Effects of Composition Changes on Mechanical Properties of Iron Based Metallic Glass Ribbon

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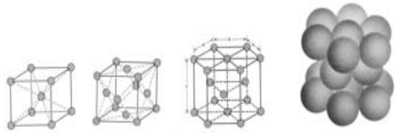
ABSTRACT

Vickers micro-hardness indentations, tension and notch toughness tests, as well as controlled strain experiments via bending over mandrels of different diameter have been performed on two different chemistries of Fe-based (Fe-Si-B) metallic glass ribbons. Vickers microhardnesses of 1020 +/- 125 and 1045 +/- 20 were obtained on $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ for the air side and wheel side, respectively. The $Fe_{78}Si_9B_{13}$ exhibited 910 +/- 100 and 1030 +/- 40, respectively. Tensile strengths of the $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ were 2000 MPa +/- 100 and 1640 MPa +/- 35 for $Fe_{78}Si_9B_{13}$, consistent with the difference in microhardness, although somewhat less than the strength predicted from micro-hardness. The notch toughnesses were similar (e.g. 89 +/- 0.9 $MPam^{1/2}$ for the former, 94.5 +/- 5.5 $MPam^{1/2}$ for the latter) although the lower strength ribbon was consistently tougher despite its lower microhardness and tensile strengths. SEM examination of notch toughness fracture surfaces revealed some differences in fractography between these samples. The "bend over mandrel" tests revealed the $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ to fracture when bent over a one mm radius in contrast to the $Fe_{78}Si_9B_{13}$ which simply deformed at this, and smaller mandrel radii.

INTRODUCTION

Common Crystal Structures – Exhibit Long Range Order

Amorphous Metal Structure – No Long Range Order



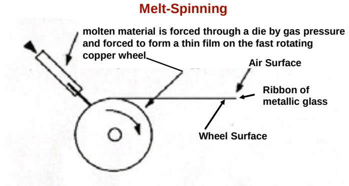
Bubble Raft Model showing Crystalline Structure

Bubble Raft Model showing Amorphous Structure

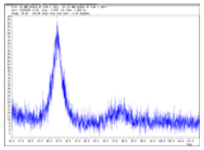
MATERIALS & METHODS

Two different compositions of Fe-based amorphous ribbons were produced via melt spinning using a chilled copper rotating wheel. The cooling rate of about 10^5 K/s was applied. The resulting ribbons were 20 mm width and had a thickness of approximately 30 μm and 38 μm for the Tough Ribbon and Brittle Ribbon respectively. The chemistries of two ribbon were $Fe_{78}Si_9B_{13}$ and $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ at. %, for the Tough and Brittle ribbons, respectively.

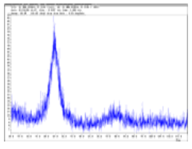
Melt-Spinning



XRD Analysis



a) Brittle Ribbon, Air Side



b) Tough Ribbon, Air Side

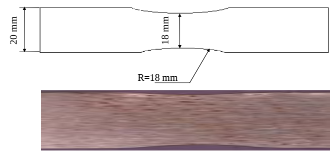
Mechanical Testing

1- Microhardness Tests

- BUEHLER micro-hardness tester with a load of 200 g

2- Uniaxial Tensile Testing

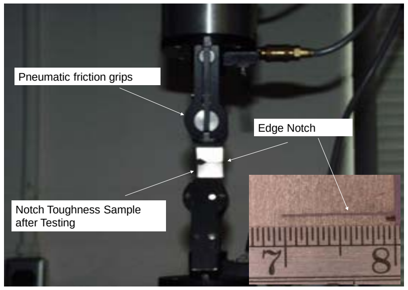
- Instron Model 1125 universal testing machine: initial strain rate 10^{-3} s^{-1}
- Hourglass shape Tension specimens with K_t = 1.25 were used



The Hourglass shape specimen with K_t = 1.25 used in Tension Test

3- Notch Toughness Testing

- The notch was placed using a slow speed diamond impregnated wire saw with a root radius of 110 μm
- Instron Model 1125 universal testing machine with pneumatic friction grips was used

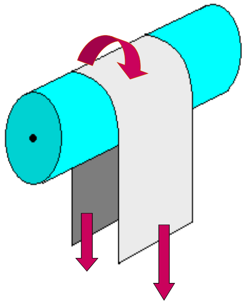


4- Bending over Mandrel Tests

- Bend over mandrel tests were conducted on both batches of ribbon.
- Initial tests used a mandrel diameter of 19.05 mm.
- The samples were sequentially bent over smaller diameter mandrels until permanent deformation or fracture occurred.
- This test produces a controlled strain :

  $\varepsilon = t/2\rho$, where t = ribbon thickness, ρ = mandrel radius
- The corresponding stress:

  $\sigma = E\,\varepsilon$, where E = modulus of elasticity



RESULTS SUMMARY

1- Microhardness Tests

- Microhardness measurements and the estimated compressive strengths

	Brittle Ribbon		Tough Ribbon	
	Air Side	Wheel Side	Air Side	Wheel Side
Microhardness, (kg/ mm²)	1020 ± 125	1045 ± 20	910 ± 100	1030 ± 40
Microhardness, (GPa)	10.006	10.251	8.927	10.104
Compressive Strength, (MPa)	3335	3417	2976	3368

2- Uniaxial Tensile Testing

- Tensile Strength of Brittle and Tough Ribbon

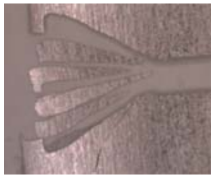
	Brittle Ribbon	Tough Ribbon
Thickness, μm	38	30
Gage Width, mm	18.0	18.0
Tensile Strength, MPa	2000 ± 100	1640 ± 35

Fracture of Hourglass Shape Tension Sample For Tough Ribbon

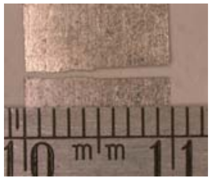
3- Notch Toughness Testing

- The Notch Toughness for Brittle and Tough Ribbon

	Brittle Ribbon	Tough Ribbon
Notch Toughness, MPa $m^{1/2}$	89 ± 0.9	94.5 ± 5.5



a) Brittle Ribbon



b) Tough Ribbon

Fracture of Notch Toughness Samples

4- Bending over Mandrels with Different Diameters

- The Controlled Strain ε, and the Corresponding Stress σ, for Brittle and Tough Ribbon

	Brittle Ribbon		Tough Ribbon	
Mandrel Diam., mm	Strain	Stress, MPa	Strain	Stress, MPa
19.05	0.002	219	0.0016	173
12.7	0.003	329	0.0024	260
5.6	0.0068	746	0.0054	589
1.98	0.02 (*)	2111 (*)	0.0152	1667
1.19	X	X	0.0252	2773
0.50	X	X	0.60 (+)	6600 (+)

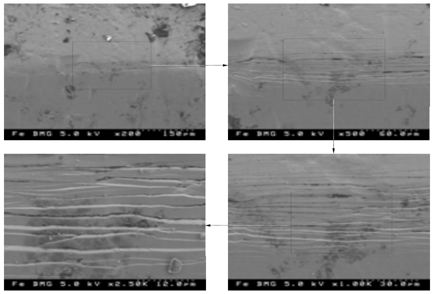
(*) Fracture of the Brittle Ribbon Sample

(+) Permanent Deformation of the Tough Ribbon Sample

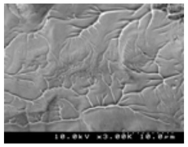
Fractography

- Optical Stereo-microscopy was used to capture the fracture appearance of the tested samples
- SEM was used to examine the shear bands as well as the fracture surfaces of the tested specimens

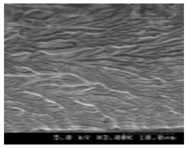
SEM Views of Shear Bands in Tough Ribbon Bent over 0.5 mm mandrel



Fracture Surfaces of Ribbon Samples Tested in Tension

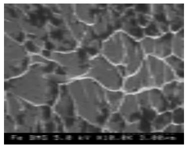


a) Brittle Ribbon Sample
σ_f = 2073 MPa

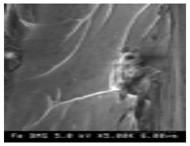


b) Tough Ribbon Sample
σ_f = 1663 MPa

Fracture Surfaces of Ribbon Samples Tested in Notch Toughness



a) Brittle Ribbon Sample
Kq = 88.3 MPa $m^{1/2}$



b) Tough Ribbon Sample
Kq = 96.4 MPa $m^{1/2}$

CONCLUSIONS

- The composition of the Ribbon has a Significant Effect on the Mechanical Properties as well as the fracture morphology of the Ribbon
- SEM examination of notch toughness fracture surfaces revealed some differences in fractography between these two batches of Ribbon

FUTURE WORK

- Evaluate the Mechanical Properties of Ribbons at Elevated Temperatures
- Study the Effects of Annealing on the Mechanical Properties of Ribbons

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