# Mechanical Behavior of Nano-structured Aluminum Composites

Case Western Reserve University
Case School of Engineering

## Hala A. Hassan [1,2], Adel B. El-Shabasy [1,2], John J. Lewandowski [2]

[1] Dept. of Design and Production Eng., Faculty of Eng., Ain Shams University, Cairo, Egypt
[2] Dept. of Materials Sci. and Eng., Case Western Reserve University, Cleveland, OH, USA

Ain Shams University
Faculty of Engineering

## ABSTRACT

The mechanical behavior of nanostructured aluminum composites was determined in tension, toughness, and fatigue at temperatures ranging from room temperature to 260°C. The materials were produced by extrusion of amorphous aluminum powders to create a nanostructured aluminum composite with high volume fraction of reinforcement. The resulting material exhibited high strength and excellent high cycle fatigue resistance over a range of test temperatures relevant to high temperature aluminum alloys. The effects of creating a nanostructured composite on the balance of properties will be summarized, along with laminated versions.

## INTRODUCTION

- Nanocrystalline metallic materials and metal–matrix composites (MMCs) both provide unique, but different combinations of properties.
- Nanocrystalline 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 from materials with nano-scale features.
- Nano-structured metal matrix composites (NMMCs) 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 NMMCs with ductile layers have the potential to provide combinations of properties not possible with conventional structural materials.

## EXPERIMENTAL

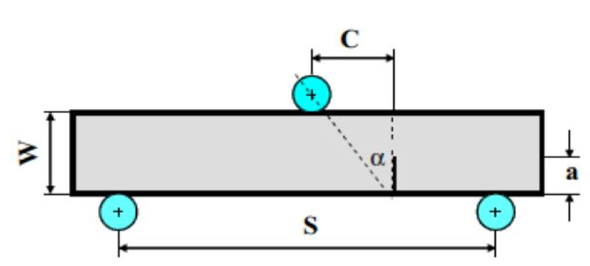
### Materials:

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 aluminum can. Hot extrusion of the amorphous powders produces a composite with high volume fraction of nano-sized intermetallic particles (*e.g.* 100 nm thick) in a nominally pure Al matrix, surrounded by the aluminum can.

### Testing Conditions:

**Mode I and Mode I/II Toughness:**

- 3PB specimen: 100 µm and 450 µm notch root radius.
- Notched toughness, fatigue pre-cracked toughness under Mode I and Mode I/II, at 298K and 498K.
- Fatigued pre-cracked at 20 Hz, sinusoidal wave, load ratio (R) = 0.1.
- Smooth bending and fracture toughness tests were carried out under displacement control (0.5 mm/min).
- Mixed mode fracture toughness was determined using the anti-symmetric 3PB loading configuration and offset ratios (2C/S) of 1/2, 3/6 and 4/6.




**The anti-symmetric three point bending specimen**

**High Cycle Fatigue (HCF):**

- High cycle fatigue at 15 Hz, sinusoidal wave, load ratio (R) of 0.1, 0.33 and -1.
- Rectangular cross-section samples for HCF tests conducted at R = 0.1 and 0.33. Hourglass samples for R = -1.

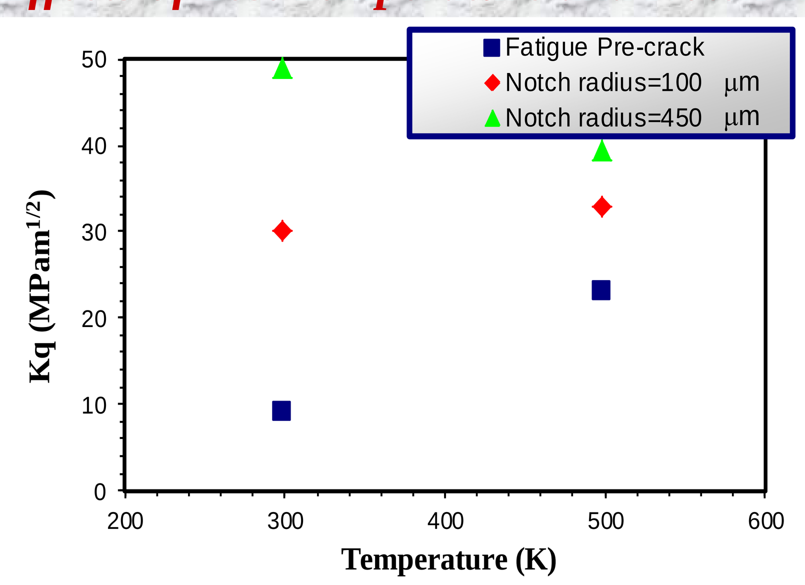
**Temperature and Load Control:**

- ATS Inc. temperature controlled cabinet ±1K.
- MTS 20 and 50 kip closed loop servohydraulic machines, MTS 458.20 controller, FTA control software.

## RESULTS

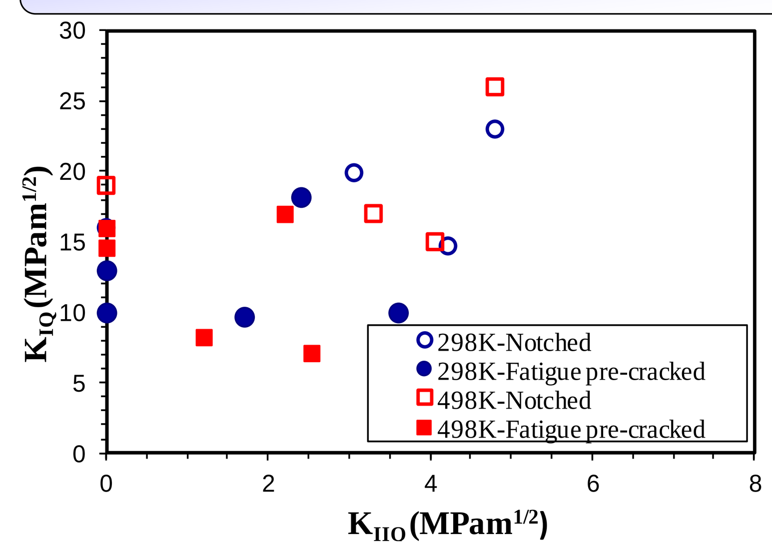
### Mode I Fracture Toughness of Nano-structured Composite

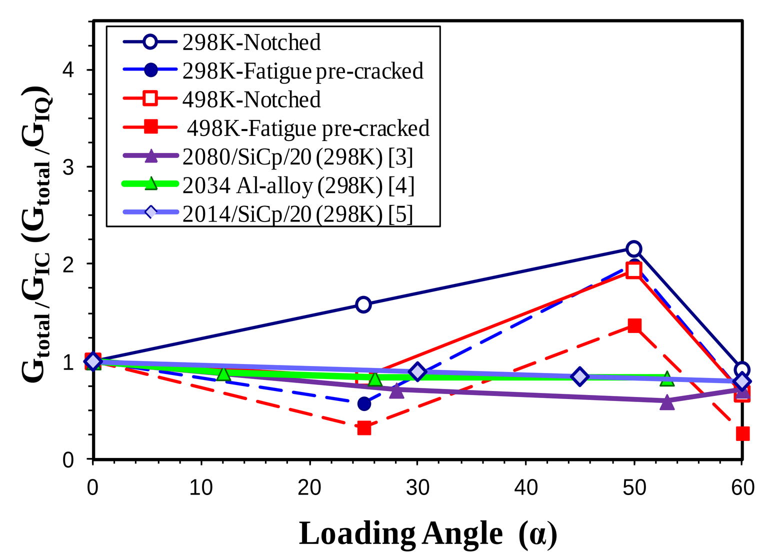
*Effects of Test Temperature and Notch Radius*




- **Significant effects of notch radius on toughness.**
- **Increase in temperature typically increases toughness.**
- **R-curve exhibited at 498K.**

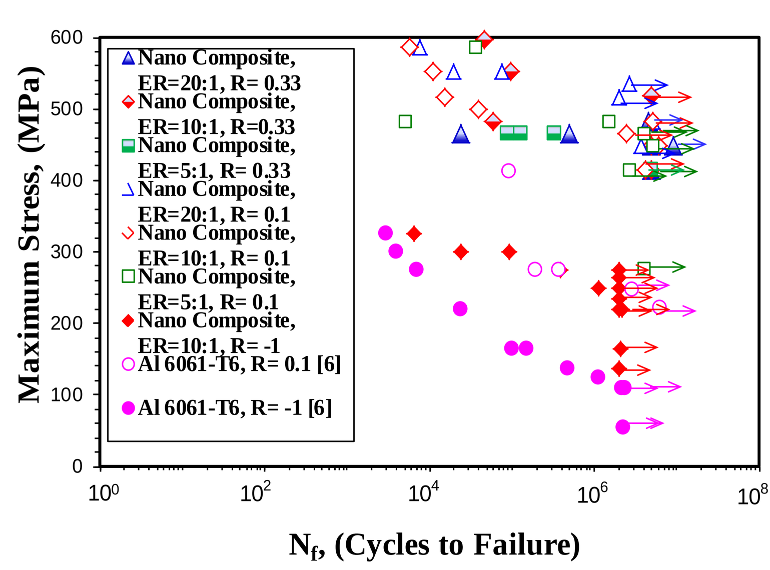
### Mode I/II Fracture Toughness



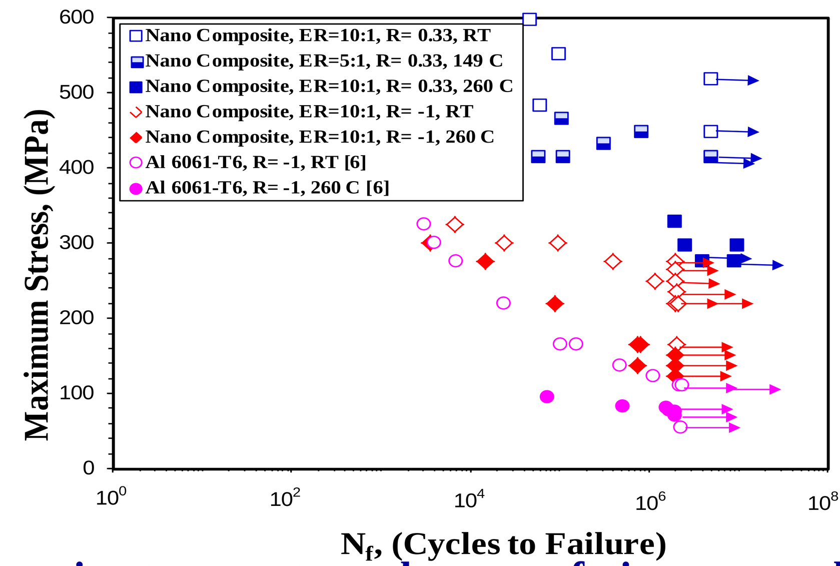




- **Significant effects of mode mixity on $G_{total}$.**
- **$G_{total}$ increases with increasing mode mixity up to 2C/S=0.50.**
- **The conventional Al/SiC$_p$ systems exhibit little effects of mode mixity compared to nano-composites.**
- **Increasing the temperature decreases $G_{total}$.**

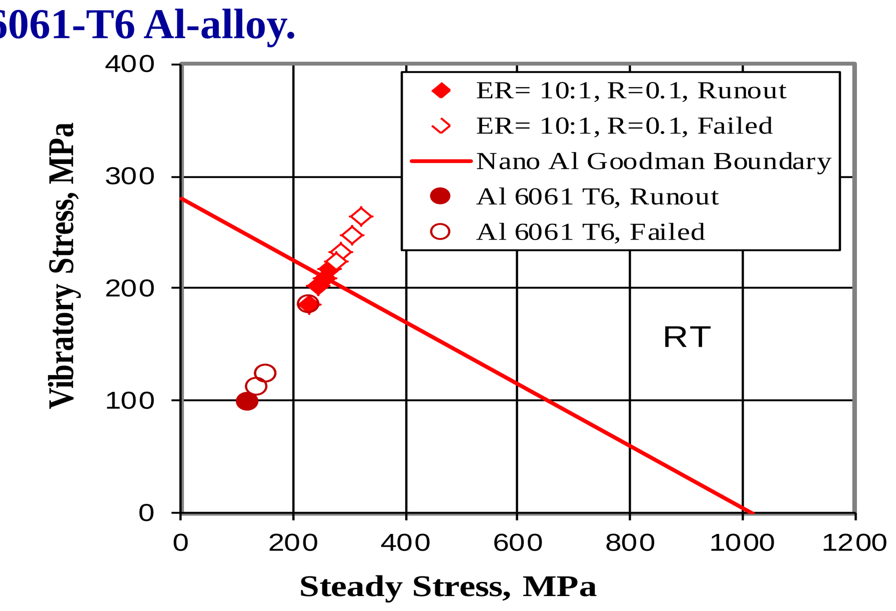
### High Cycle Fatigue




- **Higher ER improved high cycle fatigue resistance.**
- **Nano-composite is significantly better than conventional 6061-T6 Al-alloy.**

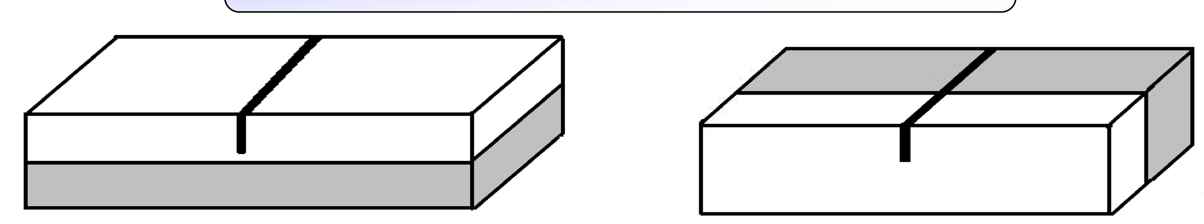



- **Increasing temperature decreases fatigue strength.**
- **Nano-composite is significantly better than conventional 6061-T6 Al-alloy.**

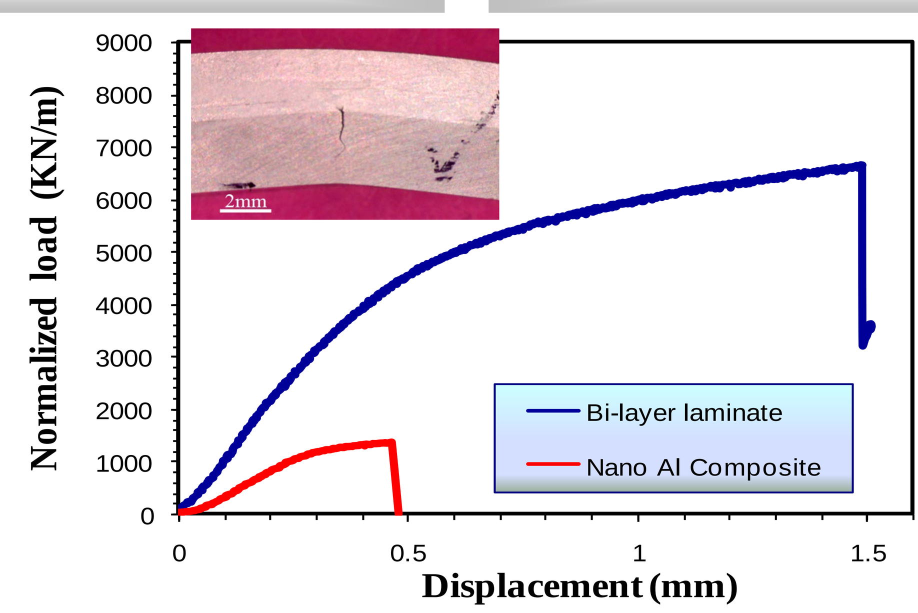



- **Goodman plot of HCF results for nano-composite.**
- **Nano-composite is better than 6061-T6.**

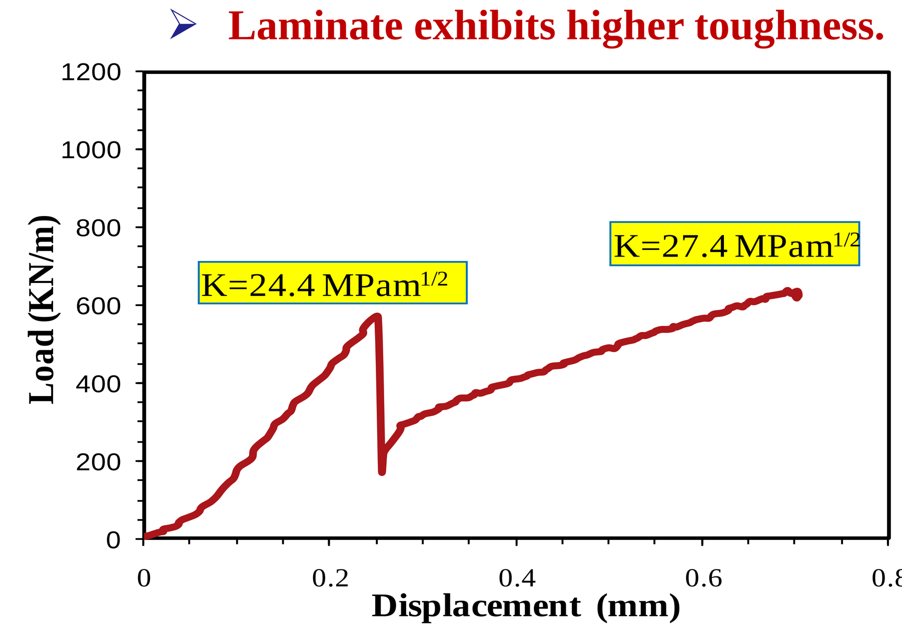
### Laminated Composites



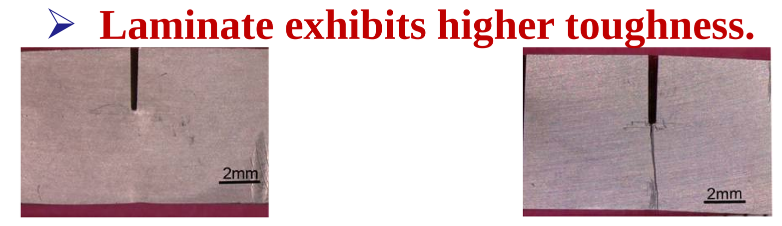
*Crack Arrestor Orientation* *Crack Divider Orientation*




- **Crack arrestor in smooth bending.**
- **Laminate exhibits higher toughness.**

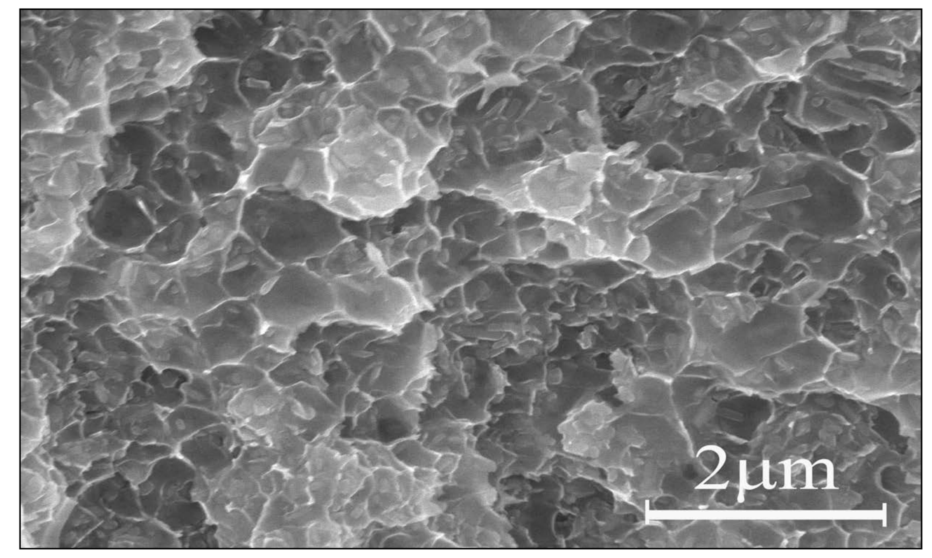



- **Crack divider in notch toughness.**
- **Laminate exhibits higher toughness.**

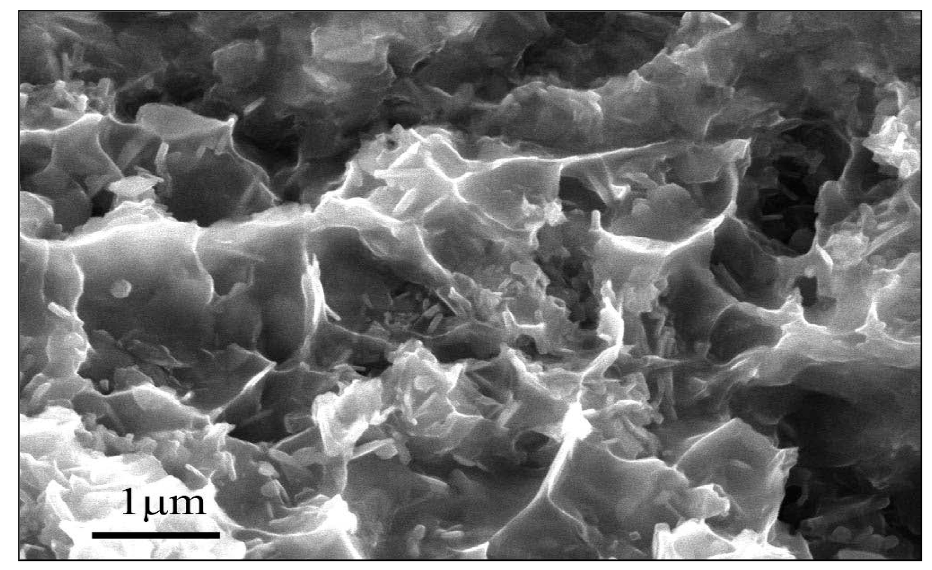


**Al layer side** **Nano-composite side**

### SEM FRACTOGRAPHY




**Mode I, T=298K, average dimple size=0.49µm**




**Mode I/II, T=498K, average dimple size=0.80µm**

## CONCLUSIONS

- Significant effects of notch radius on toughness.
- Increase in temperature generally increases toughness.
- Significant R-curve obtained at 498K.
- Significant effects of mode mixity on $G_{total}$.
- Nano-composite exceeds fatigue performance of 6061-T6.
- Increasing the temperature decreases the fatigue strength.
- Lamination improves toughness.
- Fractography shows locally ductile/ dimpled fracture surface. Dimple size increases at higher temperature.

## REFERENCES

1. D.G. Morris, Materials Science Foundations: Mechanical Behaviour of Nanostructured Materials, vol. 2, Trans Tech Publication Ltd., Uetikon-Zuerich, Switzerland, 1998, 19.
2. H.A. Hassan, J.J. Lewandowski, Mater. Sci. Eng. A 497 (2008) 212–215.
3. H.A. Hassan, Mater Sci. Tech. 27 (7) (2011) 1170–1177.
4. S.V. Kamat, J.P. Hirth, Acta Mater. 44 (1996) 201–208.
5. B. Biner, J. Mater. Sci. 36 (2001) 2505–2510.
6. A.B El-Shabasy, H.A. Hassan, J.J. Lewandowski, Unpublished research, Case Western Reserve University, 2011.

## ACKNOWLEDGEMENTS

- **HAH acknowledges US/Egypt board for 2012/2013 Grant.**
- **HAH thanks Dr. Dingqiang Li for SEM and Chris Tuma.**