A Study Of Electrical Property In Composite Of High Density Polyethylene/ Carbon Nanotubes Monofilaments for Future Intelligent Textile

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Abstract
Polyethylene matrix composite in the form of a continuous fiber enhanced the electrical conductive and strength properties with carbon nanotubes (MWNT). The composites were prepared using a conventional polymer fiber processing technology. The strength and electrical resistivity (Ω-cm) results related to a different CNTs's volume fraction of these composites. As the monofilament yarns, the composite has young modulus of 439-589 MPa, tensile strengths of 62-72 MPa, and electrical resistivity at 5.87×10^{2} Ω-cm. Scanning electron microscopy (SEM) demonstrated qualitative nanotubes morphology. This study found that the yarn can be obtained the mechanical and electrical properties by combining polymer composite /carbon nanotubes content.

***Keywords**: Carbon nanotubes, Polyethylene, Electrical resistivity, Polymer composite.*

1. Introduction
For many decades, the textile industry in Thailand has remarkably played an important role in Thailand's economy in terms of valued-added, employment and export earnings. Although the Thai textile industry has been growing rapidly and has become the leading industry of the country, the industry still has some problems in recent years [6]. Most of the export products of Thai textile are commodity types that are subject to vicious competition and have lower prices. Recently, the wage rate in textile industry tends to be higher thus, the cost of production has increased (Pinijparakarn, 2010). Besides there is no research or lack of conventional textile laboratory and development activities for testing for basic quality control in factories. [6].

Since nanotechnology is widely spreading into many practical applications, products and industries (of course in textile industry), the problems and issues raised above lead to highly interest to highlight on innovation in textile in order to make more investment channel choices for textile industry and entrepreneur. The ability to develop innovative new products can be a source of competitive advantage for those companies and the generation of ideas for new products or creativity is the first step in this innovation process [4]. For the past few years, innovative textiles represent the next generation of fibers through the incorporation of intelligent textile or electronic devices. Many intelligent textiles already feature in advanced types of clothing, The idea of producing both structural and functional multi-phase composites with enhanced performance is currently under develop-ment in a wide variety of ceramic, metallic and polymeric matrices (Joshi et al., 2010), Many research scientists believe that the excellent physical, thermal and electrical properties of carbon nanotubes can be realized at the macroscale by incorporated them into polymer matrices.

Carbon nanotubes (CNTs) have attracted particular interest because they are predicted, and indeed observed, to have remarkable mechanical and other physical properties [3]. The combina-tion of these properties with very low densities suggests that CNTs are ideal candidates for high-performance polymer composites in a sense they may be the next generation of carbon fibers [4]

2. Methodology

2.1. Materials and Equipment

2.1.1) High Density Polyethylene 5000series (HDPE 5000s) was provided by Mini Lab., Science Faculty, Mahidol University and was used as received. Multiwall Carbon Nanotubes; Babytubes C150 P was provided by Toyota Tsusho (Thailand) Co., Ltd. with purity grade of > 95%. The diameter is 5-20 nm with length of 1- >10 microns and was used as received.

2.1.3) Thesingle-screw extruder Randcastle.

2.1.4) The two-roll mill machine.The equipments were facilitated by Mini Lab., Science Faculty, Mahidol University, Salaya Campus, Nakorn Phrathom.

2.2 Method

2.2.1) The 200 g. total of HDPE chips were prepared together with specific ratios of CNTs at 3, 5 and 10% by weight (polymer-based), respectively.

2.2.2) The composite samples with different CNTs weight ratios were firstly fabricated with a two-roll mill machine. The two-roll mill machine has been operated at constant temperature of 180°C. HDPE chips were filled into the two-roll mill machine and HDPE chips slowly well melted. then CNTs powder were carefully poured into the melting HDPE started at 3, 5 and 10% by weight, respectively.

2.2.3) The machine operated (~10 min.) to ensure well dispersion of CNTs over HDPE melting. Therefore, thick sheets of homogeneous mixture (HDPE-CNTs) have been made using a hot press of two-roller. Allowed the sheets cool down in the ambient temperature, then cut into small pieces by scissor before traditional fiber extrusion processing.

2.2.4) The cut pieces of HDPE-CNTs composites have been placed in the single-screw extruder (Randcastle). Circular monofilaments were extruded through a single-hole fiber die (diameter = 0.024 inches (0.6 mm), L/D = 2/4) and let it fall freely in a surrender steel tube without any tension force in the water bath at room temperature. The fiber has been combined with a low speed godet and a drawer with constant spinning and winding rate. The spinning conditions in this work have been selected from trails and errors to ensure the stability in forming of a continuous uniform fiber (monofilament). The operating conditions of extruder can be parameterized as followings: Temperature Zone 1 = 31°C /126°C, Temperature Zone 2 =200°C, Temperature Zone 3 =250°C, and Screw Speed = 2 (50 rpm).

2.3 Electrical resistance measurement

2.3.1 Instrument

Inductance (L), Capacitance (C), Resistance (R) Meter : Instek - LCR Meter: Model 819 provided by NANOTEC, National Science and Technology Development Agency (NSTDA), Thailand.

2.3.2 Method

2.3.2.1) The electrical resistance of the conductive fiber has been measured by LCR meter with two electrical parameters as followings: Frequency (F) = 1 kHz and Voltage (V) = 1.275 V. (The voltage can be adjusted between 0.003 to 1.275 V)

2.3.2.2) The insulator were prepared by 2 x 4 cm-sized hard paper, entwined by 15 times with the conductive fiber, having the fiber twirl adjacent to one another.

2.3.2.3) The electrical resistance measurement has been performed as a bunch of fiber (15 fibers) clamped by using small alligator clips connected to LCR meter. Since the response (electrical resistance value) relatively fluctuates due to the dispersion of carbon nanotubes in the polymer matrix, the responses were collected for 10 values. Each values were multiplied by 15 to get an electrical resistance value that represented the conductive monofilament.

2.3.2.4) Repeat step 2-3 again with new fiber (same length and %weight CNTs) from a bobbin to perform the electrical resistance measurement 10 times to confirm the data were reproduced.

2.3.2.5) Repeat step 1-4 again with new fiber but with other CNTs weight ratio fibers.

2.3.2.6) The descriptive statistic has been used to analyze the electrical resistance response from the experiments.

2.4 Characterization

Scanning Electron Microscope (SEM) has been used to characterize the obtained conductive fibers to observe the CNTs dispersion corresponding to weight ratio and electrical resistance. SEM (Hitachi S-3400N) was provided by NANOTEC, National Science and Technology Development Agency (NSTDA), Thailand. SEM studies will be performed for both the surface of fibers and the cross-sectional surfaces of the cut fibers to study the dispersion of the CTSs in polymer matrix and the effect of CNTs fillers in the filaments. The fibers were clamped vertically using Scotch tape and adhesive onto SEM stubs. The stubs and the samples were coated with gold using a Denton Vacuum Desk-II sputtering machine. The cross-sectional surfaces of the cut fibers were observed under different magnification levels.

2.5 Tensile Test

The Testometric 5kN Model M350-5 AT: Materials Testing Machine was provided by Department of Textile and Garment, Faculty of Textile Industry, Rajamangala University of Technology Krungthep. The test speed wa 100 mm/min and the sample length was 100 mm with fiber width and thickness of 10 and 1 mm as the setting standard conditions (applied with the specimen) of tensile test, respectively.

3. Result

SEM images of neat HDPE and HDPE-CNTs composite fibers with different CNTs contents by weight are demonstrated in Figure 1 – 4 with average fiber diameter of 621 microns. Figure 1 shows the neat HDPE fiber and it can be observed that the roughness on the fiber surface is very low due to the CNTs fillers are not present but some impurities were normally noted as at white spots in SEM images.

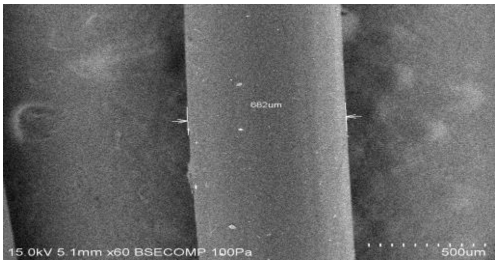

Figure 1 SEM images of the neat HDPE filaments. filament surface.

However, the roughness on the fiber surface is clearly shown that the increasing CNTs content in polymer matrix, the more high roughness of the fiber surface is observed. The roughness on the fiber surface is due to the amount of CNTs filler present in the polymer fiber.

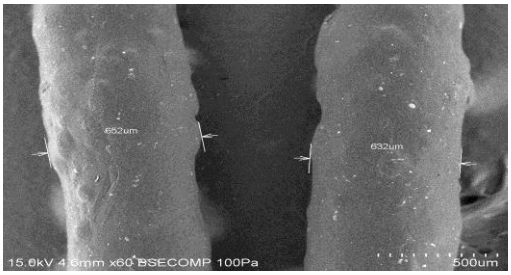

Figure 2 SEM images of HDPE-CNTs filaments with 10% CNTs content by weight, filament surface.

At the 10% CNTs content by weight, the lowest electrical resistance can be observed from the image of SEM (a) that the surface of the fiber is more rougher than the 3% and 5% CNTs content by weight.

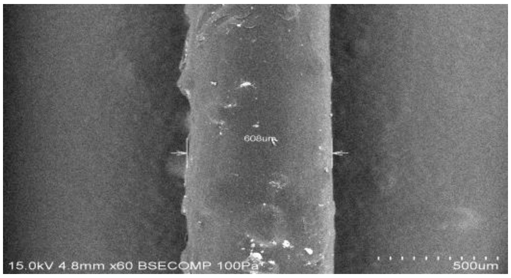

Figure 3 SEM images of HDPE-CNTs filaments with 5% CNTs content by weight, filament surface.

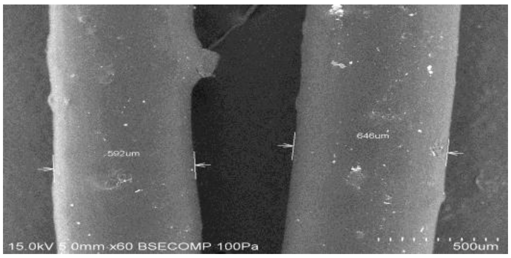

Figure 4 SEM images of HDPE-CNTs filaments with 3% CNTs content by weight, filament surface

Type	**Mean (MΩ)**	**S.D.**
CNTs 3%	114	17
CNTs 5%	37.4	12.2
CNTs 10%	0.8	0.3

Table 1 The electrical resistance (R) in conductive monofilaments with different percentages of carbon nanotubes content

The electrical resistance in conductive monofilaments of CNTs-HDPE is tabulated in Table 1 with different carbon nanotubes content. Consider the electrical resistance for fibers with 3, 5 and 10% CNTs content by weight, the electrical resistance decreases as increasing amount of CNTs. The electrical resistance shows here obtained with 95% error limits using statistical *t*-test of one sample group as shown as approximately equals to 114±34, 37±24 and 0.8±0.6 MΩ for 3, 5 and 10% CNTs content by weight, respectively. This can be naturally explained that CNTs content is a key feature in conductive property in polymer-CNTs composites.

Type	**Mean (Ω-cm)**	**S.D.**
CNTs 3%	8.6×10^{4}	13135
CNTs 5%	2.83×10^{4}	9,213
CNTs 10%	5.87×10^{2}	229

Table 2 The resistivity volume of conductive monofilaments with different percentages of carbon nanotubes content

The resistivity volume of conductive fibers with different CNTs content by weight is tabulated in Table 2. is a range of resistivity volume corresponding to insulative to conductive properties of materials.

It can be noted that the conductive monofilaments of HDPE-CNTs prepared in this work show the dissipative property as the electro-static dissipative (ESD) materials for 3, 5 and 10% CNTs content in HDPE since they fall into a range of 10^4 – 10^2 Ω-cm of resistivity volume. The resistivity volume in HDPE-CNTs filaments with different CNTs content was calculated to classify the type of obtained conductive fibers. It can be seen that the resistivity volume of conductive fibers are 8.30×10^4, 2.83×10^4 and 5.87×10^2 Ω-cm for HDPE-CNTs fiber with 3, 5 and 10% CNTs content, respectively.

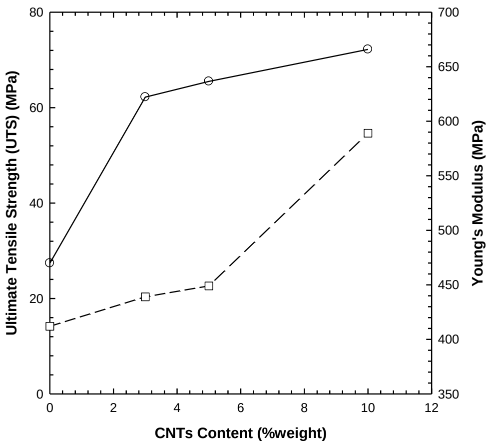

Figure 5 Ultimate tensile strength and Young's modulus as a function of CNTs content by weight for HDPE-CNTs conductive fibers.

The CNTs fillers play an important role in polymer matrix in terms of reinforcement as CNTs strength is derived from the strong in-plane graphitic bond. Consider the ultimate strength of the composite fibers, the neat HDPE shows a low ultimate strength of 27.4 MPa from this work but the ultimate strength significantly increases 200-260% when CNTs fillers increase for only 3-10% by weight. The tensile strength of CNTs-polymer composites is generally improved, although a detailed comparison of the data is difficult due to the different types of fillers, surface treatments, matrices, processing techniques, and test methods that have been used. It is also noted that Young's modulus increases as increasing CNTs content as it is the reinforced fillers in the polymer fibers.

4. Conclusions

The tensile strength of HDPE-CNTs filaments with different CNTs content is investigated by tensile testing at room temperature. It can be noted that the tensile strength increases by 200-260% when CNTs content increases only 3-10% by weight. Also, Young's modulus increases as increasing CNTs content.

The morphology of the fiber can be observed from the Scanning Electron Microscope (SEM), the fiber surface is clearly shown the roughness increases when CNTs content increases.

The resistance of HDPE-CNTs filaments decreases when CNTs content increases. This can be explained that the CNTs content plays a role as a key feature in polymer-CNTs composites.

5. Acknowledgement

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