Aligned carbon nanotube (CNT) sheets for thermally conductive pathways in cooling vest for Firefighters

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Presentation Outline

- Introduction
- Purpose of study
  - NORA Priority areas involved.
- Materials & Methods
- Results
- Conclusion
- Future work

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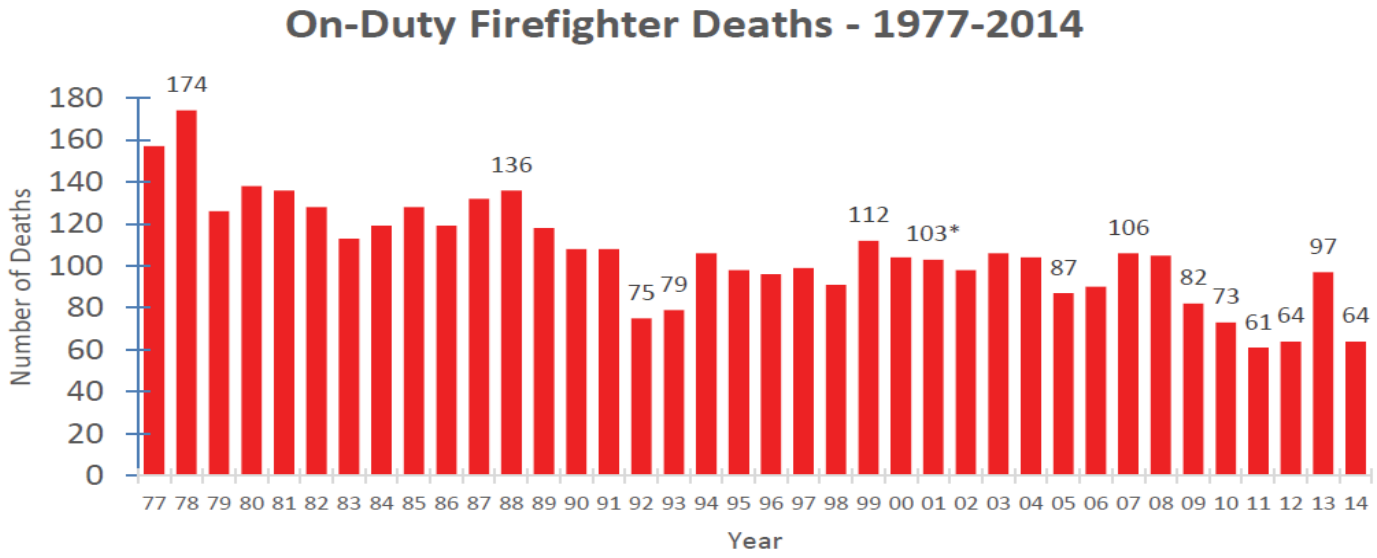
Introduction

- H. J. G. Haynes and G. Stein, “U.S. Fire Department Profile 2013”.
  - NFPA estimates there were approximately 1,140,750 local firefighters in the U.S. in 2013. Of the total number of firefighters 354,600 (31%) were career firefighters and 786,150 (69%) were volunteer firefighters. Most of the career firefighters (71%) worked in communities that protected 25,000 or more people.



* excluding the 340 firefighter deaths at the World Trade Center in 2001

R. F. Fahy, P. R. LeBlanc & J. L. Molis, “Firefighter Fatalities in the United States – 2014”.

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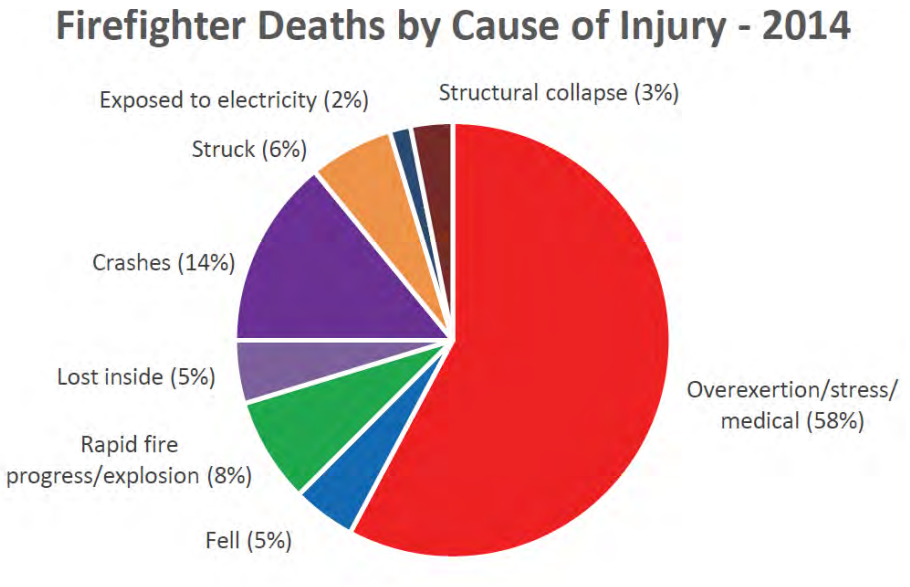
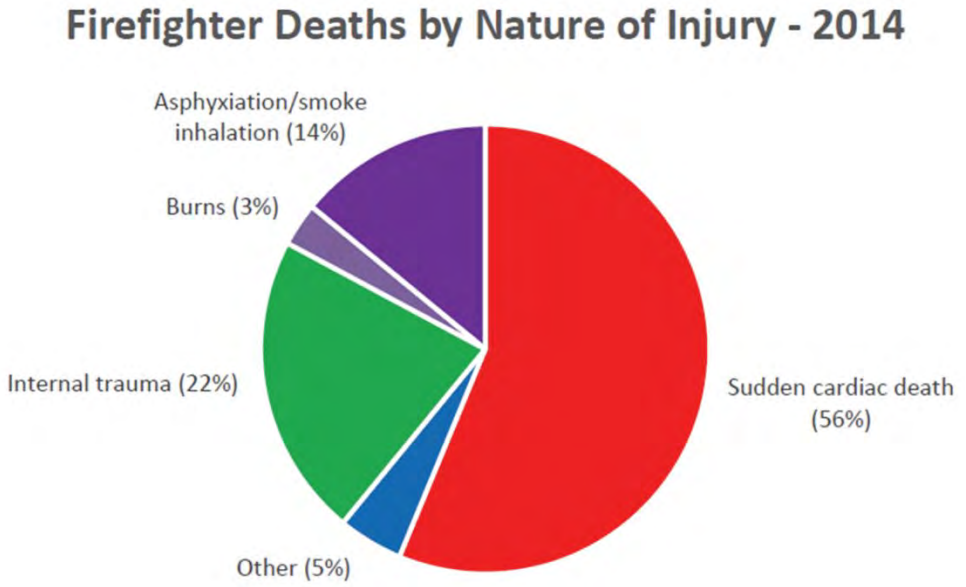
Introduction





R. F. Fahy, P. R. LeBlanc & J. L. Molis, “Firefighter Fatalities in the United States – 2014”.

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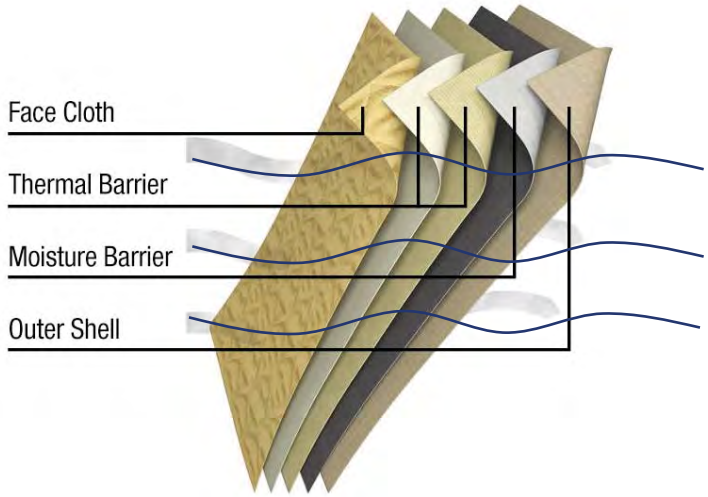
Introduction

- Personal Protective Equipment (PPE)

https://www.heimanfireequipment.com/product_info.php?cPath=7&products_id=597



http://www2.dupont.com/Media_Center/en_US/assets/images/releases/LION_Turnout_Gear_Composition.jpg

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Introduction

- Personal Protective Equipment (PPE) with active cooling
  - Air cooled garments (ACG)
    - Using rotors/fans or compressed air cylinders.
    - Significant weight increase.
  - Liquid cooled garments (LCG).
    - Require pump, heat exchanger, power supply.
    - Liquid pumped through tubing which is susceptible to kinks, ruptures.
  - Phase change material garments (PCG)
    - Have to be positioned near vital organs and large quantities needed to be effective.
    - Do no have an on/off switch and cool on contact.

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Purpose of Study

- To design a cooling vest worn under PPE to provide active cooling via conduction to a heat sink.
- Aims:
  - To manufacture and integrate sheets made of multi-walled Carbon Nanotubes (CNTs) with conventional cooling fabric.
  - Test heat transfer through CNT sheets and CNT/fabric composite.
- Hypothesis:
  - Heat sink could be made of phase change material (PCM) but will be concentrated into a single piece rather than present all along the torso.
  - CNT sheets act as thermally conductive pathways to transport heat from body to a heat sink keeping the entire garment flexible.

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Purpose of Study

- NORA Priority areas involved
  - The development of a cooling vest to direct heat away from firefighters during firefighting will significantly reduce the chances of heat stress related injuries/illnesses.
- NIOSH Public Safety Program Strategic Goals for Intramural Research
  - Strategy Goal 1 - Reduce the incidence of chronic and acute diseases by 15% in firefighters that may be related to occupational exposures such as **heat**, combustion products and other stressors.

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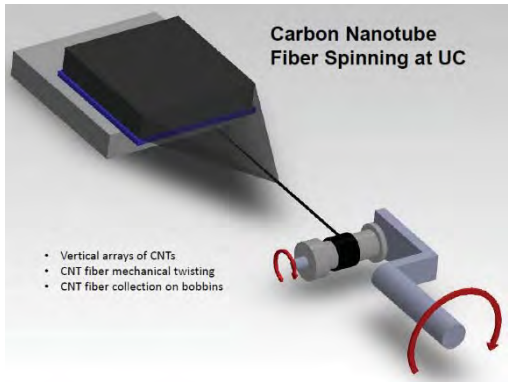
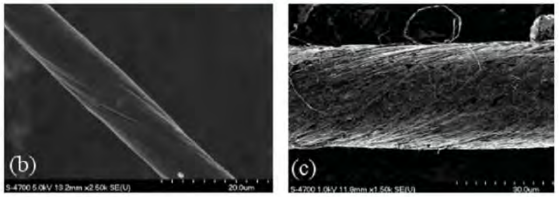
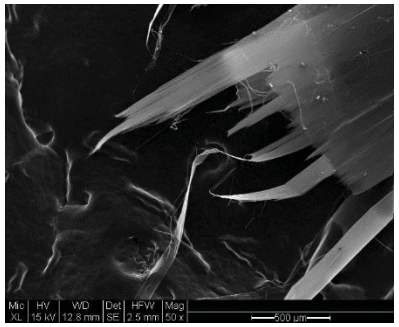
Research @ Nanoworld - University of Cincinnati







- Jakubinek, M.B., et al., Thermal and electrical conductivity of array-spun multi-walled carbon nanotube yarns. Carbon, 2012. 50(1).
- V. Shanov, R. Malik, N. Alvarez et al, “Processing, Characterization, and Application of Carbon Nanotube Sheet”, SAMPE 2012, Session: Carbon Nanotubes, Charleston, SC, October 22-25, (2012).

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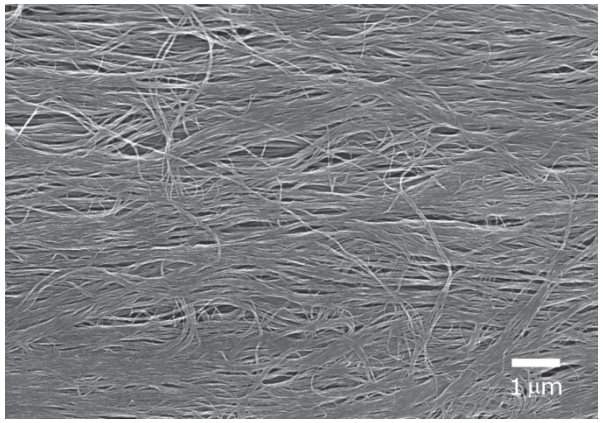
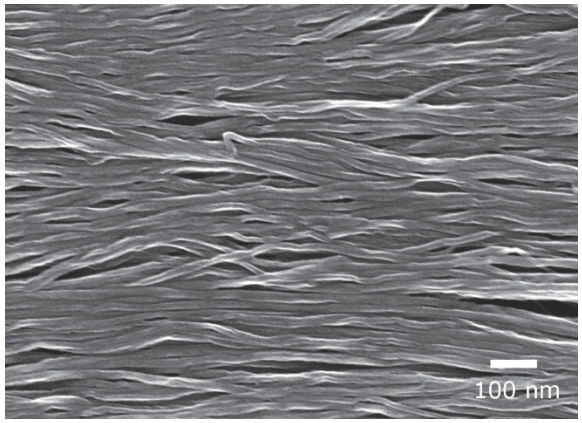
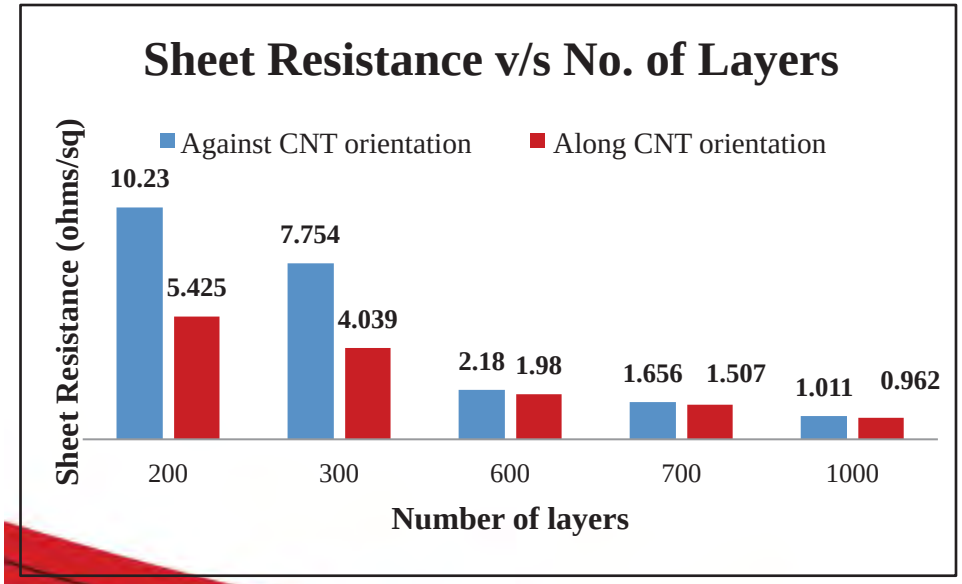
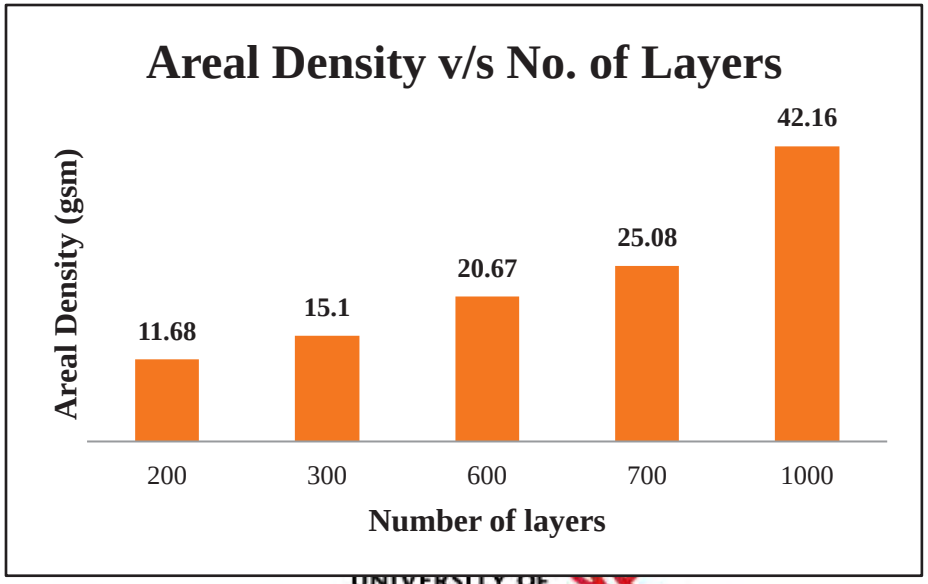
Aligned Carbon Nanotube (CNT) Sheets









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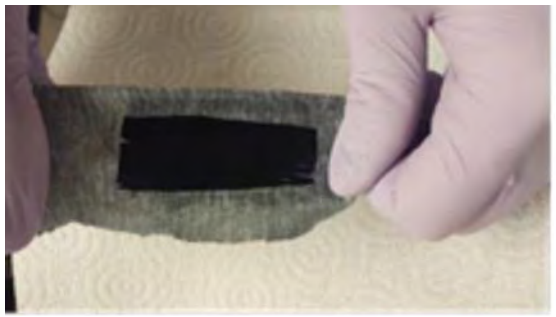
Materials & Methods

- Materials & Equipment
  - Multi-walled CNT ‘spinnable’ arrays.
  - Asics Training Dual short sleeve T-shirt
  - 3M™ Double-sided scotch tape.
  - Acetone.
  - FLIR T620 infrared camera



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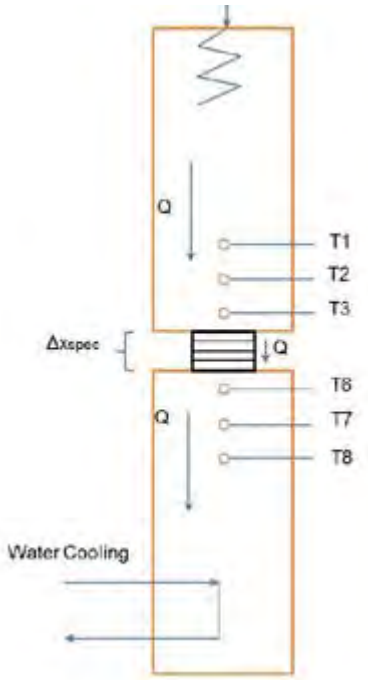
Materials & Methods

- Methods
  - Thermal conductivity (through the material)



Thermal conductivity of the sample is estimated using the following equations:

- Heat Flow $Q = VI$ (Watts) $= -KA_{spec}\frac{\Delta T}{t}$
- Temperature difference in heated section $\Delta T_{hot} = T1 - T3$
- Temperature at hot face of specimen section $\Delta T_{hotface} = T3 - \frac{T2-T3}{2}$
- Temperature at cold face of specimen section $\Delta T_{coldface} = T6 + \frac{T6-T7}{2}$
- Temperature difference in specimen section $\Delta T_{spec} = \Delta T_{hotface} - \Delta T_{coldface}$

Thermal conductivity, $K = \frac{Qt}{A_{spec}\Delta T_{spec}}$, t is thickness of the specimen, A_{spec} is the area of the specimen.

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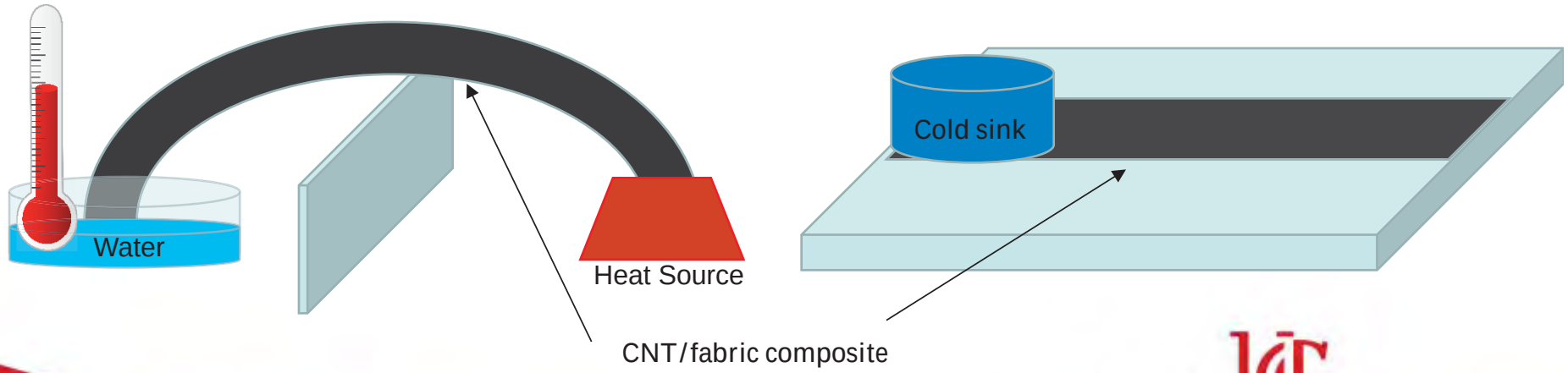
Materials & Methods

- Methods
  - Thermal conductivity (along the length of the material)
    - Measuring the time taken to increase the temperature of a constant volume (constant) of water by 1^{o}C interfaced with a constant heat source using the material as a conductive pathway.
    - Using a cold sink to draw heat into and cool the material along its length (recorded using Infrared camera).



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Results

- Thermal conductivity (through the material)

Sample	Thermal Conductivity (W/(mm.K))
Copper foil	1.51 $*10^{-2}$
Cooling fabric	9.31 $* 10^{-5}$
100 layer CNT sheet on fabric	1.47 $* 10^{-4}$
200 layer CNT sheet on fabric	1.81 $* 10^{-4}$
500 layer CNT sheet on fabric	2.07 $* 10^{-4}$

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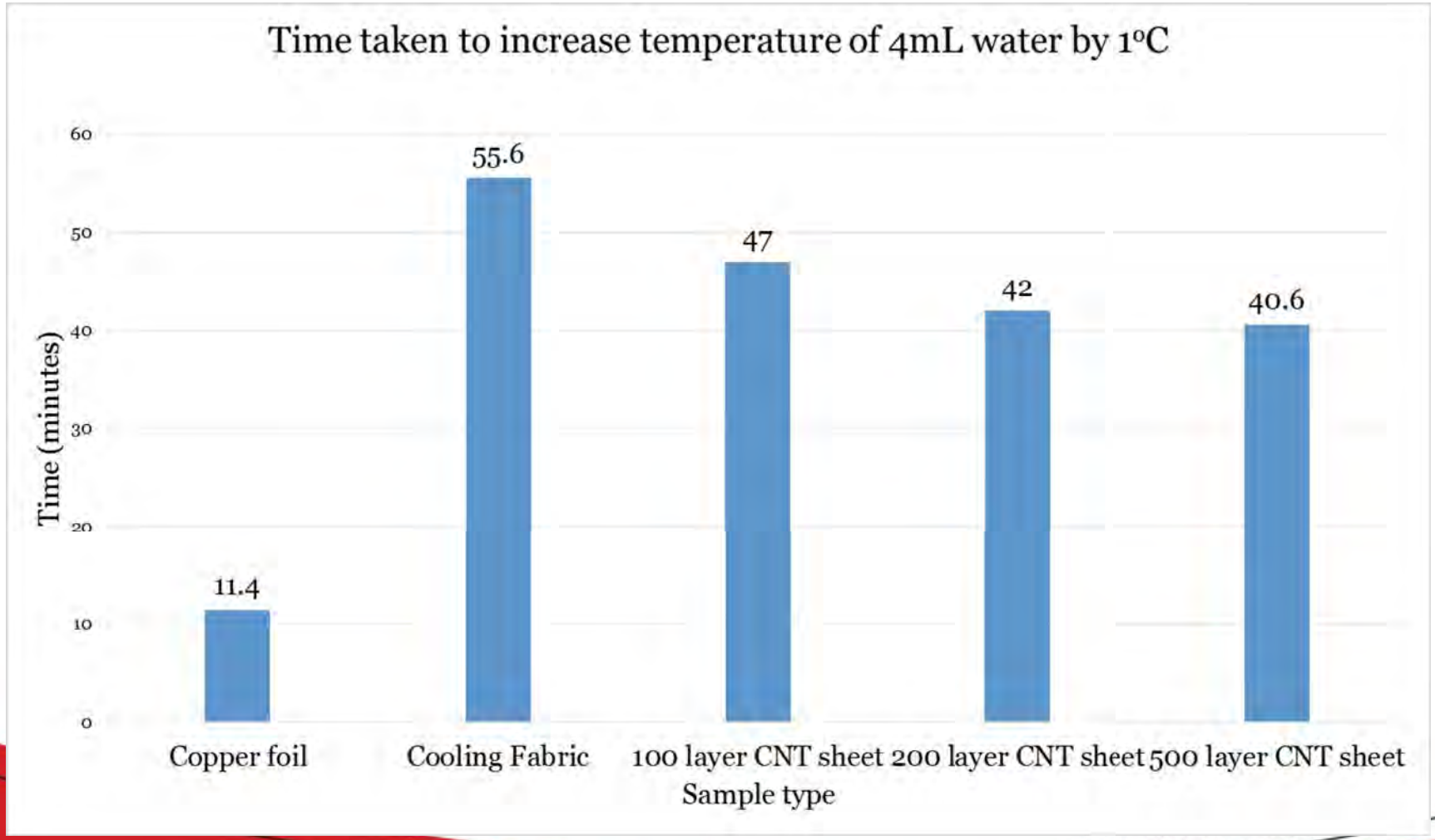
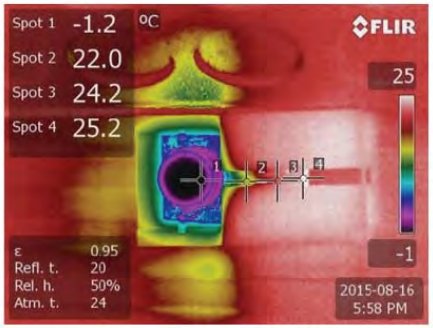
Results

- Thermal conductivity (along the length of the material)

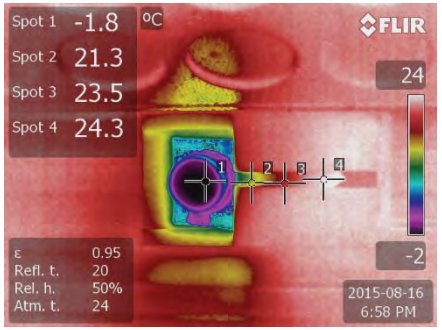


Results

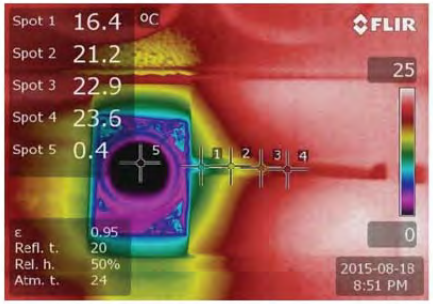
- Thermal conductivity (along the length of the material)
- Time t = 15 min



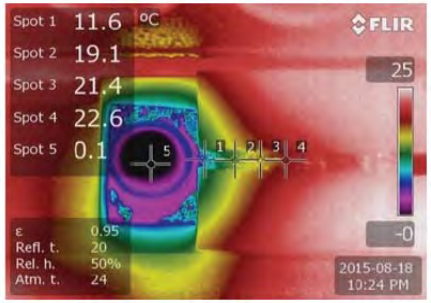
Cooling fabric



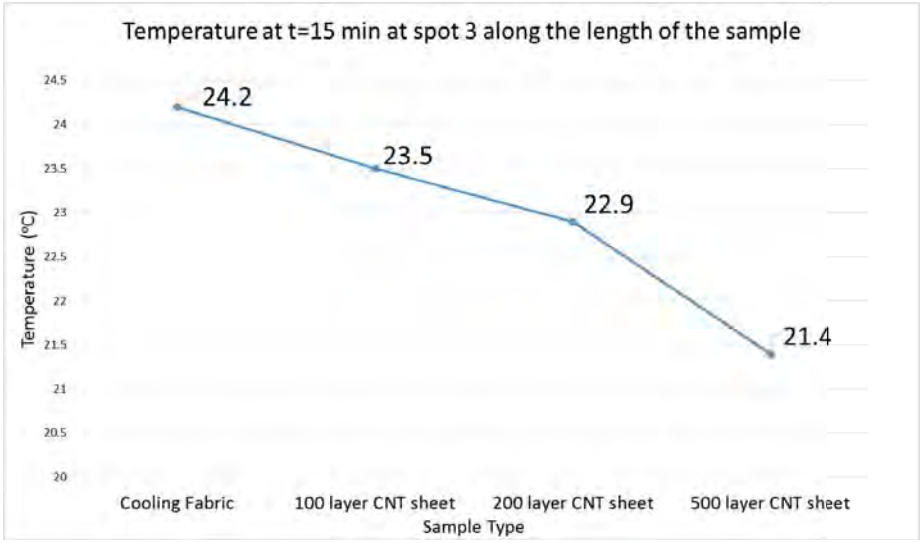
100 layer CNT sheet



200 layer CNT sheet



500 layer CNT sheet



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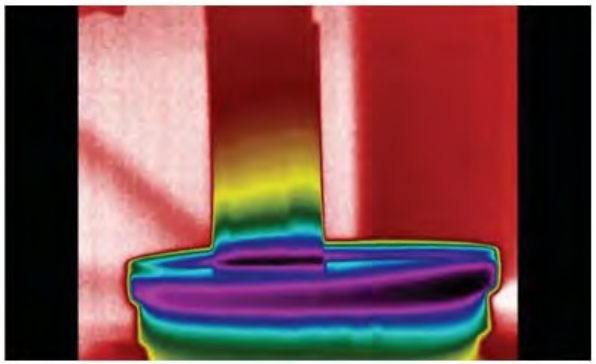
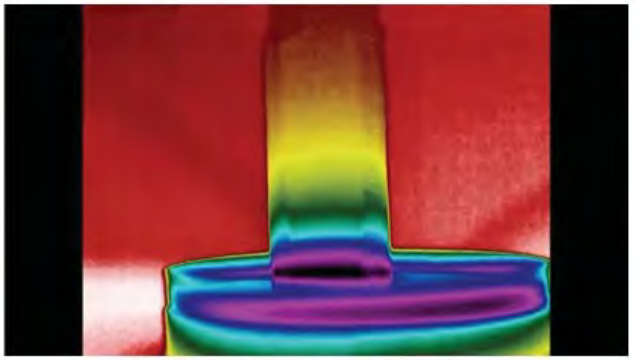
Wettability studies

- Vertical wicking
- Time t = 5 min

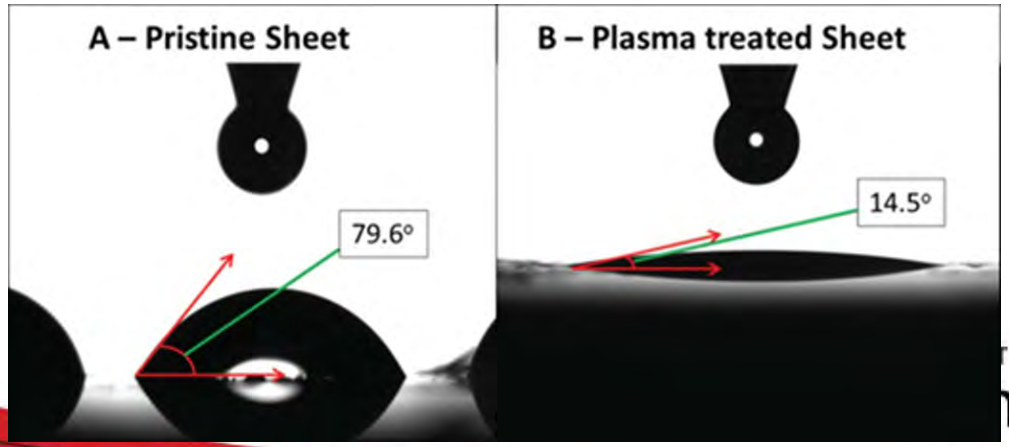


Pristine CNT sheet

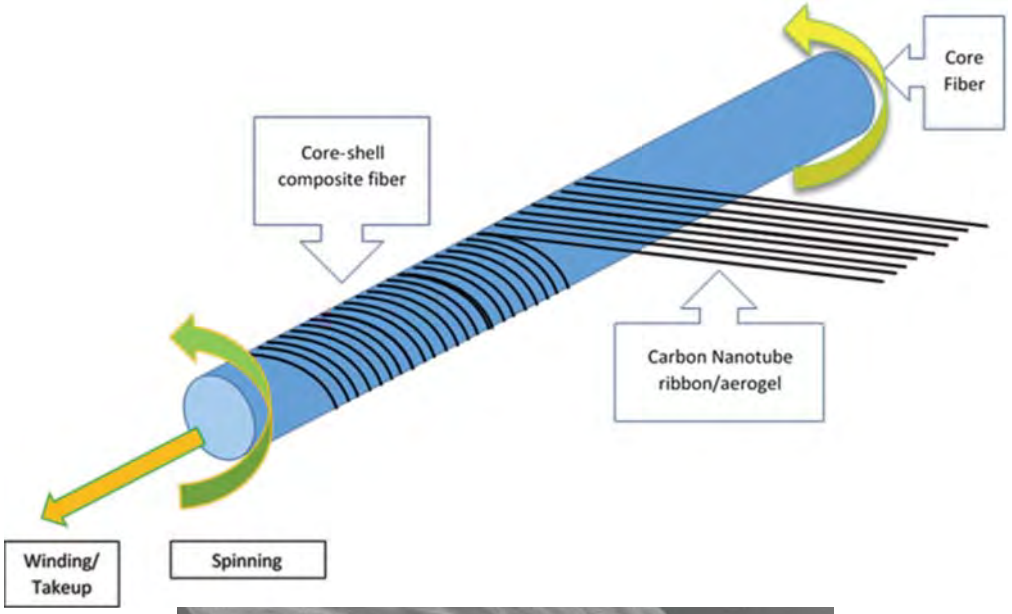


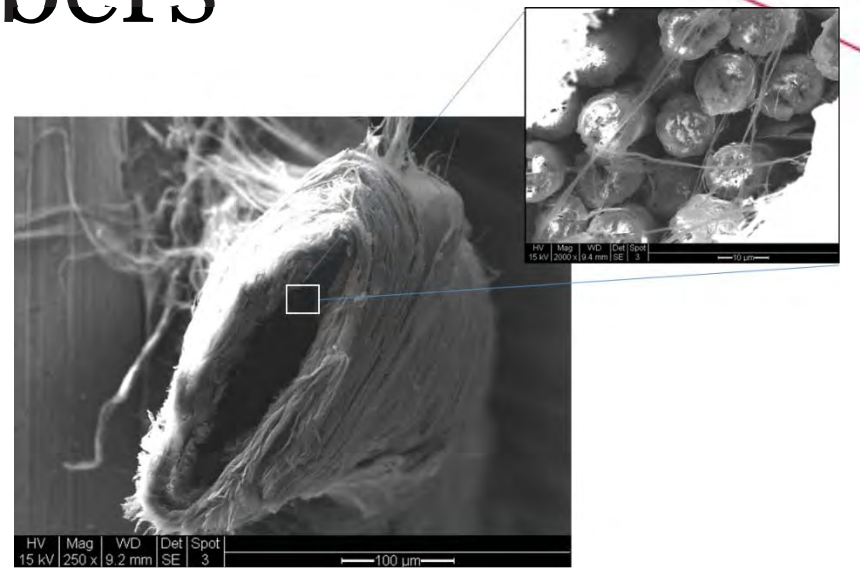
Plasma functionalized CNT sheet

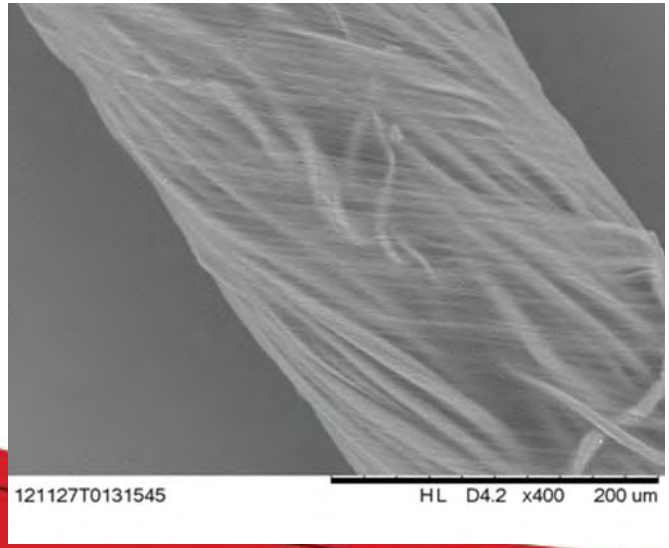
- Contact Angle measurement



CNT-clad textile fibers







Conclusions

- Successful, simple, durable integration of CNT sheets on to textile fabric.
- Qualitative analysis of CNT sheet/fabric composite demonstrates better thermal conductivity than fabric alone.
- CNT sheet treated with helium/oxygen plasma demonstrates better wettability than pristine CNT sheet.
- CNT-clad textile fiber offers novel alternative for future studies.

Future work

- Quantitative thermal conductivity measurements needed for complete assessment.
- The complete potential of CNT-clad textile fiber as a material for construction of cooling vest needs to be explored.

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Acknowledgements

- Dr. Yi Song (Albert)
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Thank you!

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