Multi-nozzle electrospinning optimization of carbon nanotube/epoxy submicron filaments – A numerical study

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Background

- Carbon fiber reinforced polymer (CFRP) prepreg composites can be enhanced by electrospinning.
 - Multiwalled carbon nanotubes (MWCNTs)/epoxy nanofibers are incorporated *in between* layers of conventional CFRP Prepreg composite.

Enhanced Properties

Uniform Structure (4% CNT in epoxy shown)

Improved Load
& Displacement;
4% CNT highest
performance

Challenge

- Previous study
 - Single Nozzle Electrospinning makes samples 4inx 4in
- Achieving the multi-nozzle electrospinning of carbon nanotube/epoxy submicron filaments is difficult due to
 - Variability in viscosity caused by temperature changes of thermosetting reinforced epoxy.
 - Non-uniformity of spinning on the collector substrate due to electrostatic repulsion between the spinnerets/needles.

Figure 4. Multi-nozzle of Epoxy/CNT filament with the pre-optimization.

Solution

- Electric fields and other parameters were simulated using COMSOL Multiphysics® software.
- Optimization of the simulated data was coupled with lab experiments to improve stability and fabricate smaller, more uniform diameter fibers with enhanced structure.

Theoretical and Experimental Set-up

COMSOL simulation of the electric field

2 models were created vertically in linear configuration for a coverage area of 24 in wide substrate.

	2 in apart model	3 in apart model
# needles	10	5

Voltage – 17 KV

2in apart multi-needle model - SIMULATED DATA VS EXPERIMENT DATA

Volume: Electric potential (V) Streamline: Electric field Arrow Volume:
Electric field

3 in apart multi-needle system - SIMULATED DATA VS EXPERIMENT DATA

Distance between two needle	1 in (less than 5 minutes)	2 in (less than 5 minutes)	3 in (10 minutes spinning)	4 in (10 minutes spinning)	6 in (10 minutes spinning)
Coverage Diameter	1 in	1.5 ~ 2in	2 ~ 2.5 in	2.5 ~ 3 in	2.5 in
Gap	~ 0.5 in	0.5 ~ 0.7in	0.7 ~ 1.5 in	2 in	3.5 ~ 4 in
% Coverage	~ 50	~ 66	~ 50	~ 51	~ 33

With the CNT/Epoxy the coverage area can be increased by keeping the nozzles away from each other which reduced columbic repulsions of the electric field.

However, the gap could not be removed.

To minimize the gap and to have a very uniform spinning over the prepreg, a new approach was developed.

A multi nozzle system with mechanical movement to move the needles from X to Y, and Y to X.

Results were carried out for difference speeds;

2 in apart needle system were used in order to reduce the distance for the mechanical movement

Results shows no gap between spinning areas for each needle

← Roll Direction

Results comparison of the fiber diameter

Figure (a-b) SEM image of horizontally electrospun fibers at 17 KV, (c-d) SEM image of vertically electrospun fibers at 17 KV, (e) Fiber size comparison between vertical and horizontal electrospinning at different applied v SEM image of horizontally Electrospun voltage.

Multi-nozzle
Electrospun
(vertical)

Single-nozzle
Electrospun
(Horizontal)

Results comparison of the structural enhancement; 3 point bending

Summary

- In this study, the effects of different nozzle arrangements on the electrospinning of CNT/Epoxy fibers deposition were studied. Two different setups of equally-spaced 2in apart and 3 in apart nozzles were tested and compared; gap and the deposition area.
- The 2in apart system with the mechanical movement setup resulted in a overcoming the electric field uniformity and the repulsion issues between the nozzles.
- Improve the uniformity of the fiber deposition and reduce in gap (2in apart) and addressed the issue of processing difficulties due to electric field interference.
- Increases in the fiber diameter in the multi-nozzle system result in Load Increment of 28% compared to the controls with a displacement at 0.62mm.

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Thank you

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