NRC·CNRC

NRC.CANADA.CA

Flame-Resistant Multifunctional Nanocomposite Fabric for Fire Protection of UHMWPE Laminates

M.B. Jakubinek*[1], Y. Martinez-Rubi[1], D. Maillard[2], V. Pankov[3], B. Ashrafi[3], B. Simard[1], C.T. Kingston[1]

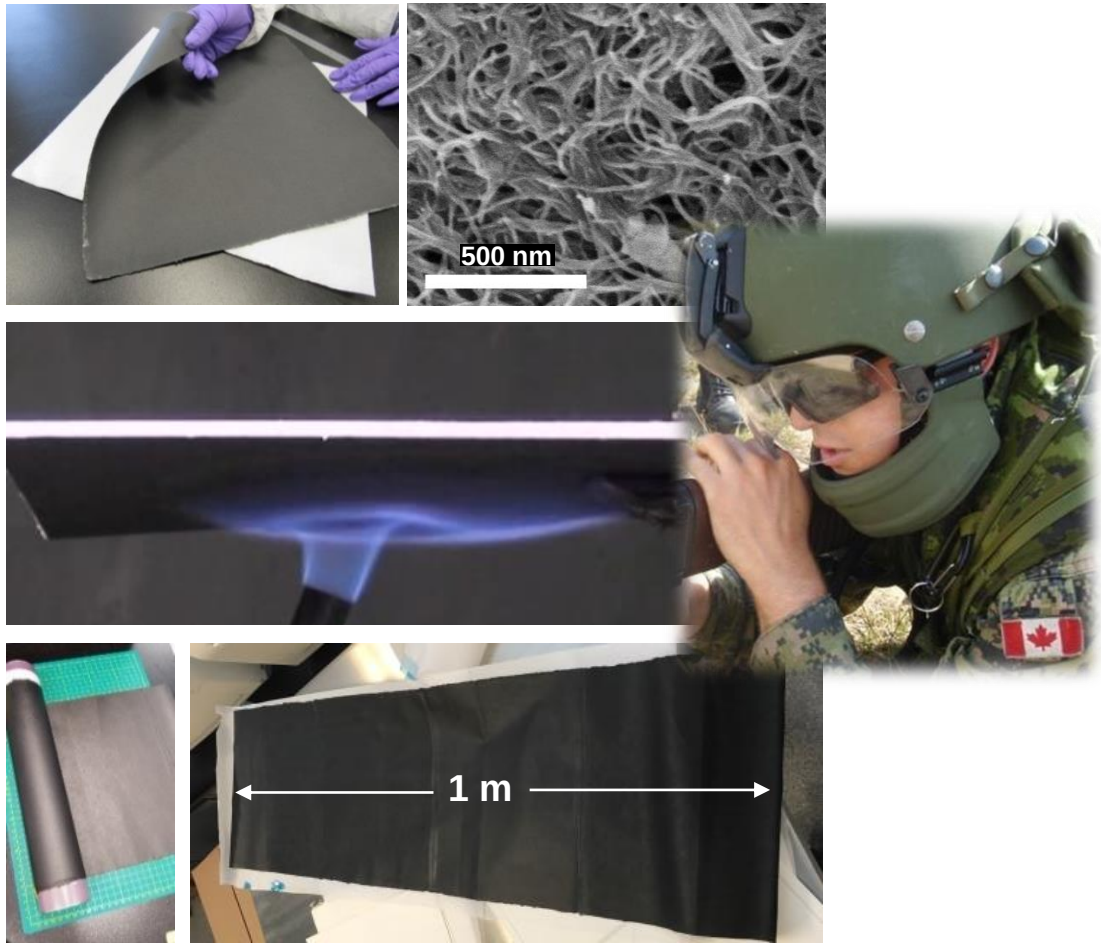
[1]Nanocomposites Group, Division of Emerging Technologies,
[2]Automotive & Surface Transportation Research Centre,
[3]Aerospace Research Centre,
National Research Council Canada

*Michael.Jakubinek@nrc.ca | linkedin.com/in/michaeljakubinek

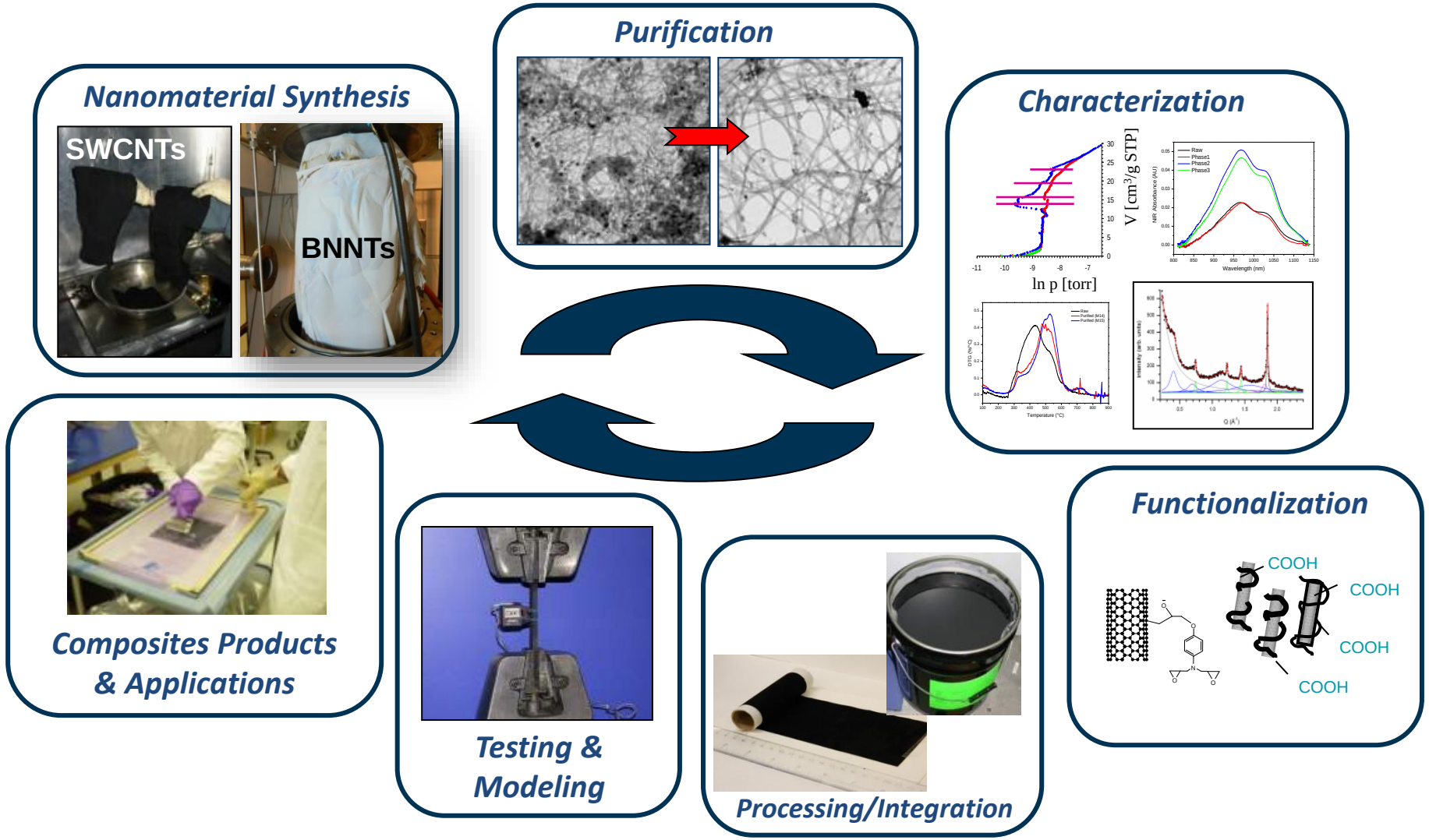
ICCM 23 – Twenty-Third International Conference on Composite Materials

Outline

- **Introduction – Nanocomposites@NRC**
- **Carbon nanotube(CNT)-based fabrics**
  - Nonwoven CNT–TPU
  - Tailorable composition, tailorable properties
- **Fire protection application**
  - Flammability of UHMWPE armor laminates
  - Nanocomposite & laminate manufacturing
  - Flammability testing & results
- **Other application directions & scalability**
- **Concluding remarks**



Nanocomposites@NRC: Integrated Approach

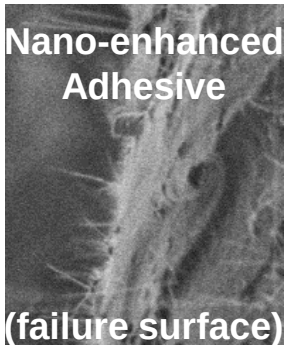


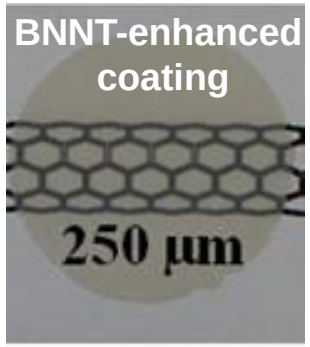
Nanotube Composites

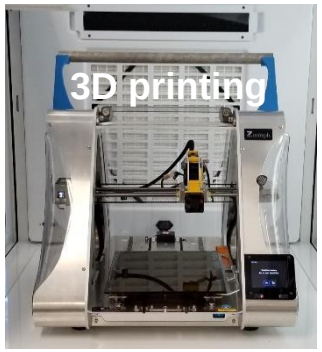
…translating the exceptional properties of individual nanotubes to macroscopic, engineering materials with useful structural and functional performance…

Dispersion Methods

(direct mixing, solvent & melt processing)





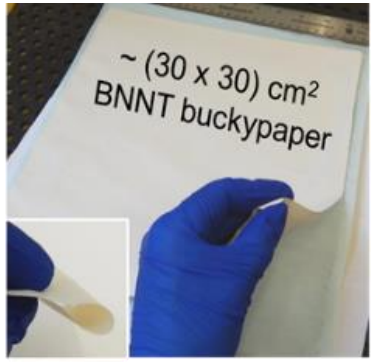


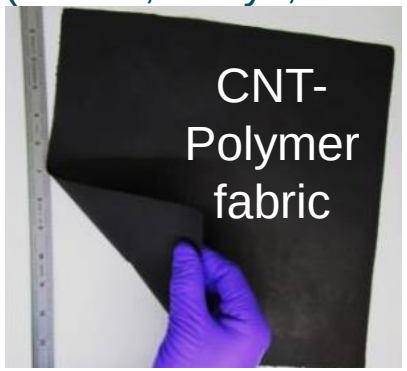
Additive/filler: **low nanotube content** (1-10 wt%)

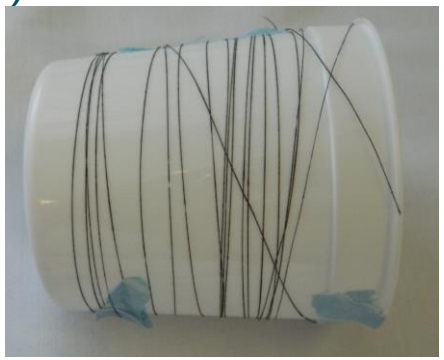
Applications: Hybrid fiber reinforced plastics (FRP) composites, coatings, adhesives, additive manufacturing

Preformed Assemblies

(sheets, arrays, fibers)







Nanotube preform: **high nanotube content**

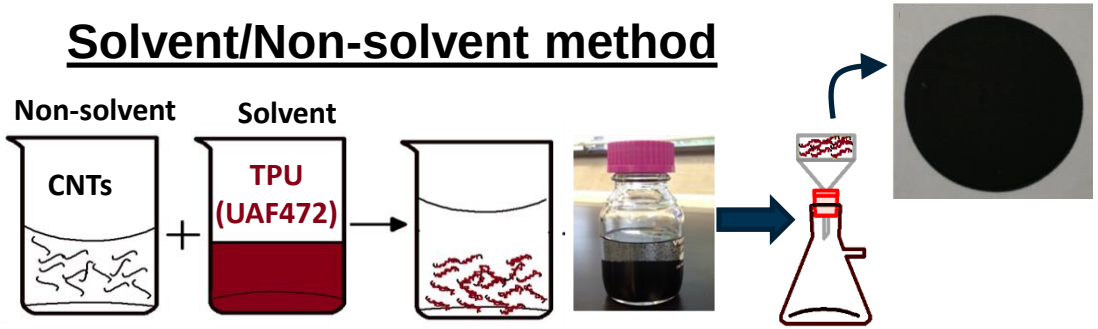
Applications: Laminated composites, surface and interlaminar modification

CNT-TPU Nanocomposite Fabrics

NRC
2015 – Present

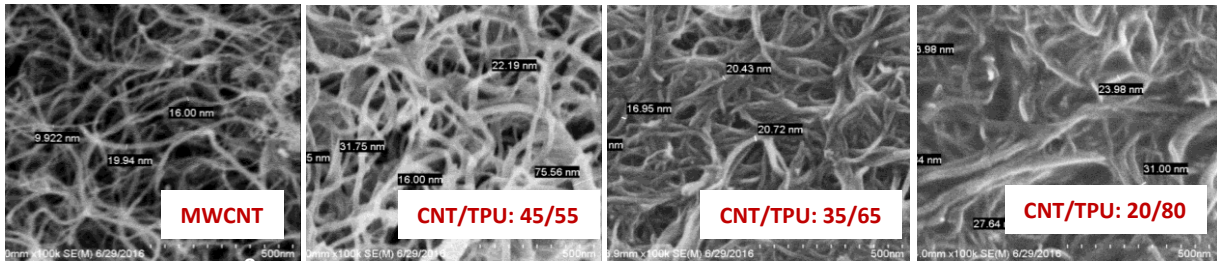
- Novel approach
- Cost-effective, industrial-grade CNT powders
- Tailor composition & properties
- Lightweight
- Convenient handling (use in fabric form)
- Scalable

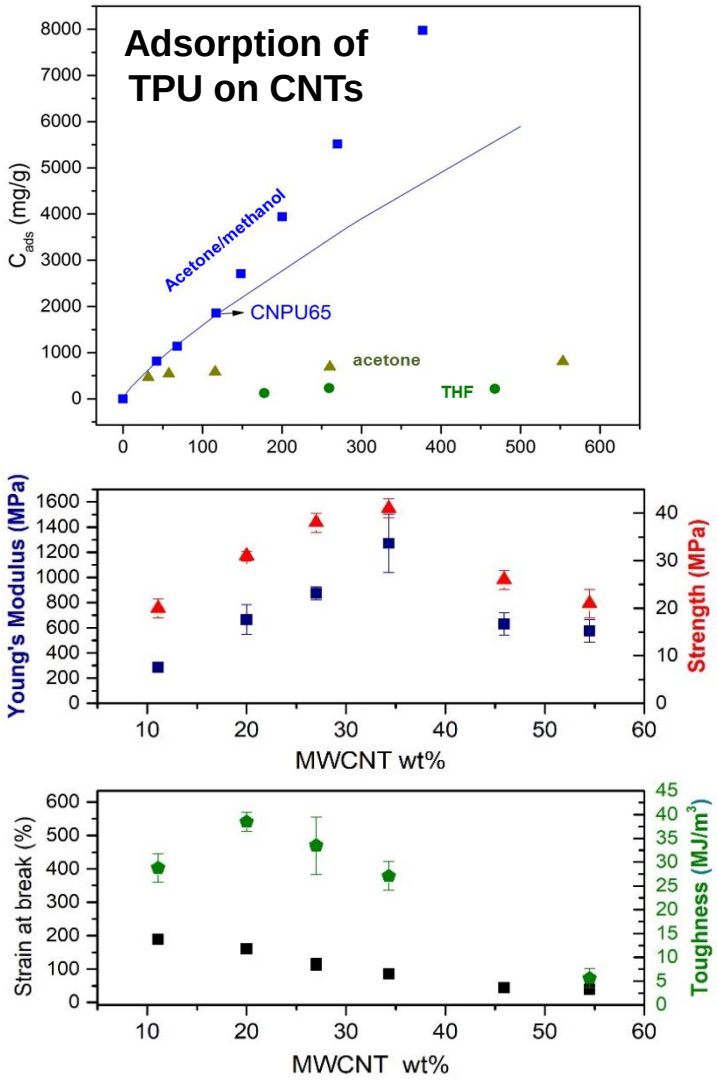
Solvent/Non-solvent method



Nanocyl NC7000 MWCNTs + thermoplastic polyurethane (TPU)

- Controlled adsorption of TPU onto CNTs
- Fast recovery by filtration
- Produces non-woven fabrics of coated CNTs





Martinez-Rubi et al, ACS AMI 2017 | Jakubinek et al, MRS Adv 2019

Application Case: UHMWPE-based Armor

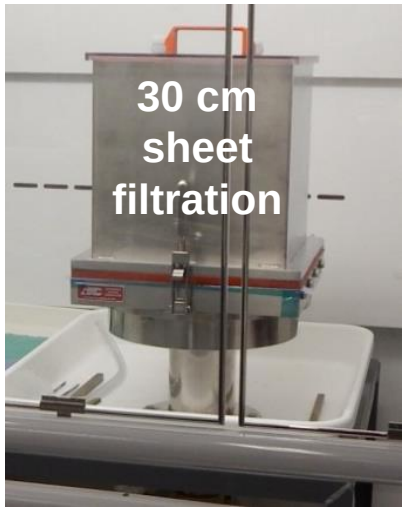
- High-performance UHMPWE materials (e.g., Dyneema® & SpectraShield®) used in armor and other protective equipment
  - Outperform Kevlar® on a per mass basis, but
  - Have low melting temperature and low fire resistance requiring additional flame protection
- Established solution (application of a layer of fire-resistant material such as Nomex) adds significant weight
- Carbon nanotubes have been shown to impart flame/fire resistance in studies of polymer and FRP composites [e.g., refs]
- Our nanocomposite fabric approach offers: (1) high-content of CNTs to maximize their effect, (2) ability of TPU component to provide for adhesion, (3) compatibility with manufacturing protocol for UHMWPE armor laminates

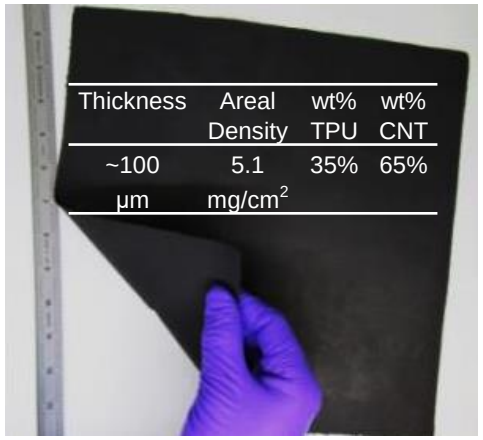
Goal: New, lighter fire protection solution

Refs:
A. Kausar et al. Polym.-Plast. Technol. Eng. 56, 470 (2017).
X. Fu et al. Nanotech. 21, 235701 (2010).
Q. Wu et al. Carbon 46, 1164 (2008).
Q. Wu et al. Carbon 48, 1799 (2010).

Nanocomposite & Panel Manufacturing

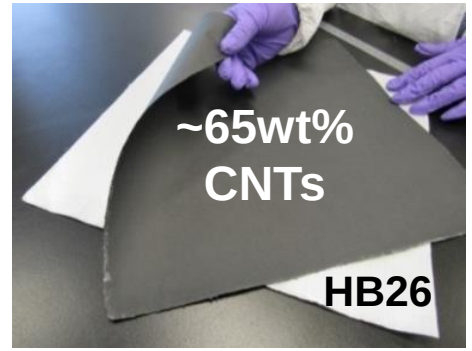
CNT-TPU Sheet Fabrication

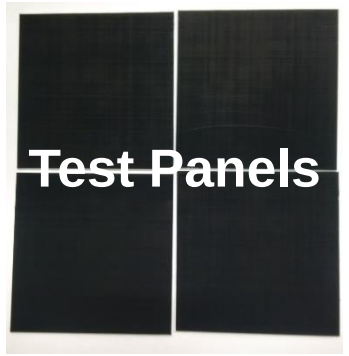


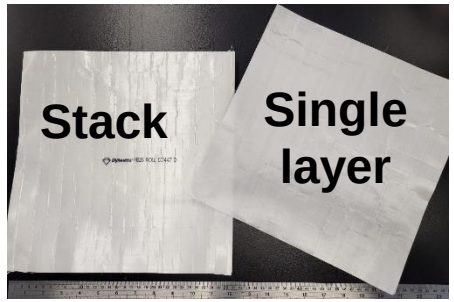


Thickness	Areal Density	wt% TPU	wt% CNT
~100 µm	5.1 mg/cm^2	35%	65%

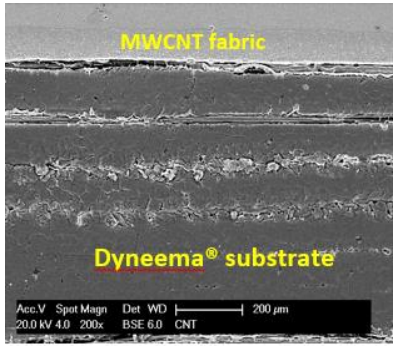
Hot-Press Lamination

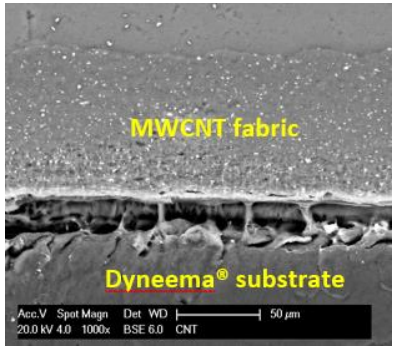




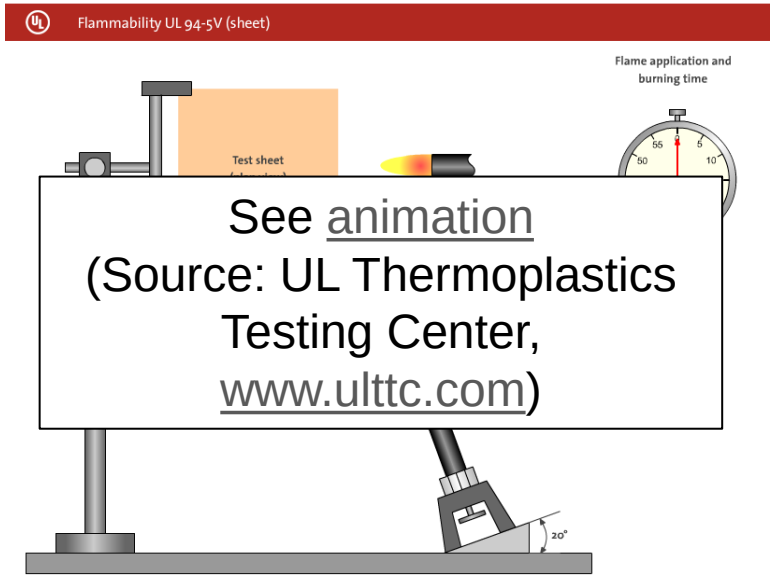


HB26 Dyneema® (DSM)

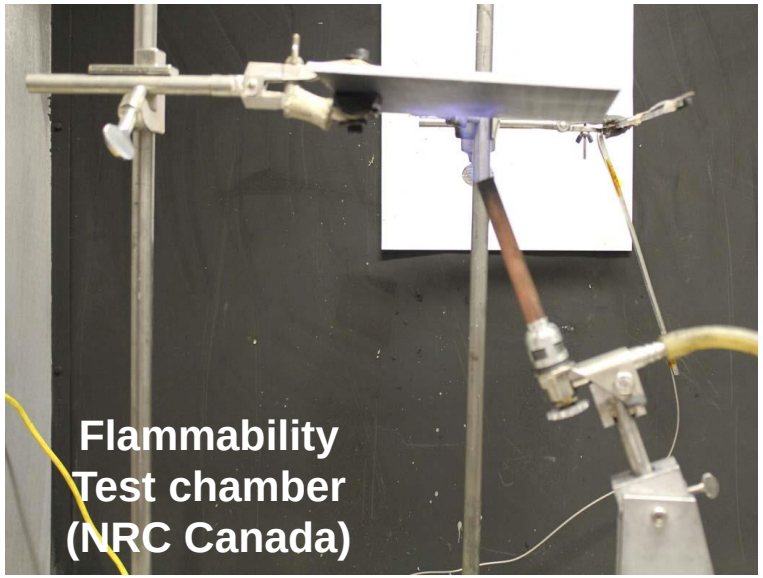




Flammability Testing



See animation
(Source: UL Thermoplastics Testing Center, www.ulttc.com)

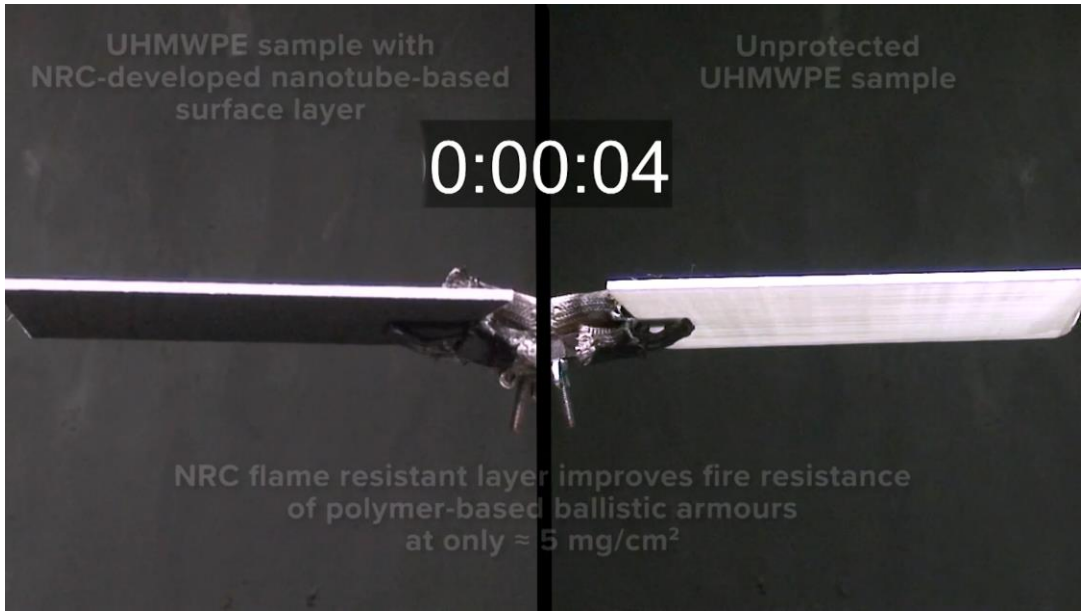


UL94-5V

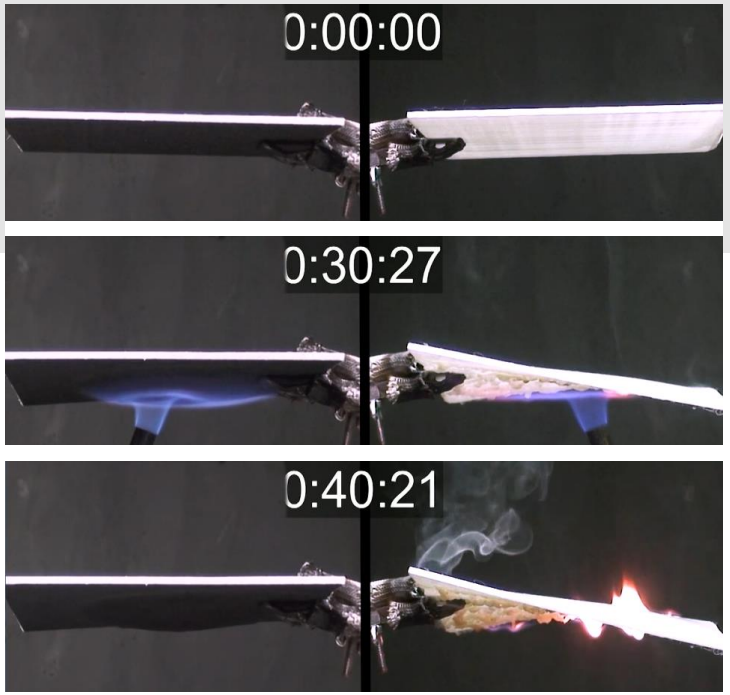
- Calibrated flame, 500 W
- 5s ON, 5s OFF
- Repeat 5x

Rating	Description
5V	No flaming or glowing after 60s, no dripping of flaming particles, no burn through by the flame, and no surface damages
5VA	No flaming or glowing after 60s, no dripping of flaming particles, no burn through by the flame, but can exhibit some surface damages
5VB	Samples exhibit no flaming or glowing after 60s, no dripping of flaming particles, but can be run through by the flame.

Flammability Testing



Continuous exposure to flame



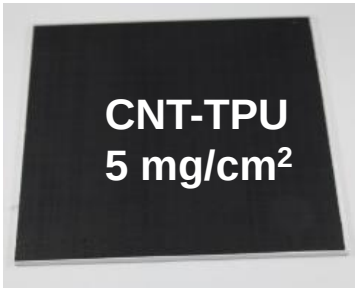
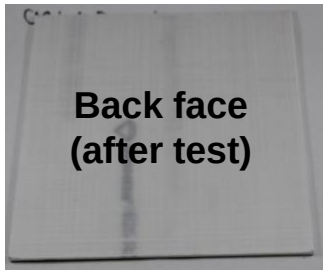
HB26 UHMWPE laminate

- Softening/meting/deflection
- Ignition
- Dripping of flaming particles
- Extensive damage

+Nanocomposite

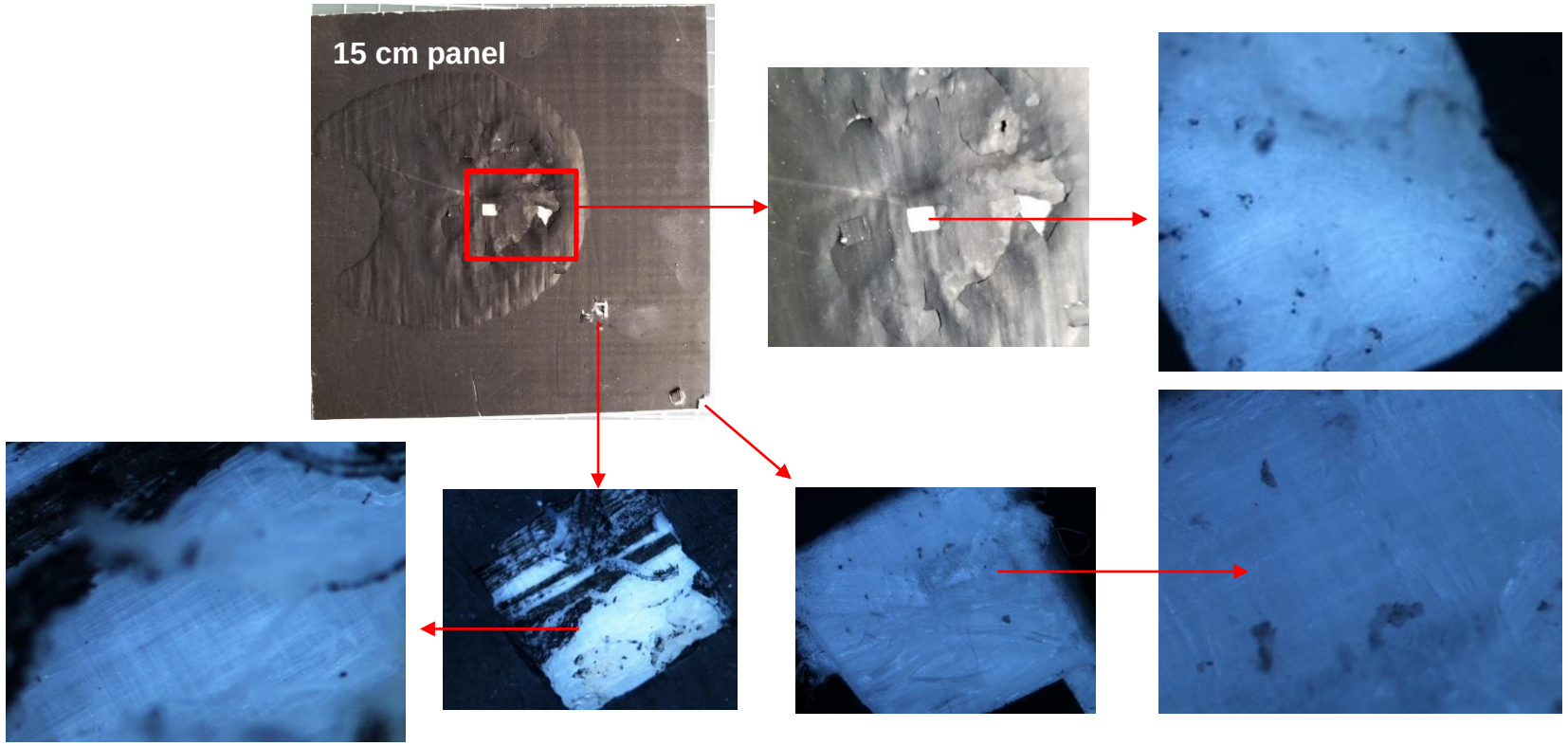
- No ignition/burning
- Modest deflection
- Surface damage only

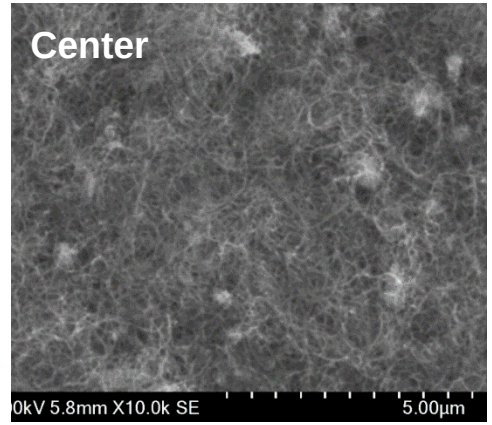
Flammability Testing – UL94-5V – Results

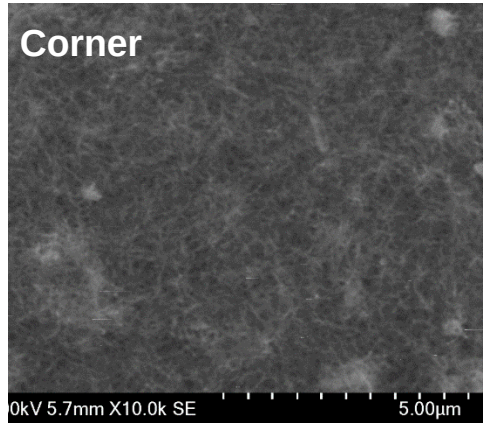
Before	After	Notes
		• Melting of the UHMWPE • Dripping of flaming particles • During the last exposure, the polymer starts to burn • If not extinguished externally, the complete sample will burn FAIL
	 	• The sample is not ignited • The polymer is contained • No dripping • No back face damage PASS UL94-5VA

- Protected panels pass UL94-5VA flammability test
- Added mass only ~ 5 mg/cm^2
- Much lighter than established solution

Post-test inspection

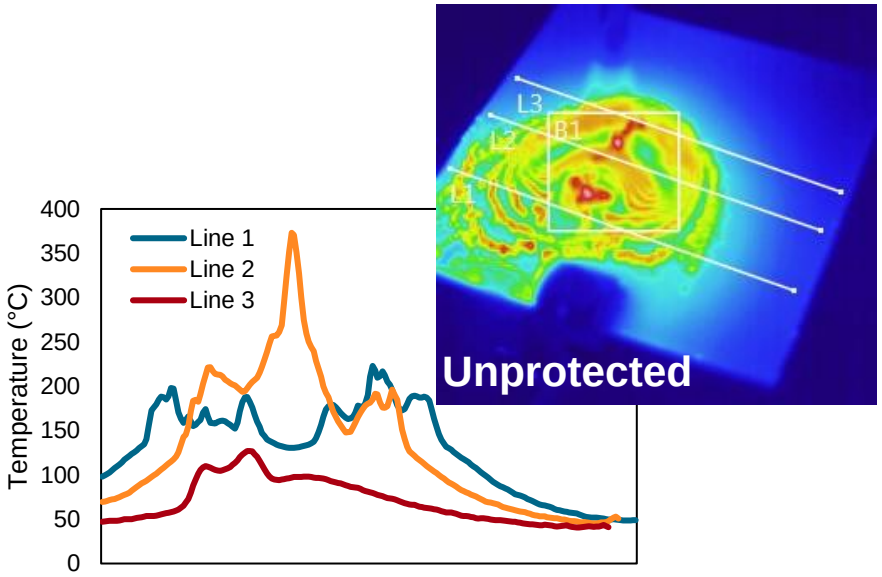


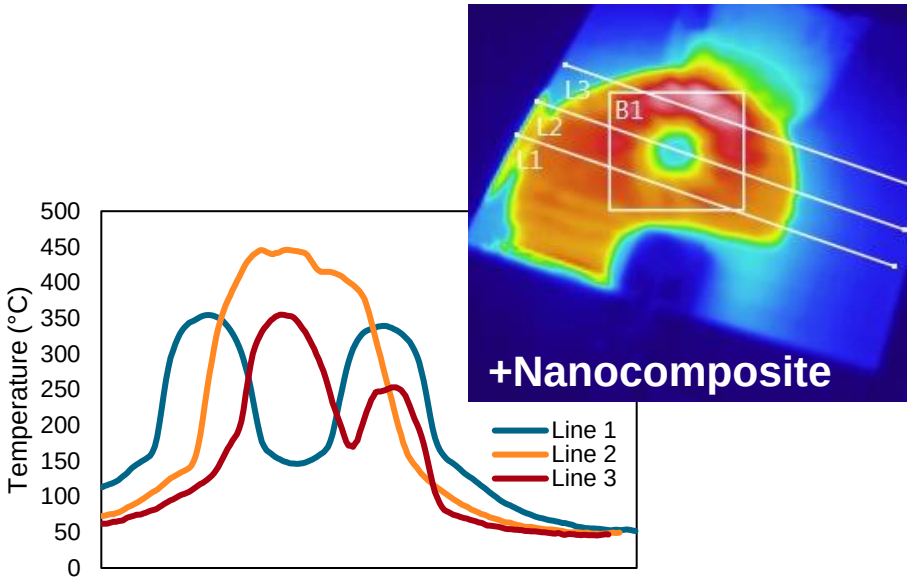


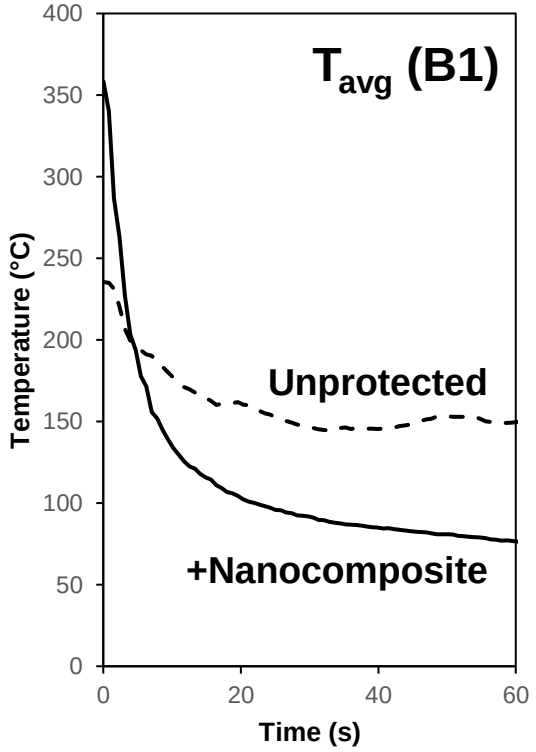


- **Debonding** of the protective coating around location of flame exposure
- UHMWPE not burnt and **fibers largely intact** in hot zone below the debonded layer
- Potential to optimize both adhesion & delamination

Thermal Imaging

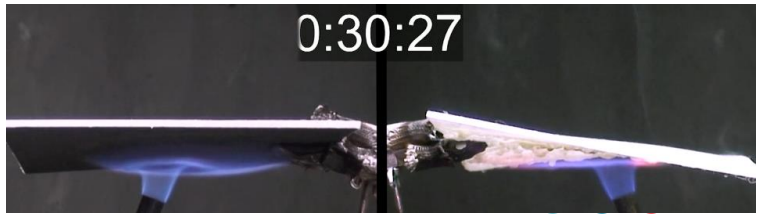






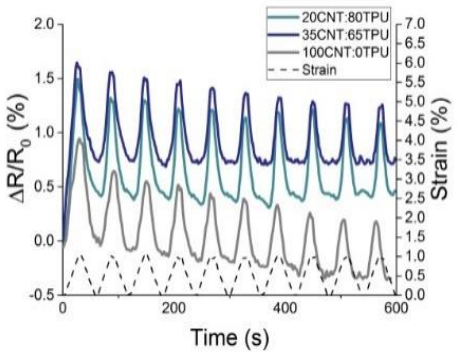
+Nanocomposite layer

- Spreads heat (more uniform surface temperature, faster cooling)
- Higher surface temperature attributed to detachment/debonding
- Reduced temperature within and on the surface of UHMWPE laminate → minimal deflection of panel, limited/reduced melting of UHMWPE fibers

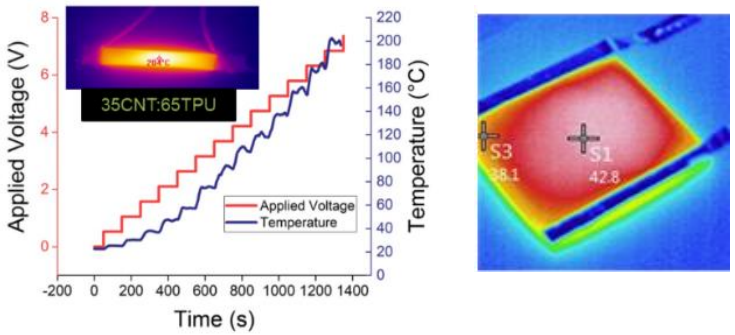


Other Application Cases

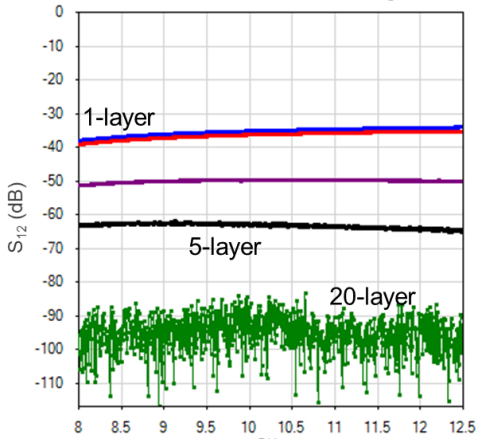
Sensing



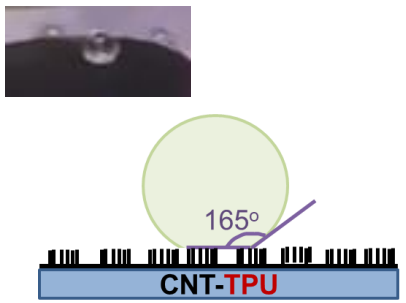
Heating



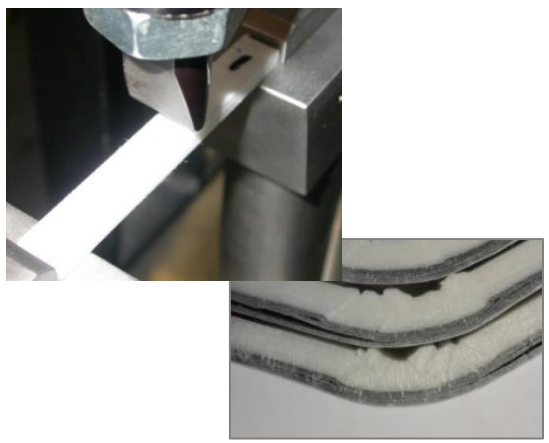
EM Shielding



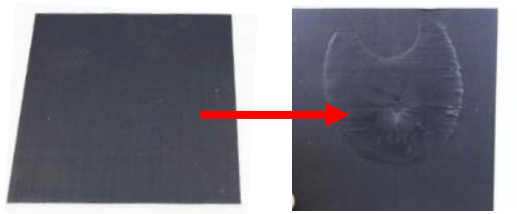
Superhydrophobicity



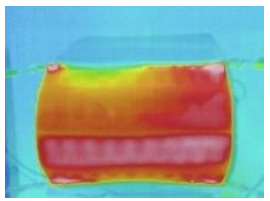
Energy Absorption

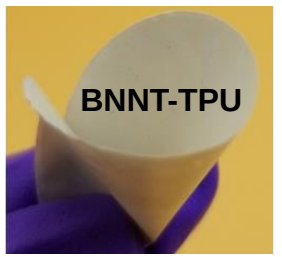


Flame Resistance



Morphing Structures





+ complimentary possibilities based on BNNTs, other nanomaterials

US Patent App. 17393457, 2022; US Patent App. US20200101202A1; PCT/P60550PC00,2022; Jakubinek *et al.*, MRS Advances, **2019**; AIAA Scitech6.2019-1857 (2019);Yamani *et al.*, J. *Mater. Res.*, **2022**

Nanocomposite Fabric: Scale-up (Roll-to-Roll)

https://www.ic.gc.ca/eic/site/101.nsf/eng/home

CHALLENGE STREAM | INNOVATIVE SOLUTIONS CANADA

Nanocomposite Fabrics Production System

From: Innovation, Science and Economic Development Canada

The National Research Council is seeking a manufacturing process solution that will produce nanocomposite sheets/fabrics comprised of carbon nanotubes and polymer by the roll in order to make the next generation of high-performance multifunctional fabric for fire protection, energy absorption, electromagnetic shielding, etc.

Challenge sponsor: National Research Council of Canada (NRC)

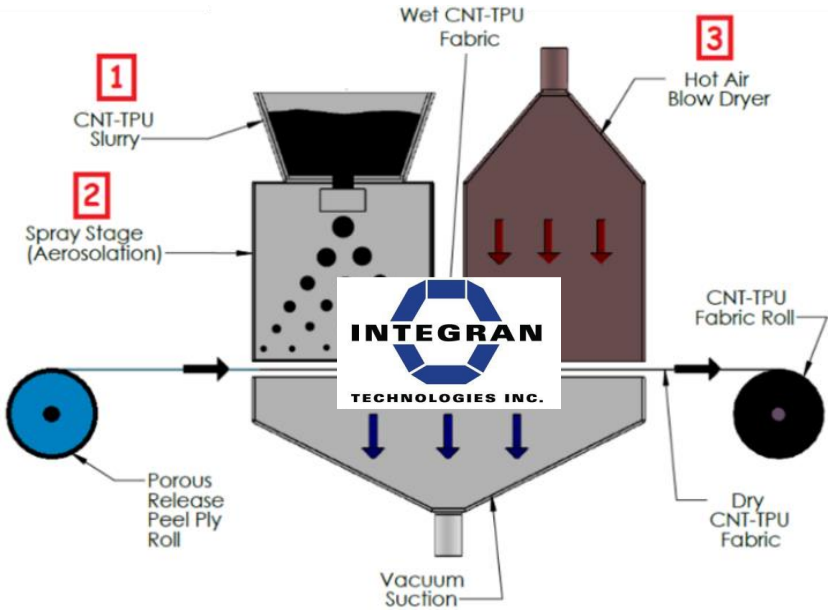
Funding mechanism: Contract

Opening date: January 27, 2020
Closing date: May 25, 2020, 14:00 Eastern Daylight Time

The National Research Council is seeking a manufacturing process solution that will produce nanocomposite sheets/fabrics comprised of carbon nanotubes and polymer by the roll in order to make the next generation of high-performance multifunctional fabric for fire protection, energy absorption, electromagnetic shielding, etc.

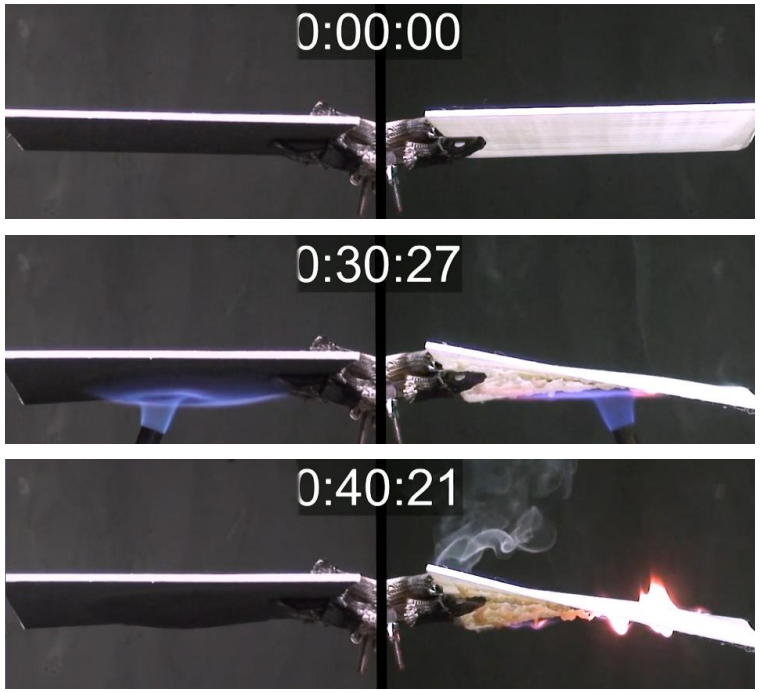
Phase 1: Proof of feasibility (6 mo./$150k)
Completed 2021

Phase 2: Prototype development (2y./$1M)
Contracted March 2022



Summary

- Nanotube-based fabrics are advantageous for composites fabrication & application: high nanotube content to better leverage properties, simplified handling for increased safety and ease-of-integration
- Nonwoven CNT-TPU fabric was applied directly to surface of Dyneema® laminates to provide fire protection
  - Panel passes UL94-5VA flammability test (unprotected panel fails, and burns dramatically under equivalent conditions)
  - The nanocomposite protective layer adds only 5 mg/cm^2 – much lighter than current solutions – and is compatible with armor laminate manufacturing
- Effectiveness in laboratory tests for flammability, and other application demonstration cases, is motivating current scale-up efforts (NRC + Integran Technologies Inc. + Innovative Solutions Canada) for the nanocomposite fabric material



Acknowledgments

NRC-Nanocomposites Group
Aqueel Alrebh
Michael Barnes
Jingwen Guan
Liliana Gaburici
Christa Homenick
Michael Jakubinek
Keun Su Kim
Chris Kingston (Group Lead)
Hao Li
Yadienka Martinez-Rubi
Marc McArthur
Mark Plunkett
Dean Ruth
Benoit Simard

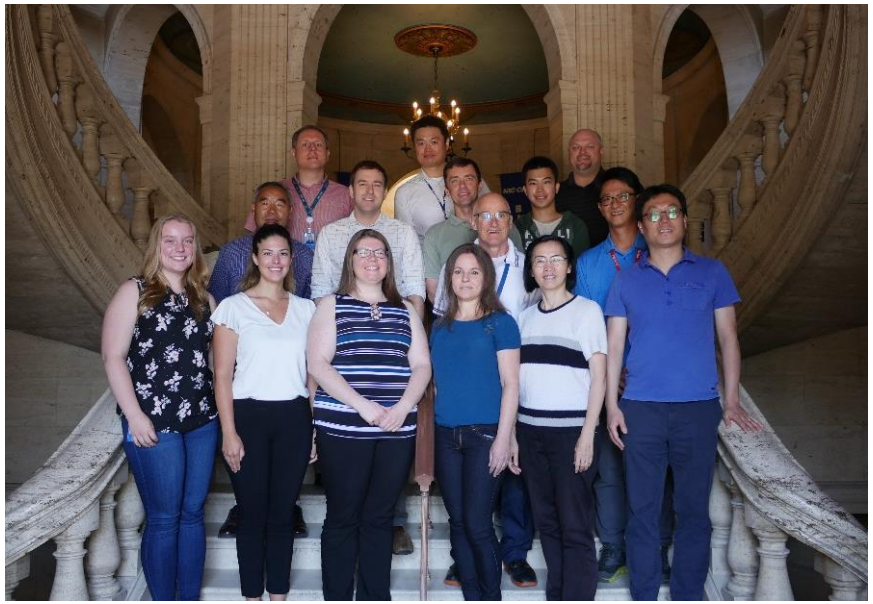
NRC-Aerospace
Behnam Ashrafi
Chun Li
Vladimir Pankov

NRC-Automotive
Simon Baril-Gosselin
Damien Maillard
Eric Patenaude

Industry discussions
NRC-Security Materials Technology Roadmap
NP Aerospace (Morgan Advanced Materials)

Integran
Herath Katugaha
Jon McCrea
Robert Pallotta
Gino Palumbo

Innovative Solutions Canada
(Contract 31103-212430/001/SI)



Contact: **Michael Jakubinek**
Senior Research Officer, Nanocomposites
National Research Council, Ottawa ON, Canada
Michael.Jakubinek@nrc.ca
linkedin.com/in/michaeljakubinek