# Spinning CNT based Composite Yarns using a dry spinning process

Canh-Dung Tran, Shaun M. Smith, G. Higgerson, Chi Huynh, Ladge Kviz, George Maudev, Stuart Lucas and Anh Bui

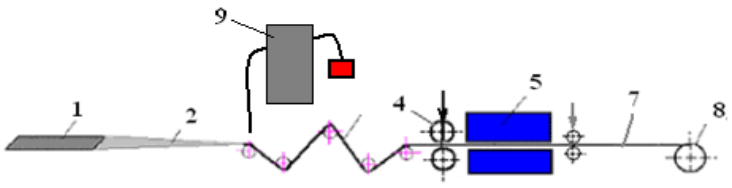
CSIRO Materials Science and Engineering - Geelong VIC 3216, Australia

The unique properties of carbon nanotubes (CNTs) of high tensile strength and Young's modulus, high aspect ratio, and good electrical and thermal conductivities [1] have opened up various novel application areas, for example, in nano-mechanics [2], advanced electronics [3] and bio-technology [4]. The superior mechanical properties of the individual CNTs alone do not ensure mechanically superior pure CNT-based products [5,6]. There has been significant effort into the fabrication of macroscopic CNT structures, including the study of blended polymer fibre-CNT composites with improved physical and mechanical properties [7]. In the most recent CNT polymer composite studies, CNTs have been used as discontinuous reinforcement of polymer matrices where CNTs are dispersed into polymers systems and subsequently fabricated into films and yarns, using a variety of techniques. Several different mixing techniques have been used to facilitate incorporation of CNTs into polymer films via solution processing [8-9]. However, the most difficult and complex problem for these approaches are the alignment and dispersion capability of CNTs because of their easy agglomeration in polymer liquids [10-11].

Recently, CSIRO has developed a modified dry spinning process for converting CNT forests into yarn in which the CNT structure is more aligned and the mechanical properties of yarns are improved [5].The partitioning of the spinning system into separate zones has enabled further development of other types of CNT based products. Using this modified system, a CNT polymer composite yarn manufacturing process was set up with simple control of the alignment and tension of the CNT-based reinforcing structure. In contrast to previous methods where the CNTs are dispersed in polymer solution, in this work, the polymer filled the pores between the stretched and aligned CNT web/sliver and formed a unique CNT-polymer composite. The aim of this work was to demonstrate a different approach for producing the CNT-based polymer composite yarns with properties that may satisfy many different engineering specifications, including biomedical device applications.

The process for manufacturing CNT polymer composite yarn is shown in Figure 1 and consists of the following (i) web formation from CNT forests together with the arrangement and alignment of CNT fibers, (ii) application of polymer onto CNT web or sliver (iii) compressing, squeezing and soaking polymer in the CNT reinforcing layer (iv) curing the resulting composite fibre (Figure 4).

In order to ensure even and deep penetration of polymer into the CNT yarn structure, polymer was applied to CNT web/sliver (Figure 2). A number of approaches for adding polymeric species to CNT webs were evaluated: (i) Combination of the CNT spinning process and a polymer electro-spinning (ii) Spraying a cloud of nano-particles of PU solution using a fluid dispensing system (iii) Absorbing PU solution using the capillary effect and (iv) A combination of the above methods.




1. Wafer 2. Web 3. Sliver 4. Squeeze rollers 5. Furnace
6. Guide rods 7. Yarn 8. Bobbin 9. Polymer Applicator

Figure 1. The schematic of the CNT polymer composite yarn spinning process.

The selected method depended on the specifications of resin species (e.g. melting temperature) and the characteristics of the components of polymerization (i.e. resin and hardener) used for curing the composite.

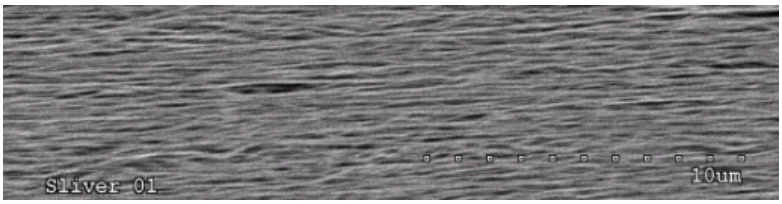



Figure 2. Micrograph of a CNT sliver (web) using the modified process depicting CNT bundle alignment.

While passing through a capstan effect rod system (CERS), the web (2) comes through a membrane of solution of polymer which was formed on the first rod of CERS due to the continuous supplying of a peristaltic pump (9). After contact with the CNT web, the polymer solution was absorbed into the web spaces by the capillary effect. A compression of yarn of very low twist is possible when the yarn passes through the squeeze rollers (4) prior to curing in the furnace (5).

The process enables the development of unique polymer-CNT based composite yarns. These yarns will have different mechanical properties suitable for a range of applications depending on the resin system employed. In this work, polyurethane elastomer (supplied by Urethane Compounds PTY. LTD) dissolved in dimethyl formamide (6%wt – 10%wt), was employed as the resin.

In order to qualitatively investigate the distribution of polymer within the yarn structure, a morphological observation of web and yarn was carried out using the Scanning Electron Microscopic (SEM) (F igure 3).

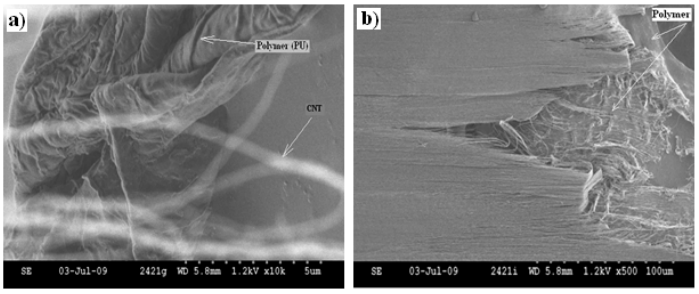



Figure 3. SEM images of CNT-PU based structures using the present approach: a) the initial formation of PU membrane between CNTs; b) A sliver structure of CNT/PU composite.

The structure of the CNT polymer composite yarn was investigated using Scanning Electron Microscopy coupled with Focused Ion Beam. The results show the significant differences between the surfaces (Figure 4) and the cross-sections of the pure CNT and CNT polymer composite yarns (Figure 5)

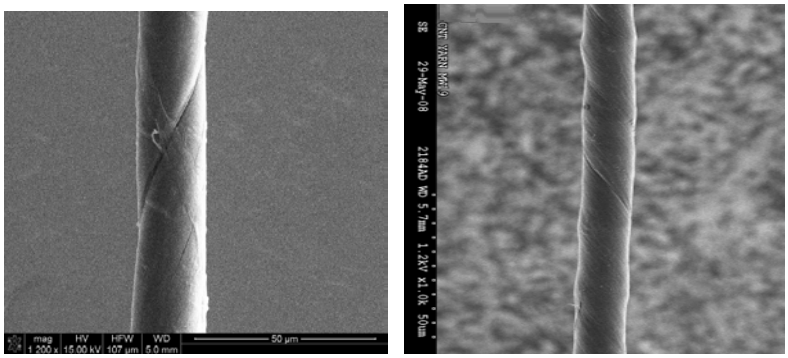



Figure 4. Micrograph (SEM images) of the surface layer for MWCNT yarn using the modified process: i) CNT-PU composite yarns (Left); ii) Pure CNT yarn (Right).

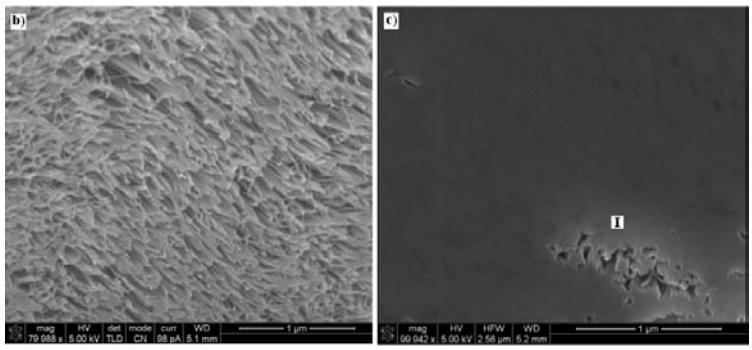



Figure 5. Morphology of the cross-sections of pure MWCNT and MWCNT-PU composite yarns using SEM-FIB: i) Cross-sections of a pure CNT yarn (Left) ii) Cross-section of a MWCNT-PU composite yarns (Right)

The tensile strength and strain data measured on the tensile tester installed at CSIRO (0.2 mm/min, room temperature) cover a range from 1.6GPa to 2GPa and 1.5%-2.5%, respectively (Figure 6). The storage modulus was characterised by a DMA and Figure 7 shows a typical result of the constant frequency temperature scan (1Hz, 5°C/min) on the elastic and damping behavior of the CNT-PU composite yarns. The curves depict that the storage modulus of CNT/PU composite yarn is very high (from 120GPa to 150GPa).

The Fourier Transform Infrared Spectrometry was also used to chemically analyze the presence of polymer in the composite yarns and this data will be presented at the conference.

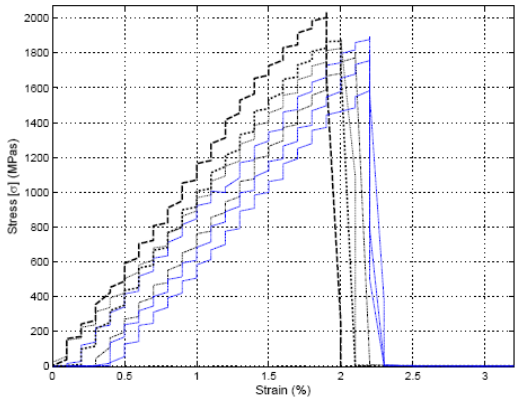



Figure 6. The stress-strain curve of CNT-PU composite yarn samples on the tensile tester (Chatilon, 0.1mm/min, room temperature, Twist factor 2000 turms per metre).

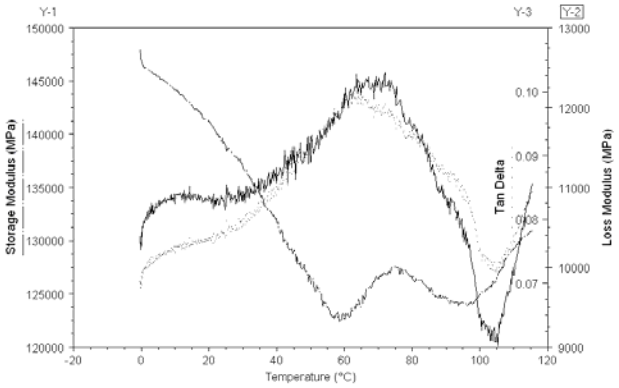



Figure 7. The schematic of DMA results for a CNT-PU composite yarn: Storage Modulus, Loss Modulus and Tan Delta plotted against temperature using the constant frequency mode yarn spinning.

## REFERENCES


[1] T.W. Ebbesen Carbon nanotubes: preparation and properties. New York, CRC (1997).

[2] K. Jiang, Q. Li and S. Fan, Nature 419, 801 (2002).

[3] S.J. Tan, A.R.M. Verschueren and C. Dekker, Nature 393, 49-52 (1998).

[4] E.B. Malarkey and V. Parpura, Neurodegenerative Diseases 4, 292-299 (2007).

[5] C.D. Tran, W. Humphries, S.M. Smith, C. Huynh and S.Lucas, Carbon 47(11), 2662-2670 (2009).

[6] Y. Li, I.A. Kinloch and A.H. Windle, Science 304, 276–278 (2004).

[7] P. Poulin, B. Vigolo and P. Launois, Carbon 40, 1741–1749 (2002).

[8] F Du, J.E. Fischer and K.I. Winey.,Journal of Polymer Science Part B: Polymer Physics 41(24), 3333–3338 (2003).

[9] Y. Bin, M. Kitanaka, D. Zhu and M. Matsuo, Macromolecules 36(16), 6213–6219 (2003).

[10] Z. Jia, Z. Wang, C. Xu, J. Liang, B. Wei, D.Z. Wu and W. Shao, Materials Science and Engineering A271, 395–400 (1999).

[11] M. Wong, M. Paramsothy, X.J. Xu, Y. Ren, S. Li and K. Liao. Polymer 44, 7757–7764 (2003).