FSP SWNT to Increase Thermal Conductivity of Aluminum

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Introduction

Single walled carbon nanotubes (SWNT) **(Figure 1.)** have many remarkable properties. One of which is their excellent thermal conductivity values reaching 6000 W/m-K. By comparison, pure aluminum has a thermal conductivity of ~ 220 W/m-K.

Although SWNT are very thermally conductive, scaling them up from the nano scale to large scale applications has proven to be difficult.

Other research has already concluded that carbon nanotubes (CNT) can withstand the temperatures and stresses involved in friction stir processing (FSP) with aluminum and magnesium substrates [1-3]. Furthermore, significant increases in hardness were observed in the nugget region of the FSP CNT [2,3].

No known research has explored the increase in thermal conductivity of any substrate with FSP CNT or aluminum-CNT metal matrix composites.

Objective

To show that FSP SWNT into aluminum increases the thermal conductivity of aluminum.

Procedure

- SWNT were packed into an 1/8" square aluminum tube in an argon chamber. **(Figure 2.)**
- The tube was sandwiched between two 1/8" sheets of Al 1100 **(Figure 3.)** and was FSP. **(Figure 4.)** Three 10 inch weld passes offset from one another were made at 1400 RPM and 6 IPM to fully distribute the SWNT throughout the nugget region
- The FSP nugget was then rolled down from ¼" to 1/8" **(Figure 4.)** and again down to .050" **(Figure 5.)** and sheared to a ½" width.
- The 1/8" FSP SWNT sample was fractured and observed in a SEM (Zeiss Supra 40 VP field emission). Intact SWNT were observed in the nugget region **(Figures 7-9)**.
- The 1/8" x 18" SWNT sample was tested for thermal conductivity with thermocouples incremented every 6" from one end dipped into liquid nitrogen and compared to a control specimen that went through the same procedure only with pure Al powder **(Figure 11.)**. At ~ 800 seconds, the ends of the samples were taken out of the liquid nitrogen and placed onto a hot plate.

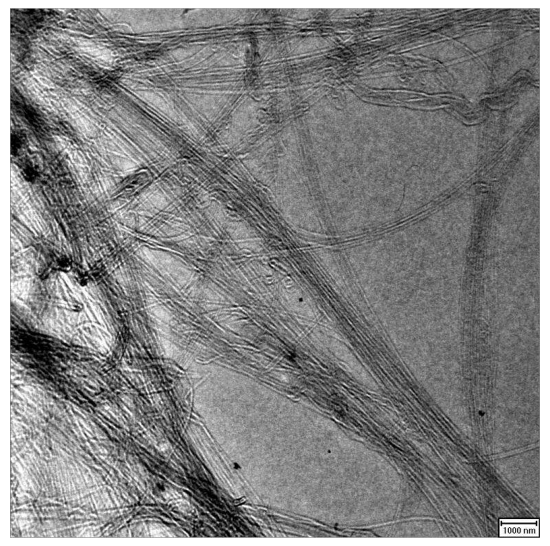

Figure 1. – TEM image of SWNT.

Figure 2. – SWNT packing process.

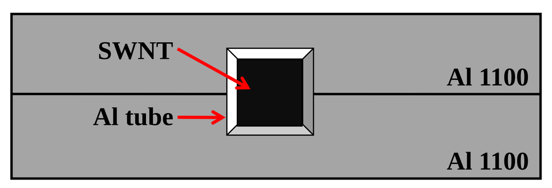

Figure 3. – Cross section of SWNT specimen before FSP.

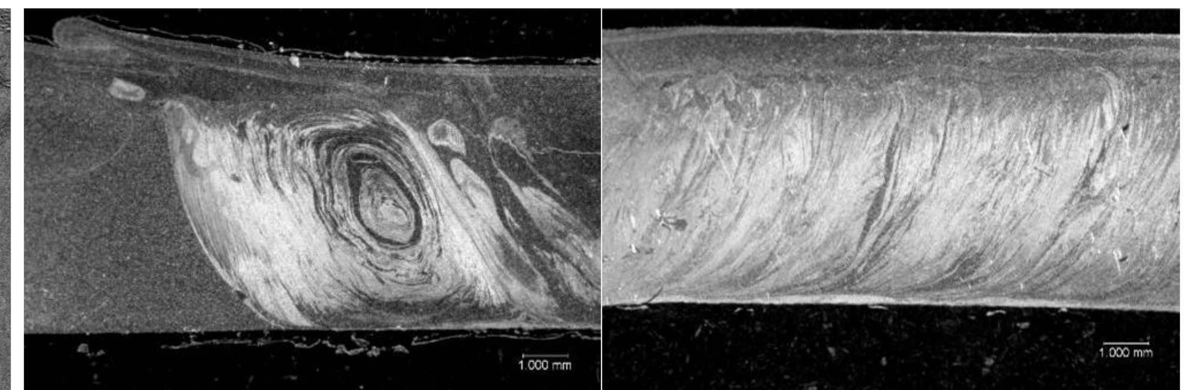

Figure 4. – Cross and longitudinal sections of SWNT specimen after FSP.

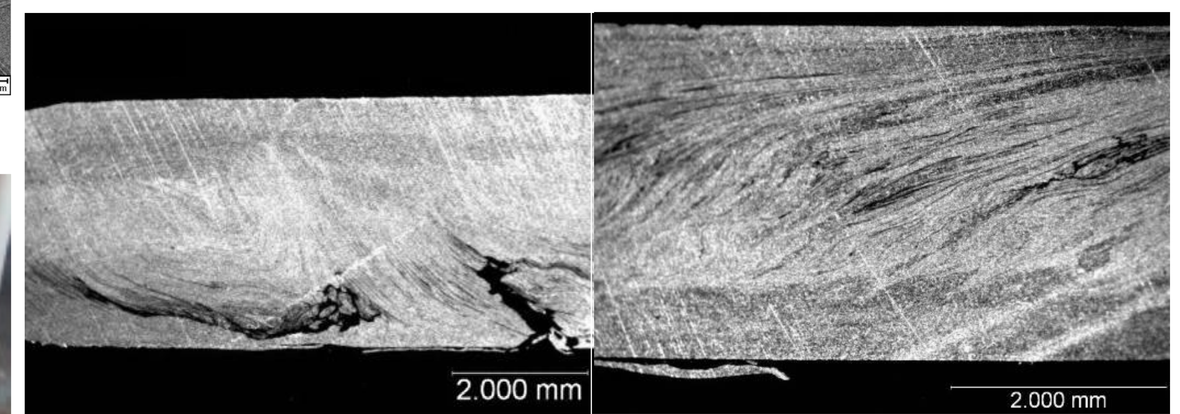

Figure 5. – Cross and longitudinal sections after a 50% reduction in area.

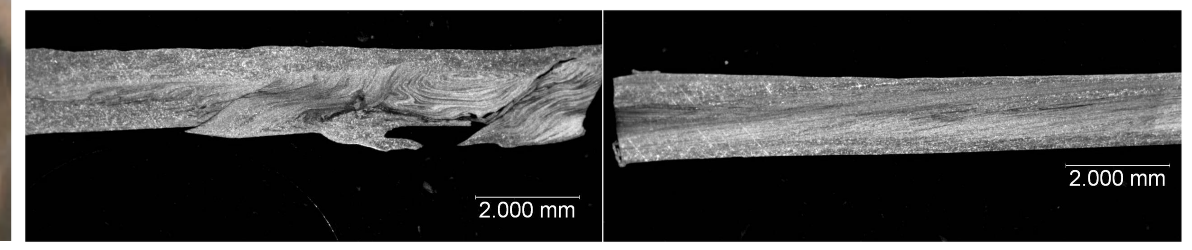

Figure 6. – Cross and longitudinal sections after an 80% reduction in area.

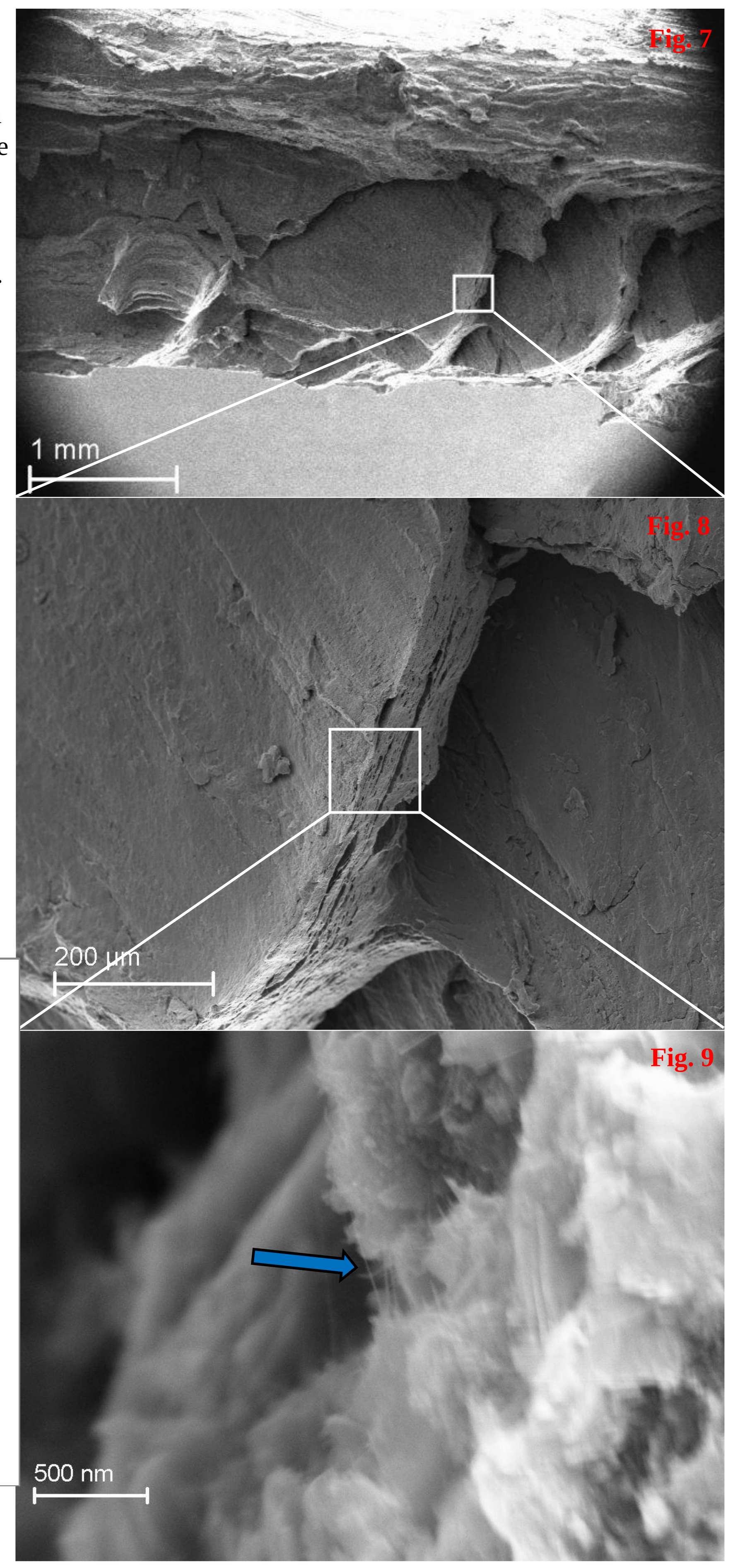

Figure 7. – Fracture surface of 1/8" FSP SWNT sample.
Figure 8. – Location of SWNT within the fracture surface.
Figure 9. – Visible SWNT located on the fracture surface.

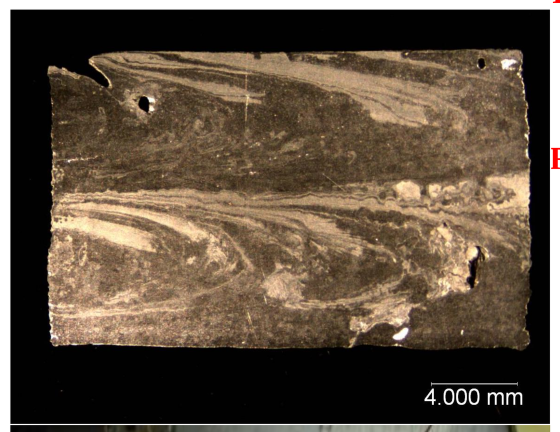

Figure 10. – Surface of .050" SWNT sample showing lamellar structure that occurs during FSP

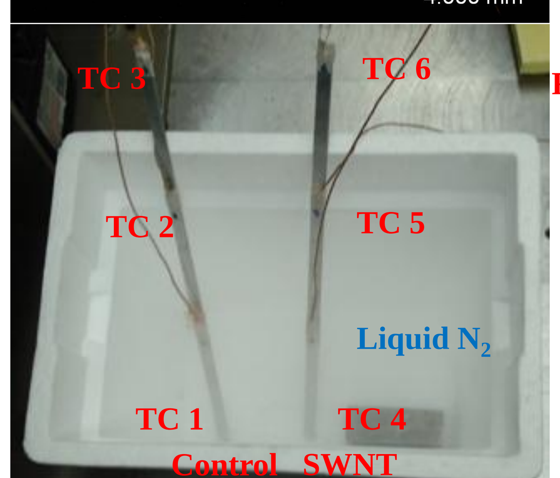

Figure 11. – Setup of thermal conductivity comparison experiment. Thermocouples were placed at 6", 12", and 18" from ends dipped ~1" of liquid nitrogen.

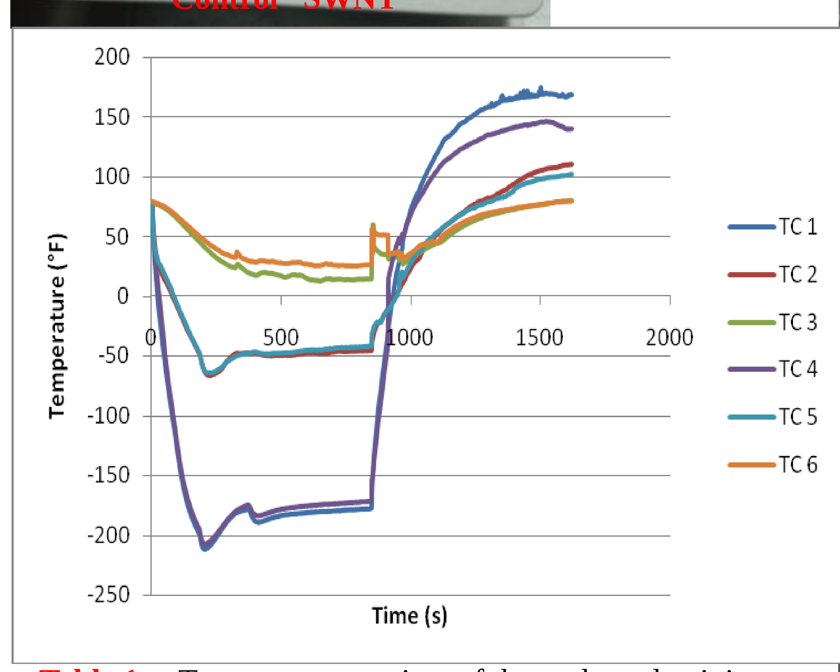

Table 1. – Temperature vs. time of thermal conductivity experiment shown in **Fig. 11.** Ends of the samples were taken out of liquid N_2 at ~ 800 s and placed on a hot plate.

Discussion

- During the rolling process, the FSP SWNT sample began to crack significantly at the surface **(Figure 5.)**. From .a 36% reduction in area, the sample was frequently annealed and hot rolled to close up the cracks **(Figure 6.)**. The cracking indicates a sharp rise in hardness as observed by Morisada et al. [2,3].
- Angle measurement of the longitudinal lamellar structure was ~65° before rolling, ~22° after a 50% reduction, and ~10° after an 80% reduction.
- Thermal conductivity of the 1/8" SWNT sample appeared to be slightly less compared to the control sample. Two known factors may have played a part in this result.
  - Significant cracking during rolling **(Figure 5.)** created large interfaces throughout the sample that would slow the heat transfer in the sample.
  - Poor interfacial bonding between CNT and aluminum in metal matrix composites have been reported [4] which would also slow heat transfer.
- Hot plate thermal conductivity testing was conducted on the surface of the .050" sample, but the sample was too thin and only erroneous values were returned.

Conclusion

- SWNT have been FSP into aluminum without complete deterioration from the temperatures and stresses associated with FSP.
- Rolling FSP SWNT even in some of the softest of aluminum alloys requires frequent annealing and subsequent hot rolling of the samples.
- No increase in thermal conductivity has yet to be observed.

Future Work

- Finding a more precise way to measure thermal conductivity.
- Finding thermal conductivity of a SWNT sample encapsulated by FSW instead of FSP.
- Etching the surfaces of current samples to expose more SWNT to the surface for higher surface thermal conductivities.
- Repeating the procedure for nanocopper and nanosilver powders, diamond particles, multi-walled nanotubes, and electroless plated nanotubes.

Acknowledgements

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