Fracture and Fatigue of $Fe_{78}Si_9B_{13}$ Metallic Glass Ribbon

Case Western Reserve University
School of Engineering

Adel B. El-Shabasy [a1], Hala A. Hassan [a2], Wei Hua Wang [b3], and John J. Lewandowski [c4]

a Dept. of Design and Production Eng., Faculty of Engineering, Ain Shams University, Cairo, Egypt
b Institute of Physics, Chinese Academy of Sciences, Beijing100080, People's Republic of China.
c Dept. of Materials Science and Eng., Case Western Reserve University, Cleveland, Ohio, U.S.A.
1-AME10@case.edu 2-HAH6@case.edu 3-WHW@aphy.iphy.ac.cn 4-JJL3@case.edu

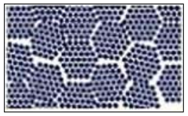
Ain Shams University

ABSTRACT

Vickers microhardness indentations, tension and notch toughness tests, as well as controlled static and cyclic strain experiments via bending over mandrels of different diameter have been performed on 30 μm thick $Fe_{78}Si_9B_{13}$ metallic glass ribbons. Vickers microhardnesses of 910 ± 100 kg/mm² and 1030 ± 40 kg/mm² were obtained for the air side and wheel side, respectively. Tensile strengths were 1640 MPa ± 35, somewhat less than the strength predicted from microhardness. The notch toughness values obtained were 94.5 ± 5.5 $MPam^{1/2}$. The static "bend over mandrel" tests revealed that the ribbons simply deformed via shear banding for mandrel diameter as small as 0.225 mm. Fully reversed flex bending fatigue experiments revealed a fatigue limit of ≥ 260 MPa via testing over mandrels with different radii under cyclic strain control. SEM examination was used to characterize all fracture surface details. These results are discussed in the light of recent work on metallic glass systems.

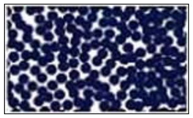
INTRODUCTION

Common Crystal Structures Exhibit Long Range Order & Grain Boundaries



Bubble Raft Model showing Crystalline Structure

Amorphous Metal Structures Exhibit No Long Range Order- No Grain Boundaries

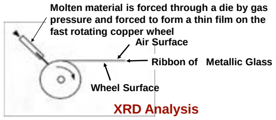


Bubble Raft Model showing Amorphous Structure

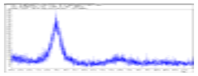
MATERIALS & METHODS

- Fe-based amorphous ribbon was produced via melt spinning.
- The cooling rate of about 10^5 K/s was applied.
- The resulting ribbon had 20 mm width and 30 μm thickness.
- The chemistry of the ribbon was Fe_{78} Si_9 B_{13} at. %.
- XRD analysis revealed the ribbon to be fully amorphous.
- Surface roughness was measured using Confocal microscopy.

Melt-Spinning



XRD Analysis



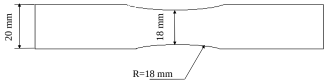
Mechanical Testing

Microhardness Tests

- BUEHLER micro-hardness tester with a load of 100 g.

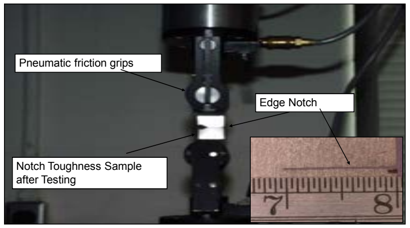
Uniaxial Tensile Testing

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



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.

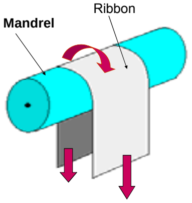


Static Bend over Mandrel Tests

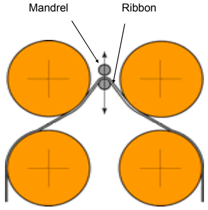
- Bend over mandrel tests were conducted on the ribbons.
- Initial tests used a mandrel diameter of 19.05 mm.
- The samples were sequentially bent over smaller diameter mandrels until permanent deformation or fracture occurred.
- This test produces a controlled strain:
  $\varepsilon = t / 2\rho$, where t = ribbon thickness, ρ = mandrel radius
- The corresponding stress:
  $\sigma = E\,\varepsilon$, where E = 110 GPa (modulus of elasticity)

Cyclic Strain Controlled Fatigue Tests

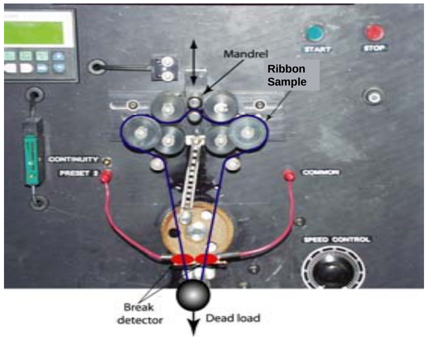
- Cyclic Strain Controlled Fatigue Tests were conducted using Flex Tester.
- Fully reversed fatigue tests (i.e. R = -1), at frequency of 1 Hz.
- Different Mandrel diameters were used (19.05 mm to 1.19 mm).
- For each mandrel diameter, number of cycles to failure were recorded.
- The strain and stress values are similar to Bend over Mandrel Tests.



Bend over Mandrel Test



Cyclic Fatigue Test



Flex tester used to conduct cyclic fatigue tests on the $Fe_{78}Si_9B_{13}$ ribbon. Cyclic frequency = 1 Hz. Break detector automatically detects failure and stops cycle counter.

RESULTS SUMMARY

Surface Roughness Analysis via Confocal Microscopy

Roughness Measurements	Air Side	Wheel Side
RMS Roughness, (μm)	3.8	1.6
Average roughness, (μm)	2.9	1.2

Mechanical Behavior

Mechanical Properties	Air Side	Wheel Side
Microhardness, (kg/ mm²)	910 ± 100	1030 ± 40
Microhardness, (VHN), (GPa)	8.9	10.1
Compressive Strength, (VHN/3), (MPa)	2976	3368
Average Compressive Strength, (MPa)	3172	
Tensile Strength, (MPa)	1640 ± 35	
Notch Toughness, (MPa $m^{1/2}$)	94.5 ± 5.5	
Bend over Mandrel Stress, σ_b, (MPa)	$2770 < \sigma_b < 6600$	

RESULTS SUMMARY

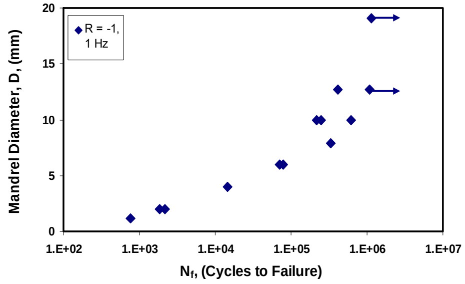
Bend over Mandrels with Different Diameters

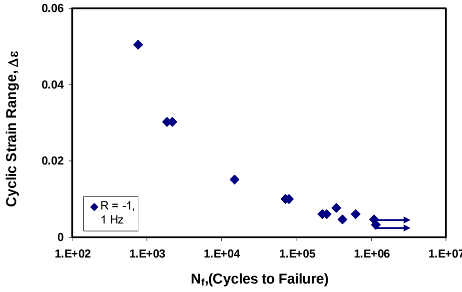
Controlled Strain ε, and the Corresponding Stress σ, for tested Ribbon

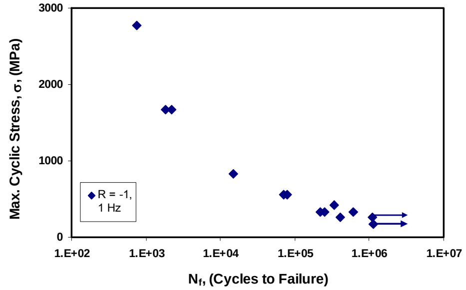
Mandrel Diam., mm	Strain, ε	Stress, σ MPa
19.05	0.00157	173
12.7	0.00236	260
9.92	0.00302	333
7.92	0.00379	417
5.95	0.00504	555
3.96	0.00758	833
1.98	0.01515	1667
1.19	0.02521	2773
0.50	0.06 (+)	6600 (+)
0.225	0.13 (+)	14667 (+)

(+) Permanent Deformation of the Tested Ribbon Sample

Cyclic Strain Controlled Fatigue Results

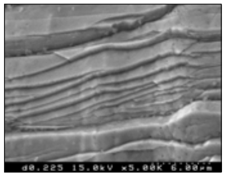




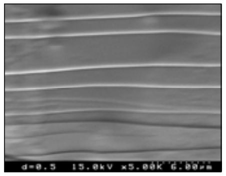


Fractography

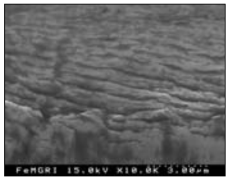
High Resolution SEM was used to examine the shear bands as well as the fracture surfaces of the tested specimens



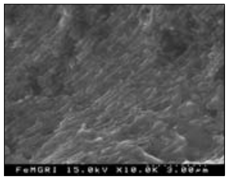
Shear Bands in Ribbon Bent over 0.225 mm mandrel



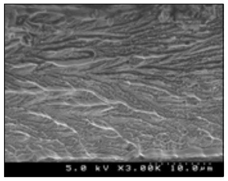
Shear Bands in Ribbon Bent over 0. 50 mm mandrel



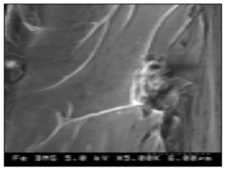
Coarse Fatigue Striations in Ribbon Tested in Cyclic Fatigue Test Using Mandrel Diameter of 1.19 mm



Fine Fatigue Striations in Ribbon Tested in Cyclic Fatigue Test Using Mandrel Diameter of 9.92 mm



Fracture Surface of Ribbon Sample Tested in Tension
σ_f = 1663 MPa



Fracture Surface of Ribbon Tested in Notch Toughness
Kq = 96.4 MPa $m^{1/2}$

CONCLUSIONS

- Bend over mandrel tests show permanent deformation at strain > 2.5 %.
- The cyclic fatigue tests revealed fatigue limit ≥ 260 MPa.
- The ribbons show significant plasticity via extensive shear banding.
- Shear bands & fatigue striation spacing is ƒ (mandrel diameter).

FUTURE WORK

- Evaluate the Mechanical Properties of Ribbons at low Temperatures.
- Study the Cyclic Fatigue Properties at different R Ratio.

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