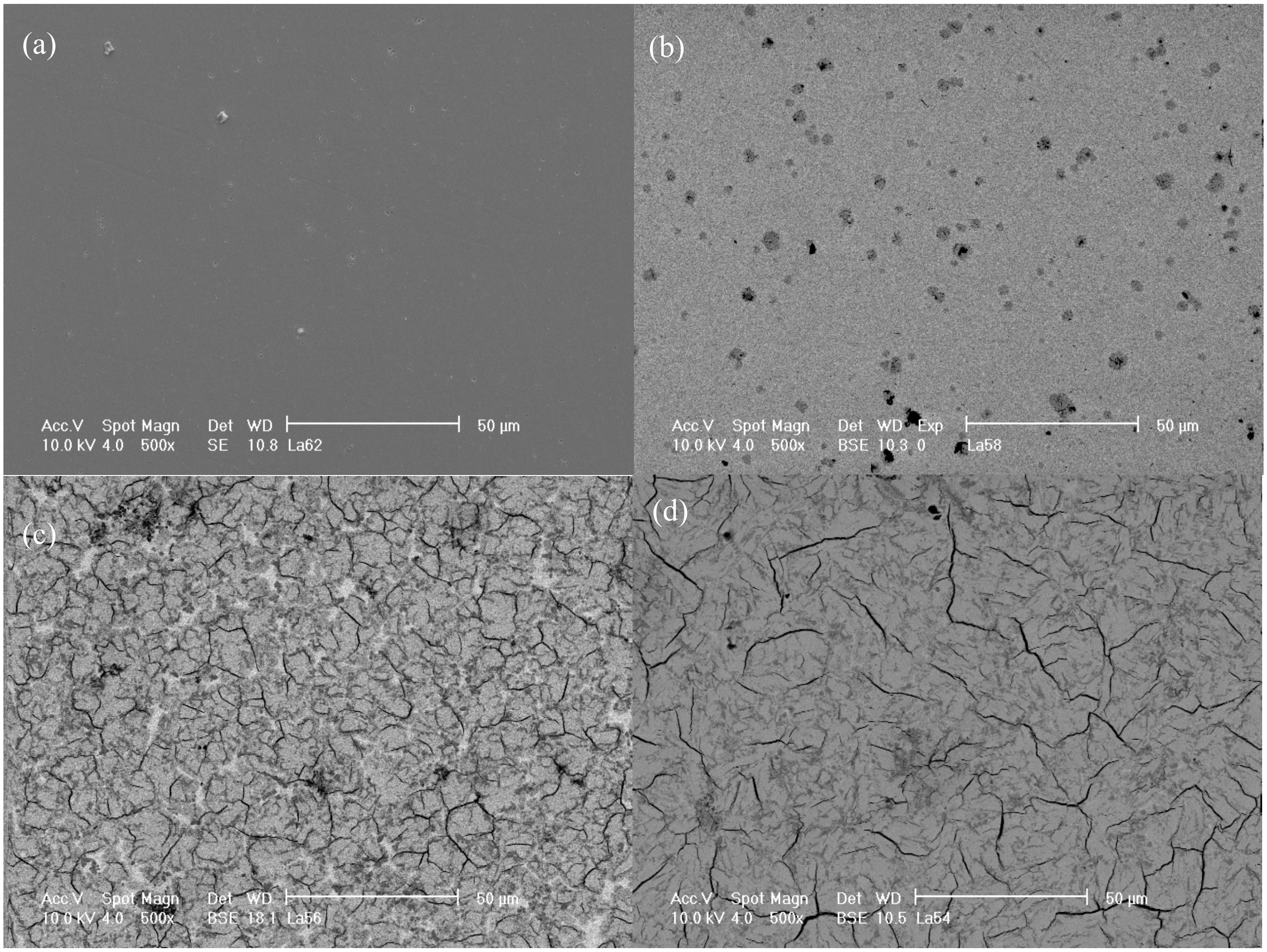

Figure 2: Backscattering SEM images of polished and chemically etched cross sections of amorphous and in-situ composite microstructures; (a) LA, (b) LI1, (c) LI2 and (d) LC alloys. The 2^{nd} phases appear dark, the fully amorphous matrix phase appears bright.

the LA sample was featureless, the in-situ composite LI1 microstructure revealed the presence of two phases (a hcp-La and LaNi as determined from the XRD scan) in a glassy matrix. The micrographs of LI2 and LC showed higher volume fraction of these two phases and an almost fully crystalline structure respectively. DSC scan were also carried out for these samples as seen in Figure 3. Table 1 summarizes these findings.

<u>Mechanical Properties</u>

Compressive tests were performed on the monolithic amorphous sample and its composites. Figure 4 shows uniaxial compressive stress-strain curves typical for the amorphous and composite materials. All the test results are summarized in Table 2. The monolithic bulk metallic glasses show linear elastic behavior up to fracture stress of ~560MPa and fail without any macroscopic plasticity at fracture strains of ~ 1.28%. Much higher fracture stress and strain were reached for the composite material. With the presence of crystalline phases in the matrix such as in the case of LI1, the composite fail at a higher fracture stress of 596 MPa. With further increase in volume fraction of crystalline phases, the stress-strain curve exhibits work hardening behavior. The stress-strain curve of LI2 showed similar elastic properties at the early part of loading up to an elastic limit of 0.7%, but as the load

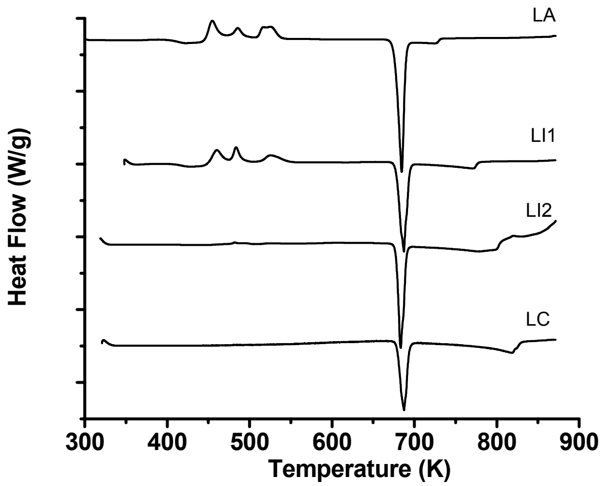

Figure 3: DSC scan of as-cast La-based bulk amorphous alloy and composites

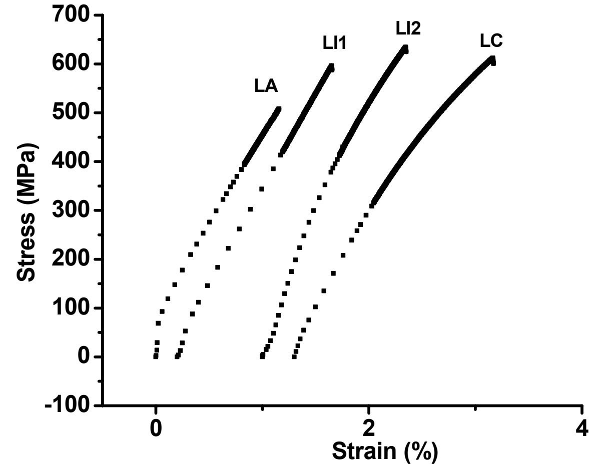

Figure 4: Compression result for as-cast La-based bulk amorphous alloy and composites

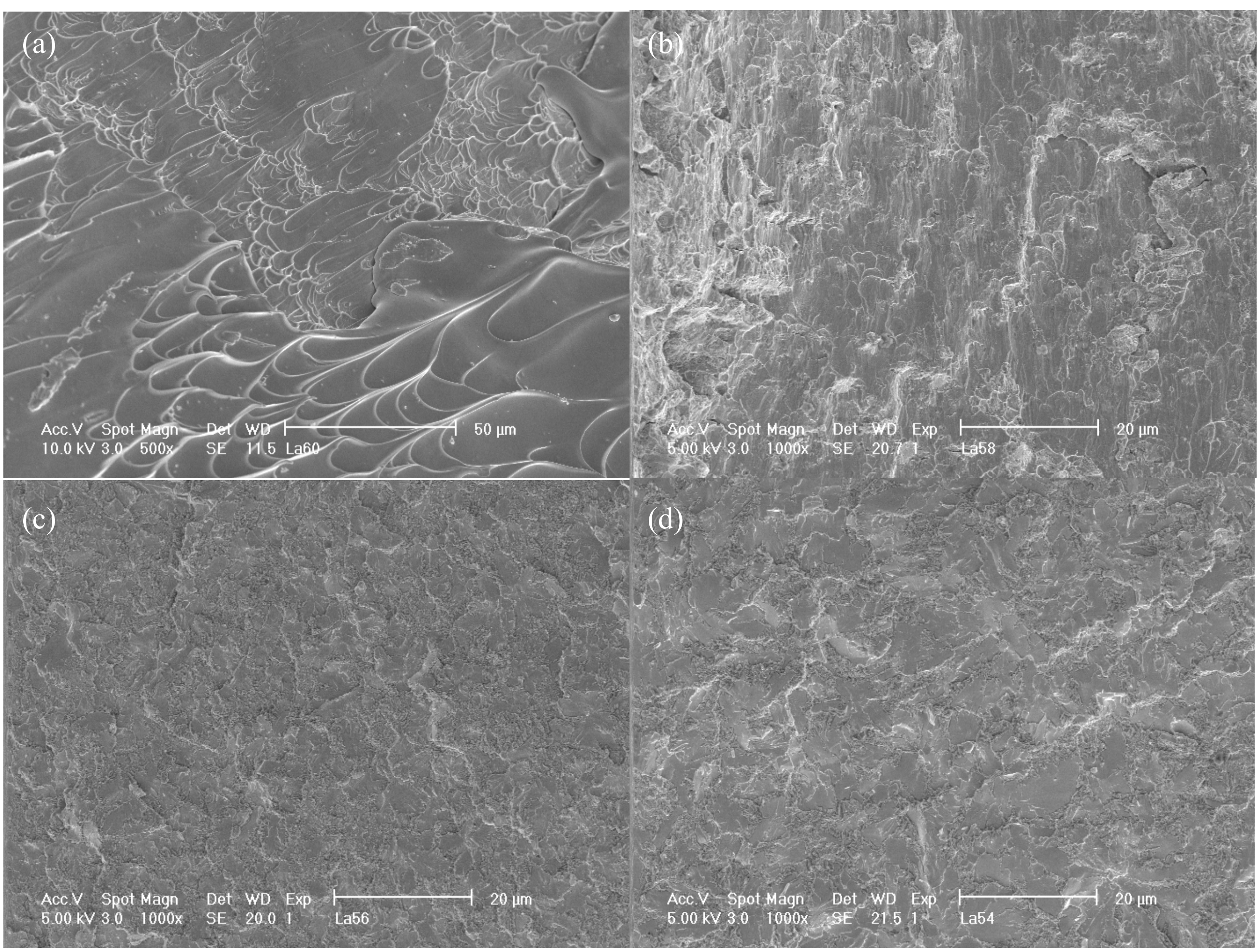

Figure 5: SEM fracture surface micrograph of (a) LA, (b) LI1, (c) LI2 and (d) LC

Table 1 : Summary of DSC result

Samples	Alloys	Phases	Tg (K)	Tx (K)	Tm(K)	Tl (K)	DTx (K)	Trg	DHx (J/g)
LA	$La_{62}Al_{14}(Cu,Ni)_{24}$	BMG	413.63	445.46	671.79	732.24	31.83	0.56	46.17
LI1	$La_{58}Al_{14}(Cu,Ni)_{28}$	BMG + 2 phases	418.93	476.57	672.64	781.04	57.64	0.54	36.08
LI2	$La_{56}Al_{14}(Cu,Ni)_{30}$	BMG + 2 phases	417.57	476.77	673.60	815.05	59.2	0.51	2.331
LC	$La_{54}Al_{14}(Cu,Ni)_{32}$	Nano-composite	-	-	674.78	832.22	-	-	0

Table 2: Summary of compressive test data. Volume Fraction, Young's modulus E, yield stress s_y, strain at the yield point e_y, fracture stress s_f, fracture strain e_f and compressive fracture angle q_c are listed. Test runs on pure La sample was stopped without reaching fracture.

Sample	Volume Fraction	E (GPa)	s_y (MPa)	e_y(%)	s_f(MPa)	e_f(%)	q_c (^{o})
$La_{54}Cu_{16}Ni_{16}Al_{14}$	0.95 ≤ 0.03	38.6	308.9	0.73	612.5	1.87	0
$La_{56}Cu_{15}Ni_{15}Al_{14}$	0.8 ≤ 0.05	56.8	403.9	0.70	634.7	1.35	21
$La_{58}Cu_{14}Ni_{14}Al_{14}$	0.21 ≤ 0.01	38.8	-	-	596.3	1.45	40
$La_{62}Cu_{12}Ni_{12}Al_{14}$	0	36.9	-	-	560.7	1.28	45

continue to increase, yielding of the composite occurs at a stress of 404 MPa and finally fail at a fracture stress of 635MPa and a total strain of 1.35%. Sample LC (with 0.95 volume fracture of crystalline phases) showed similar behavior as LI2 but fracture with a much longer strain of 1.9%.

Figure 5 revealed the characteristic vein pattern on the fracture surface of the monolithic amorphous sample. With increase volume fraction of crystalline phases in the matrix, the fracture surface showed shallower and thinner vein pattern. The dispersed crystalline phases seem to be responsible for the promoting plastic deformation in the composites, which is not observed in the fully amorphous samples loaded under the same conditions. The crystalline phases present in the composite can affect the localized deformation in the glassy matrix. For low volume fraction of crystalline phases, the phases may impede shear band propagation by acting as pinning centers or by inducing redistribution or branching of shear bands. For LC alloy where it has an almost crystalline structure, the improvement in strength and ductility might be due to the intrinsic properties of the phases itself. Further investigations are needed.

The presence of crystalline phases in the amorphous matrix affects the compressive fracture angle of the system. The compressive fracture for the monolithic amorphous sample takes place along the maximum shear plane, which is inclined by about 45^o to the direction of compressive load. For the composite samples, the compressive fracture angle decreases with increase volume fracture of crystalline phases. LC composite with the most amount of crystalline phases fracture along a plane nearly parallel to the compressive axis.

IV CONCLUSION

A study on the monolithic amorphous metal and composite has been investigated. It was shown that with increase amount of crystalline phases, the fracture stress and total failure strain increases. The compressive stress-strain curves also show work-hardening behavior. The crystalline phases also affect the compressive fracture angle of the system. This suggests that properties of composite are better than that of monolithic metallic glass.

ACKNOWLEDGEMENTS

This research is supported by the Singapore-MIT Alliance (SMA).

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