Fatigue and Toughness of Niobium-Silicon Alloys

David M. Herman and John J. Lewandowski

Materials Science and Engineering, Case Western Reserve University

ABSTRACT

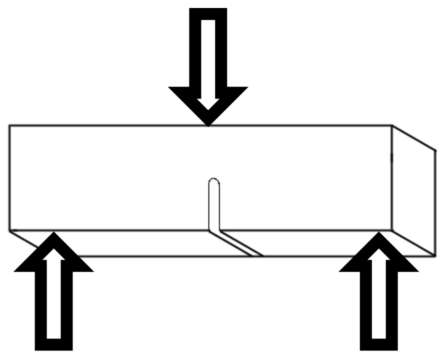
Advanced aerospace materials continue to be developed in order to address the continuing need for high temperature materials that retain high strength at high temperatures. An important property of any high temperature aerospace engineering material is its resistance to fatigue crack growth and toughness both at room temperature and elevated temperatures. In this work, the Center for Mechanical Characterization of Materials at CWRU and the unique equipment housed therein is being utilized to mechanically evaluate the fatigue crack growth properties of advanced Niobium Silicon alloys. The poster will present experimental work that has been performed to determine the fatigue crack growth resistance and toughness of these alloys at room temperature and high temperatures. Detailed examination has been performed on the alloys in order to correlate the mechanical properties to the microstructures. Analysis included Scanning Electron Microscopy and Laser Confocal Microscopy.

Testing Performed

- Analysis of microstructures
- Notch toughness
- Fatigue crack growth
    - Room temperature and 550ºC threshold
    - Room temperature and 550ºC Paris slope
    - Room temperature and 550ºC fracture toughness
    - Analysis of fatigue crack path

Toughness

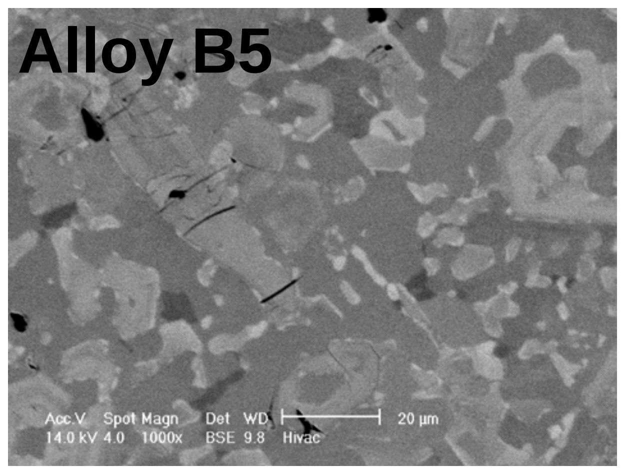
- Notch toughness
    - 3 point bend testing, a/w = 0.45-0.55
    - Notched to 200 μm root radius
    - Displacement rate = 0.2 mm / min
    - RT testing
- Fatigue crack growth toughness
    - Fatigue crack grown to catastrophic failure
    - Room temperature and 550ºC

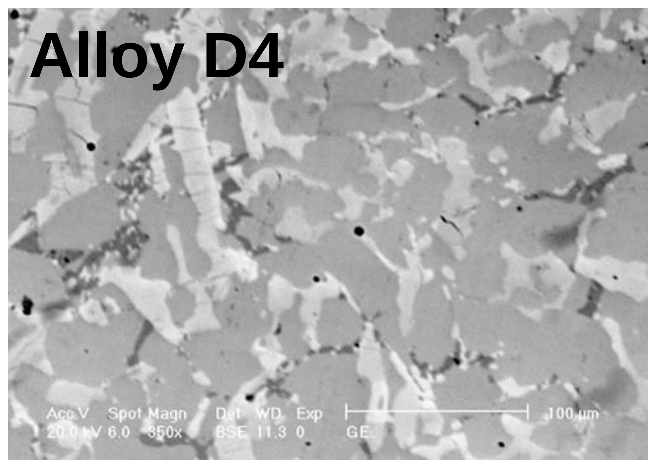


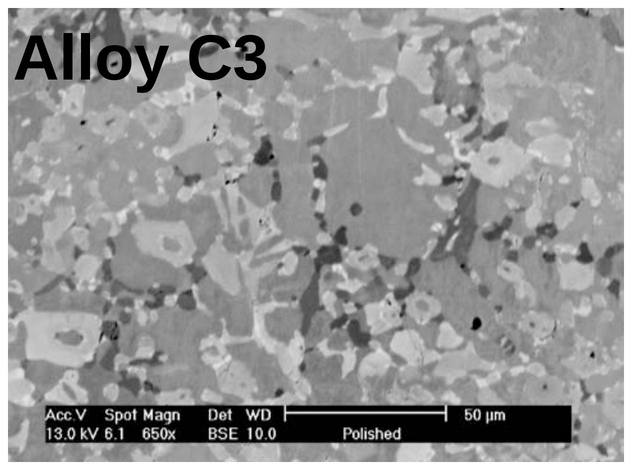
Fatigue Crack Growth

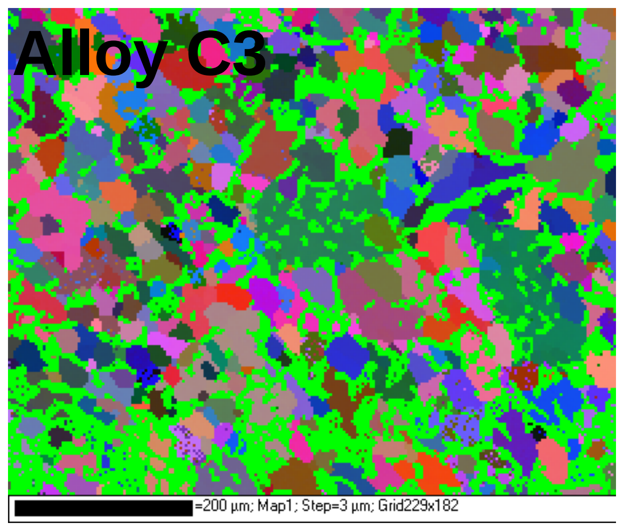
- 3 point bend testing, R = 0.1
- Room temperature, 550ºC
- Test frequency 16-18 Hz
- da/dN monitored via DC potential drop
    - Current 3.5 amps

Microstructures



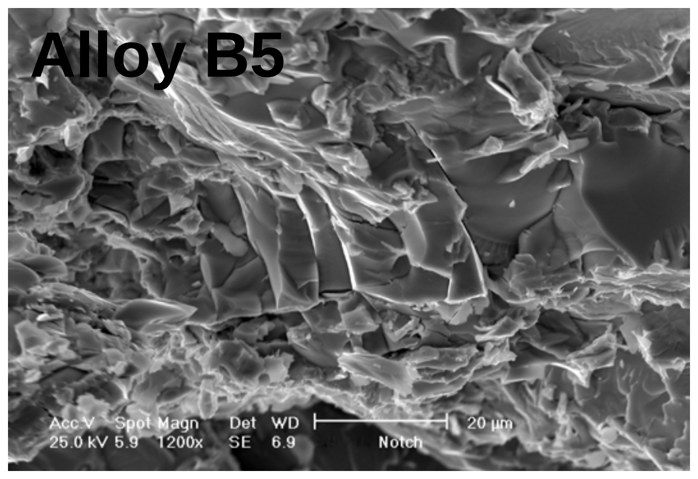


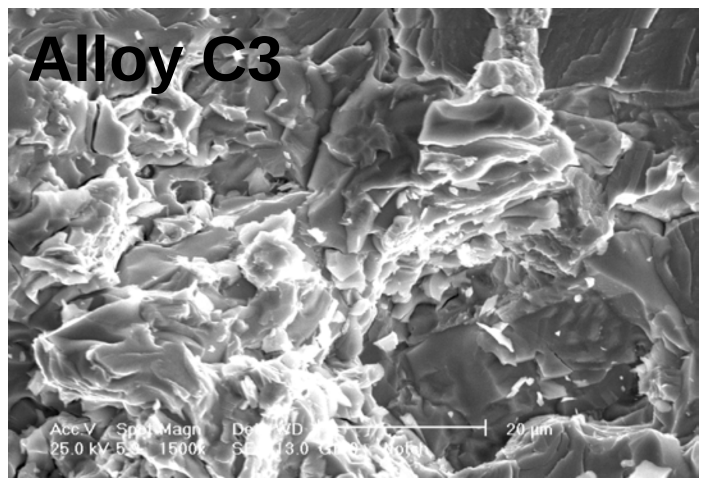




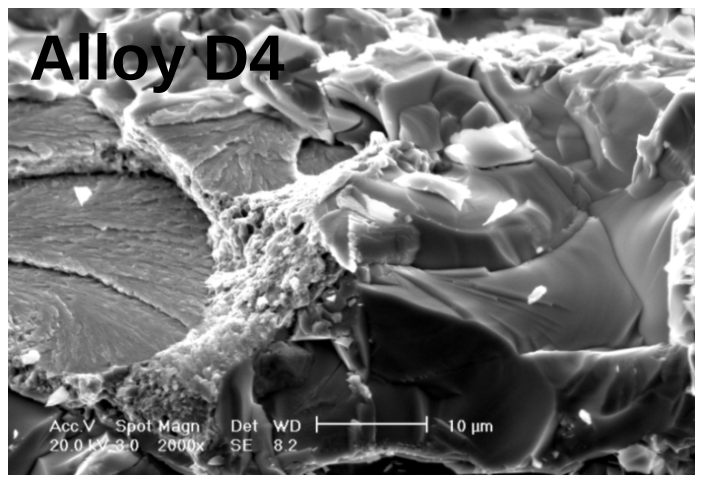
- SEM BSE images taken + EBSD analysis on Alloy C3
- Volume fraction analysis via systematic point count ASTM E562-95

Notch Toughness



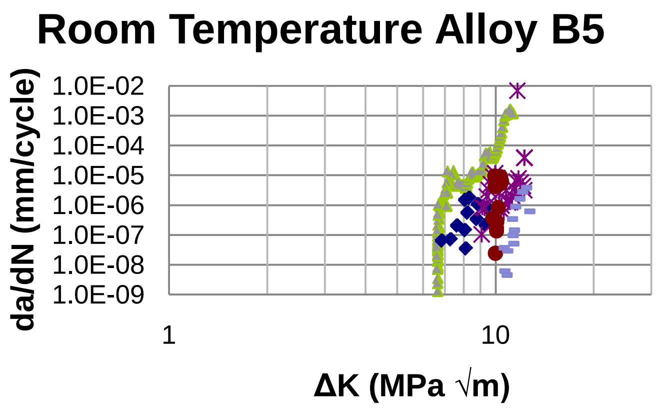


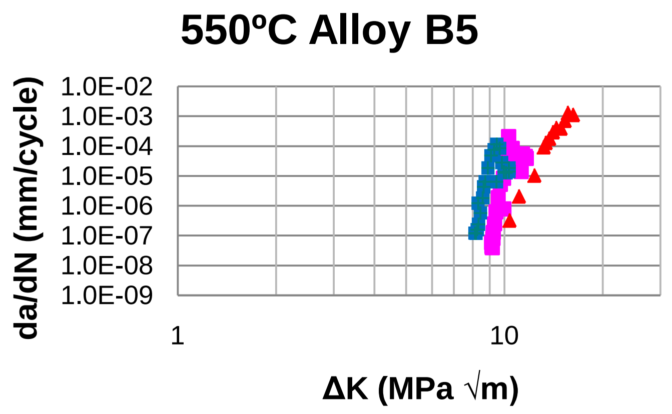
Sample ID	Notch Toughness (MPa √m)
Alloy B5	15.0, 19.3
Alloy C3	16.5, 16.1
Alloy D4	16.7

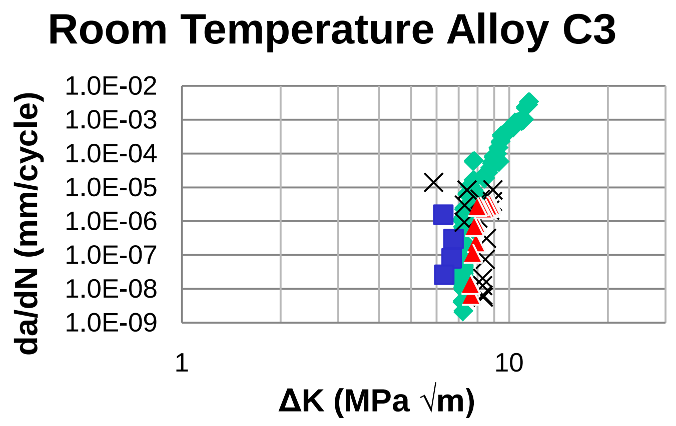


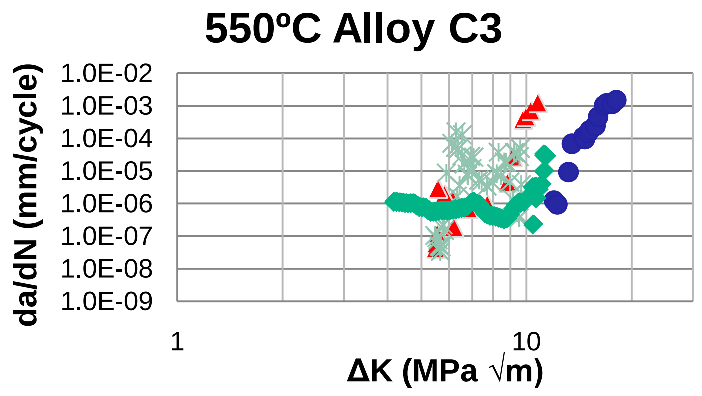
- Niobium matrix fails via cleavage/brittle fracture
- Some evidence of local plasticity
- Secondary phases fail in a brittle manner

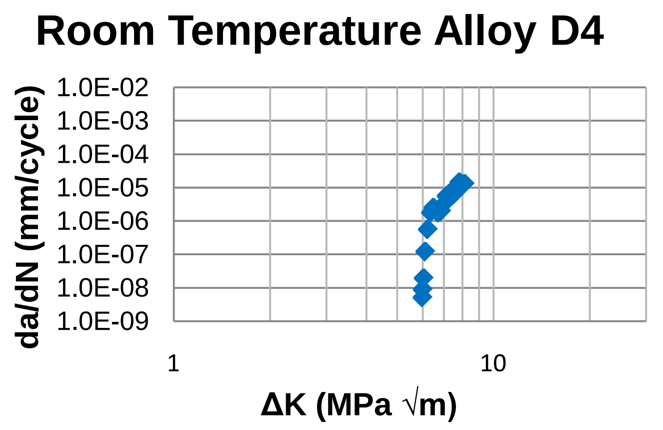
Fatigue Crack Growth

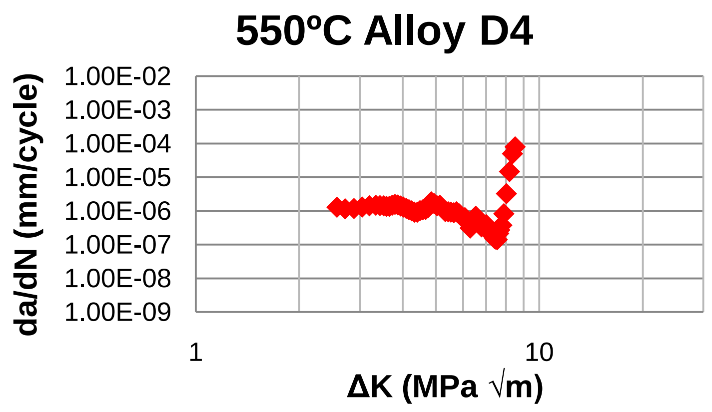




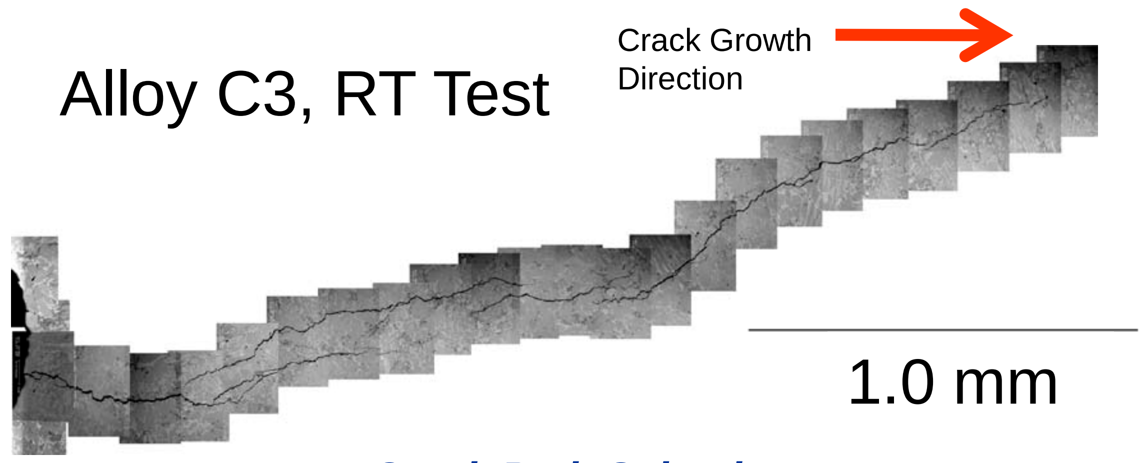








Sample ID	RT Threshold (MPa √m)	550ºC threshold (MPa √m)	RT K_q (MPa √m)	550ºC K_q (MPa √m)	RT Paris Slope	550ºC Paris Slope
Alloy B5	8.1 ± 1.4	7.6 ± 1.9	20 ± 10.6	15.5 ± 3.5	13.8	14.2
Alloy C3	7.2 ± 0.6	5.5 ± 0.1	12.4	20 ± 4.2	20.5	16.8
Alloy D4	6.0	<3	--	TBD	9.8	TBD



Crack Path Selection

- Fatigue crack path imaged via SEM
- Extensive crack bridging and branching

Fracture Path Analysis

- Fatigue crack growth to threshold at RT, 550ºC
- SEM BSE images taken of total crack length
- Fatigue crack path determined and quantified
    - Cracking through Nb phase
    - Cracking through brittle (i.e. silicide, Laves) phases
    - Cracking along Nb/Brittle phase interfaces
- Quantified fracture path roughness and branching
    - Linear roughness quantified
    - Extent of crack bridging/branching determined
- RT Crack path selects secondary phases and interface

	Microstructure Constituents	Volume %	Crack Path Selection
Alloy B5	Matrix	53	35
	Secondary Phases	47	60
	Interface	NA	5
Alloy C3	Matrix	58	49
	Secondary Phases	42	44
	Interface	NA	6
Alloy D4	Matrix	64	54
	Secondary Phases	36	42
	Interface	NA	4

Conclusions

- Nb-Si Alloys tested exhibited toughness greater than 15 MPa √m
    - Nb matrix fails via cleavage and brittle fracture
    - Secondary phases fail via brittle fracture
    - Toughness greater than ceramics
- Fatigue behavior determined at room temperature and 550ºC
    - Fatigue Threshold is higher than ceramics
    - Paris slope is lower than ceramics
    - RT fatigue crack path selects secondary phases/interface

References

1. R.O. RITCHIE. *Mechanisms of fatigue-crack propagation in ductile and brittle solids*. International Journal of Fracture. 100: 55–83, 1999.
2. ASTM E 647. *Standard Test Method for Measurement of Fatigue Crack Growth Rates. ASTM, Philadelphia, PA.*

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