Effects of Notch Radius, Test Temperature and Mixed Mode Loading on the Toughness of a Nano-Structured Al Composite

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ABSTRACT

A nano-structured $Al_{89}Gd_7Ni_3Fe_1$ composite was processed by extruding atomized amorphous powders at different extrusion ratios (ER). The extruded composite contained fcc α-Al, intermetallic particles, and a small amount of τ_1 particles. The effects of changing the notch radius from fatigue pre-crack to 100 µm on mode I fracture toughness were studied at different test temperatures (*e.g.* 298K and 498K). The effects of mixed mode (I/II) loading using different offset ratios were also studied at these temperatures. Increasing the test temperature showed a significant effect on the fracture toughness for both mode I and mixed mode I/II conditions. Fracture surfaces were examined to reveal the nature of failure of such nano-structured Al composite materials at these loading conditions.

Objectives:

- Determine the effects of notch radius and test temperature on the fracture toughness of the present materials.
- Determine the effects of mixed mode loading on the fracture toughness of nano-structured Al composite at room temperature (RT) and 498K.

INTRODUCTION

- Nano-crystalline metallic materials and metal–matrix composites (MMCs) both provide unique, but different combinations of properties.
- Nano-crystalline metallic materials typically possess high yield strength, as predicted by the Hall–Petch relationship [1, 2]. Many techniques have recently been developed to produce tubes, wires, and disks with nano-scale features.
- MMCs possess attractive properties such as high specific stiffness, modulus, and strength, although their damage tolerance (*i.e.* toughness) is typically not high enough to permit their more widespread use.
- Combining the two concepts of MMCs and nano-crystalline materials in the form of nano-structured MMCs have the potential to provide combinations of properties not possible with conventional structural materials.
- Nano-structured MMC's (NMMC's) can be produced by ball milling, spray deposition, and laser deposition. The present work uses the consolidation and subsequent extrusion of amorphous metal powders to produce NMMC's.

EXPERIMENTAL

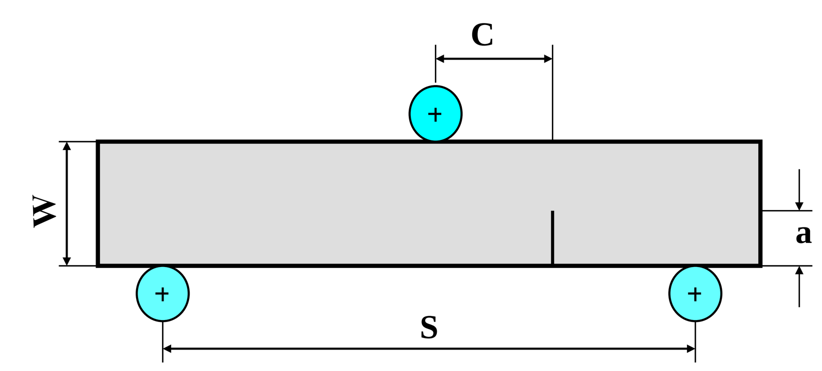
Materials:

Atomized amorphous $Al_{89}Ni_3Gd_7Fe_1$ powders were placed inside an aluminum can and were extruded into rods of 15.9 mm diameter. The rods contained the extruded powder and a 2 mm thick Al ring. Hot extrusion of the amorphous powders produces an ultra-fine structure consisting of high volume fraction of nano-structured intermetallic particles (*e.g.* 100 nm thick), embedded in the aluminum matrix.

Testing conditions:

- 3PB specimen: 100 µm and 450 µm notch root radius.
- Notched toughness, fatigue pre-cracked toughness.
- Test temperatures: 298K and 498K.
- ATS Inc. temperature controlled cabinet ±1K.
- MTS 20 Kip servohydraulic rig, MTS 458.20 controller, FTA control software.
- Specimens fatigue pre-cracked at 20 Hz, sinusoidal wave, load ratio (R) =0.1.
- Fatigue crack length measured with metallic foil KRAK© (KG-A05)-gages monitored by a Fractomat model 1288 crack measurement system.
- Mixed Mode: different offset ratio (2C/S) were studied 0.2, 0.5, and 0.67.

Sample Configuration

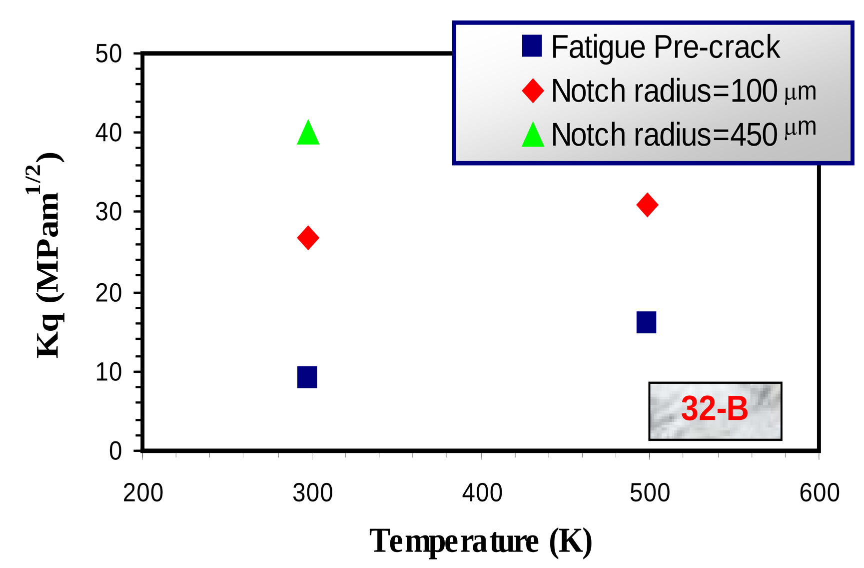


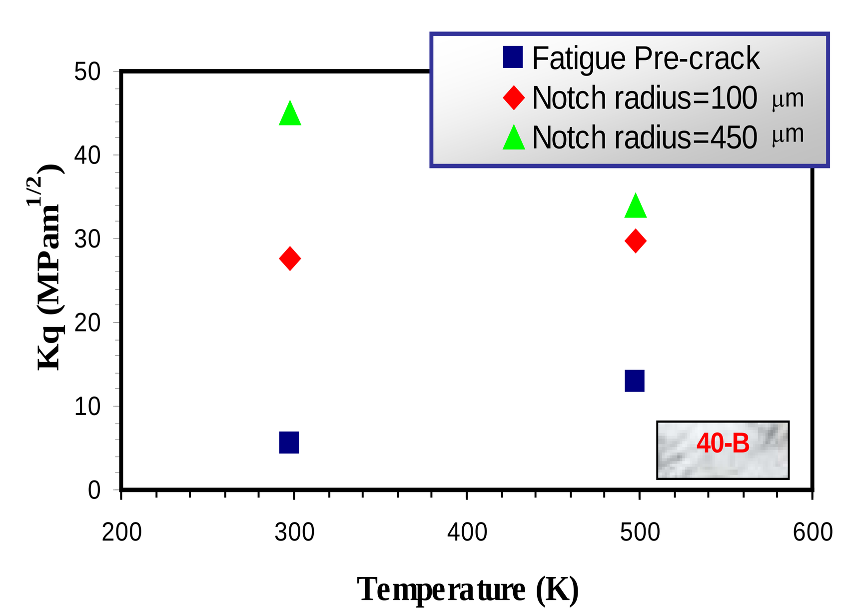
Mixed mode I/II configuration. Ratio 2C/S controls the mode mixity.

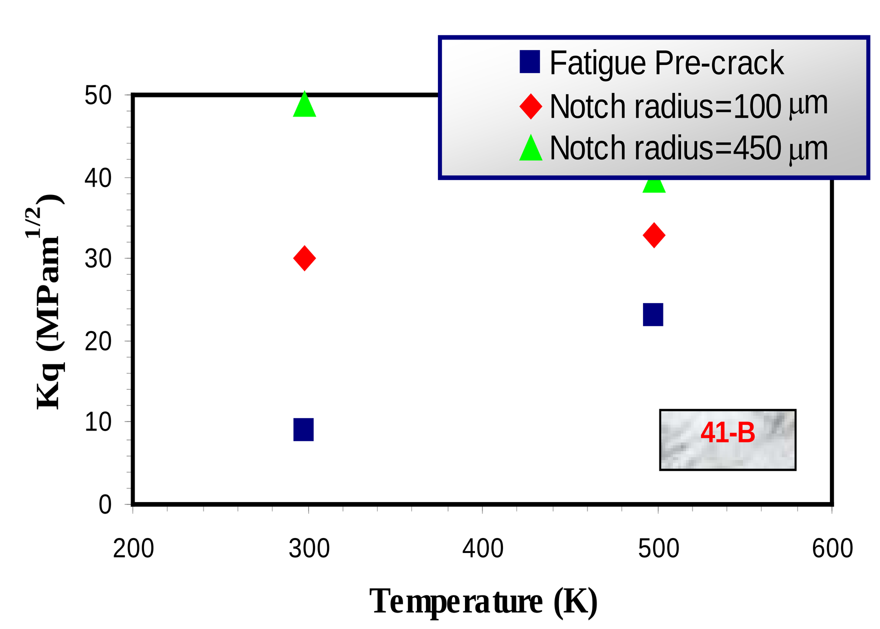
RESULTS

Mode I Fracture Toughness

Effects of Test Temperature and Notch Radius





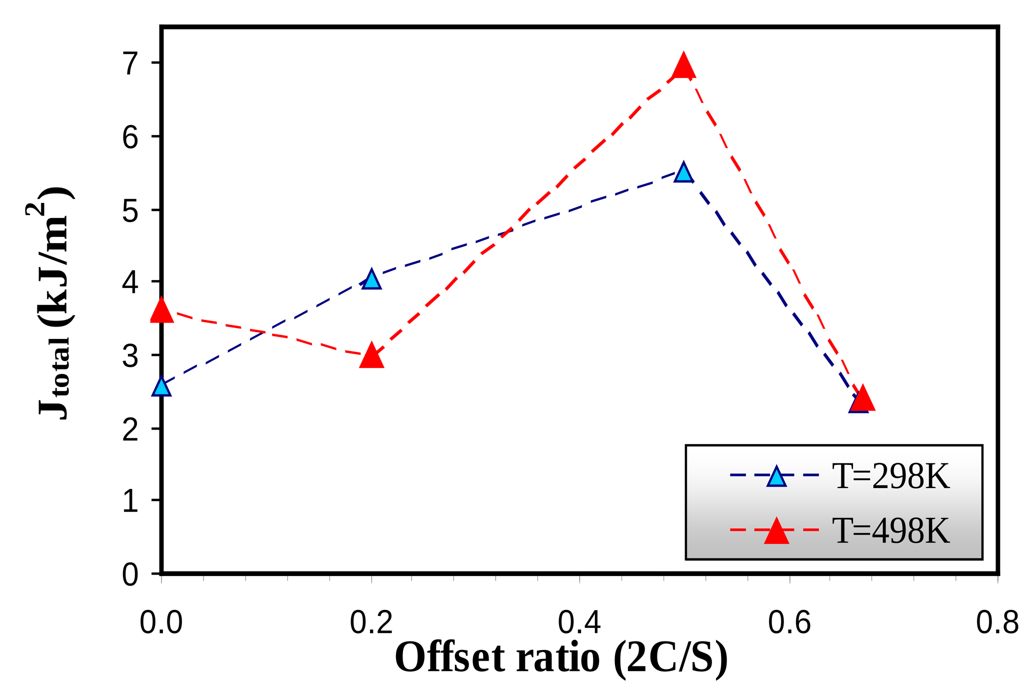


★ Significant effects of notch radius on toughness.

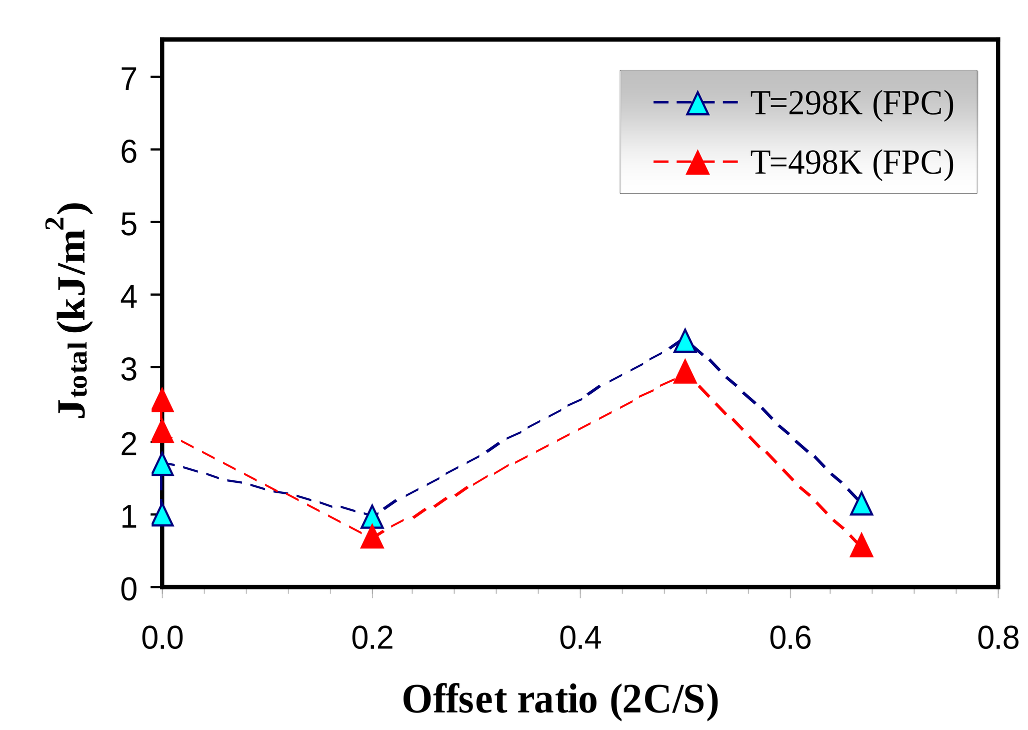
★ Increase in test temperature increases toughness (except for 450 µm notch root radius).

Mixed Mode Fracture Energy

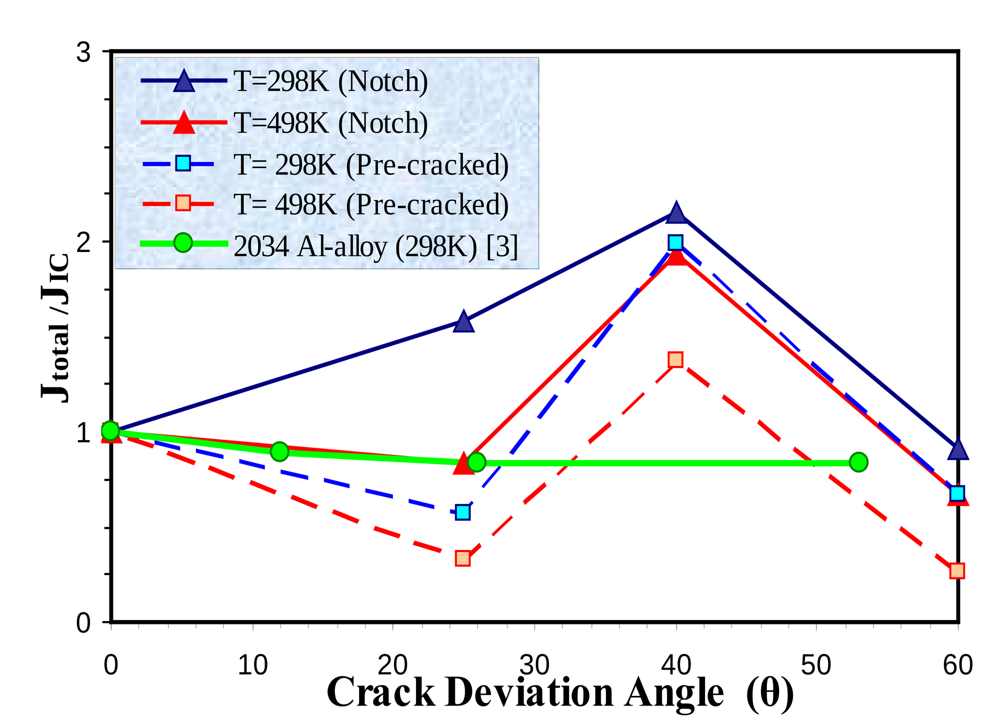
Notched Samples



Fatigued Pre-cracked Samples



Comparison between the nano-structured Al- composite and conventional Al-alloy under different Mode mixity (I/II)



★ Increasing Mode mixity (I/II) initially increases the total fracture energy.

★ Further increases in Mode mixity (I/II) decreases the total fracture energy

ACKNOWLEDGEMENTS

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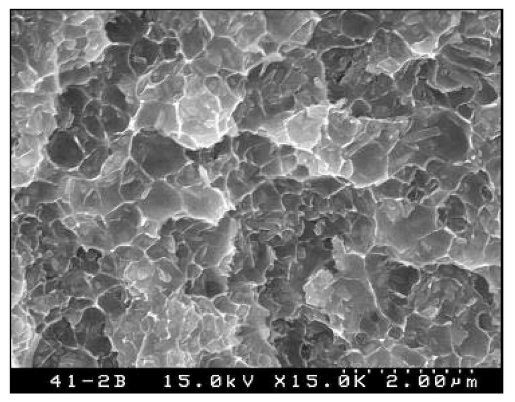
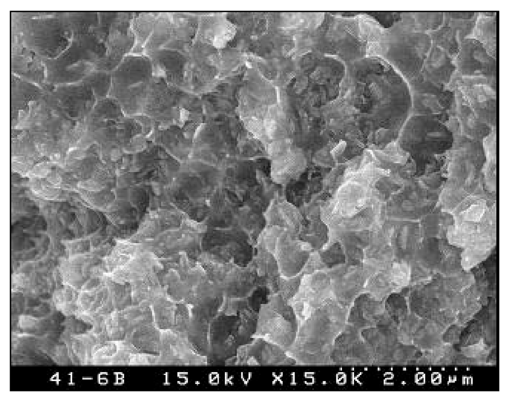
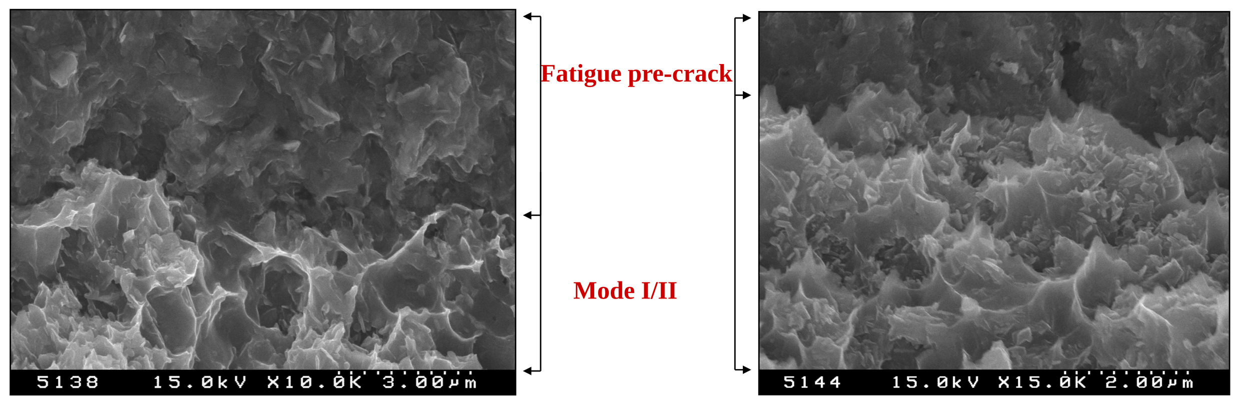
SEM FRACTOGRAPHY



Mode I: T=298K, average dimple size=49µm



Mode I:T=498K, average dimple size=80µm



Mode I/II : T=498K, offset ratio=3/6 | Mode I/II : T=498K, offset ratio=4/6

★ Different mixed mode fracture appearance for 3/6 vs. 4/6 offset ratios

RESULTS SUMMARY

Material	Offset ratio	θ	K_I (MPam^1/2)	K_{II} (MPam^1/2)	K_C, K_{eq} (MPam^1/2)	J_I kJ/m²	J_{II} kJ/m²	J_{Total} kJ/m²
Nano Al-composite (notch)	0	0	16	0	16	2.56	0	2.56
	0.2	25	19.9	3.06	20	3.96	0.09	4.05
	0.5	40	23	4.8	23.6-26	5.29	0.23	5.52
	0.67	60	14.7	4.22	14.7-15.2	2.16	0.18	2.34
Nano Al-composite (FPC)	0	0	13	0	13	1.69	0.00	1.69
	0.2	25	9.7	1.7	10	0.94	0.03	0.97
	0.5	40	18.2	2.4	18.6	3.31	0.06	3.37
	0.67	60	10	3.6	10.6	1.0	0.13	1.13
2034 Al-alloy [3]		0	37	0	37	17.8	0	17.8
		13	35.2	5.1	35.57	16.1	0.34	16.44
		26	33.7	9	34.88	14.76	1.06	15.52
		53	28.9	18.4	34.26	10.86	4.4	15.26

CONCLUSIONS

- Significant effects of notch radius on the facture toughness.
- Increasing test temperature increases the toughness.
- Increasing Mode mixity increases the fracture energy of nano-structured Al-composite, while decreasing the fracture energy of 2034 Al-alloy.
- Fractography shows locally ductile/ dimpled fracture surface. Dimple size increases with increasing test temperature (Mode I).
- Different fracture surface appearance for Mode I vs. Mode I/II.
- Changing the offset ratios changed the fracture surface appearance.

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