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Effect of Carbon Nanotube on Electrical and Morphological Properties of Tissue Equivalent Polyamide/Polyethylene Nanocomposite

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Abstract—A tissue equivalent nanocomposite based on polyamide6 and polyethylene filled with different parts of CNT (1-4%) was prepared. Electrical conductivity measurements showed that by adding only 3% CNT to PA6/PE blend, it reaches to percolation threshold. The electrical conductivity of the nanocomposite with 3% CNT reaches to 3×10^{-6} S/cm which is in the range of semi-conductive materials. SEM studies of conductive PA6/PE/CNT nanocomposite showed two distinct, co-continuous morphologies for PA and PE phases. TEM observation confirmed the co-continuous morphology for PA6/PE/CNT nanocomposite and selective localization of CNTs in PA phase and at the interface of two phases. Due to high aspect ratio of CNTs, they are in contact with each other inside the continuous PA phase and formed a conductive network which could provide electrical properties in nanocomposite. Consequently, low percolation threshold of PA6/PE/CNT nanocomposite is resulted from formation of double percolation structure in co-continuous phases of PE and PA and in CNT networks in PA phase of nanocomposite.

Index Terms—Polyamide6/Polyethylene blend; Carbon nanotube; Nanocomposite; Electrical conductivity; Double percolation

I. INTRODUCTION

The distribution of absorbed dose in the body of a patient undergoing radiotherapy can be obtained by microdosimetry in tissue equivalent materials. These materials should have elemental composition and electrical conductivity similar to human tissue. From the standpoint of elemental composition, polymers are a good substitute for these materials but they are non-conductive [1]. By adding a carbon based conductive filler such as carbon black [2], carbon nano tube [3], graphite [4] or metal powder [5], polymers can be made electrically conductive. At a critical concentration of conductive filler which is called the percolation threshold, the carbon particles begin to coagulate so as to form networks which facilitate electrical conduction [6]. The unique structure of CNT with high aspect ratio (L/D) enables CNTs to be in contact with each other inside the polymer matrix and provides extraordinary electrical properties.

and provides extraordinary electrical properties. The PA6/PE blend with hydrogen, carbon, nitrogen and oxygen elements has chosen as a tissue equivalent material [7]. Furthermore, multi wall carbon nanotube is used as filler to create electrical conductivity at low percolation. The dispersion of CNTs in such nanocomposites plays a crucial role in the achievement of appropriate electrical conductivity. In this work, the amount of CNT for creating electrical conductivity in PA6/PE blend and morphology of the prepared conductive PA6/PE/CNT nanocomposite have been investigated. Also, the density of the composite compared with the soft tissue.

II. MATERIALS AND METHOD

Polyamide 6 and high density polyethylene (HDPE0035) were purchased from the Kolon Company (Korea) and Bandar Emam petrochemical co. (Iran), respectively. PE-g-MA was supplied from Aldrich co. as compatibilizer. The carbon nanotube with outer diameter of 10-20 nm, length of 10-30 μm and specific surface area of 200 m^2 /g was obtained from Tarbiat Modarres University.

Prior to compounding, the polyamide 6 granules were dried in the vacuum oven at 80 °C for 16 hours. The PA6/PE/CNT blend composites with PA/PE ratio of 1:1.5, 5% compatibilizer and 1- 4 wt. % carbon nanotube were prepared by melt compounding in a brabender internal mixer at 240 °C with the rotational speed of 70 rpm for 8 minutes. Sheet samples with 2 mm thickness were prepared with Dr. Collin hot press at 240°C to obtain specimens for testing.

The electrical conductivity of the samples was measured using Keithley electrometer, according to the equation of σ = L/RA, where σ (S/cm) is the electrical conductivity, R (ohm) is the electrical resistance, L (cm) is the measured sample length and A (cm^2) is the area of the cross section of the sample.

The morphology of PA6/PE/CNT blend nanocomposite was studied through scanning electron microscopic (SEM) analysis by using Zeiss EVO-18. Samples were cryofractured in liquid nitrogen. In order to distinguish PA phase from PE phase, the samples were etched by formic acid for removing PA phase. The etched surface was gold sputtered to avoid the charging of the sample.

TEM micrograph was carried out with a Philips instrument. Thin layers of sample (100 nm) were cut by ultramicrotome and were exposed to osmium tetroxide vapor (OsO4) for one hour to generate a contrast between PE and PA6 domains.

Density of the PA-PE-CNT nanocomposites was determined by the ratio of the mass to the volume of the sample. The uncertainties in the measurement of mass and volume were 0.0001 g and 0.01 cm^3, respectively.

III. RESULTS AND DISCUSSION

Figure 1 shows the relation between electrical conductivity and carbon nanotube (CNT) fraction in PA6/PE/CNT nanocomposite. It is observed that at 2% and lower CNT loading, the blend is

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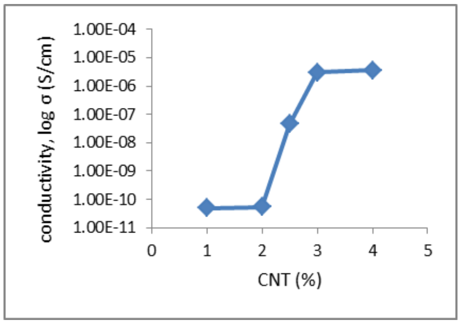

Fig. 1. The changes of electrical conductivity of PA6/PE/CNT nanocomposite with CNT amount.

nonconductive. By increasing of CNT amount, at 2.5% CNT electrical conductivity of the PE/PA6 nanocomposite begins to increase and at 3% CNT the nanocomposite reached to percolation threshold and changed to conductive material. Increasing of CNT content leads to the coagulation of carbon nanotubes to form networks which facilitate the electron conductivity through the nanocomposite. The electrical conductivity of the nanocomposite with only 3% CNT reaches to 3×10^{-6} S/cm which is in the range of semi-conductive materials. This amount of filler is much lower than traditionally used conductive fillers, such as carbon black which is usually used around 10-20% [8]. As it is observed, further increasing of CNT amount (4%) has not significant effect on electrical conductivity of the nanocomposite.

Scanning electron microscopy (SEM) photographs of conductive CNT filled (3%) PA6/PE/CNT nanocomposite with 5 and 40 kx magnifications are shown in fig. 2a and 2b, respectively. In Figure 2a two distinct regions are observed which are related to PE matrix and continuous PA phase which is removed by etching. So, it is seen as empty regions in PE matrix. This figure shows continuous phase for both regions which indicates the co-continuous structure of the prepared nanocomposite.

The high magnification SEM image of conductive PA6/PE/CNT nanocomposite (Fig. 2b) shows that CNTs are preferentially located in the PA6 phase and at the interfaces between the PE matrix and PA phase instead of being randomly distributed throughout the whole system. This is attributed to the higher affinity of CNTs with polar PA phase than nonpolar PE phase [9].

TEM was also used to observe the details of the structure in the conductive PA6/PE/CNT nanocomposite filled with 3% CNT, as displayed in Fig. 3. In this figure two distinct regions are observed. The light region belongs to PE matrix and the dark region with CNTs is PA phase because polyamide with functional groups is more readily stained than PE. In this figure, it is observed that CNTs are selectively dispersed in PA phase and at the interface of two phases and formed conductive networks. Although the amount of CNT is low (3%) but due to high aspect ratio of CNTs, they are in contact with each other inside the continuous polyamide phase of nanocomposite and formed a conductive network which could provide extraordinary electrical properties.

As the result, in PA6/PE/CNT nanocomposite, co-continuous phases of PE and PA (first percolation) in combination with the formation of CNT networks in PA phase (second percolation) built the double percolation structure which reduces the percolation threshold value.

The density of the PA/PE/CNT composite was obtained 1.06 g

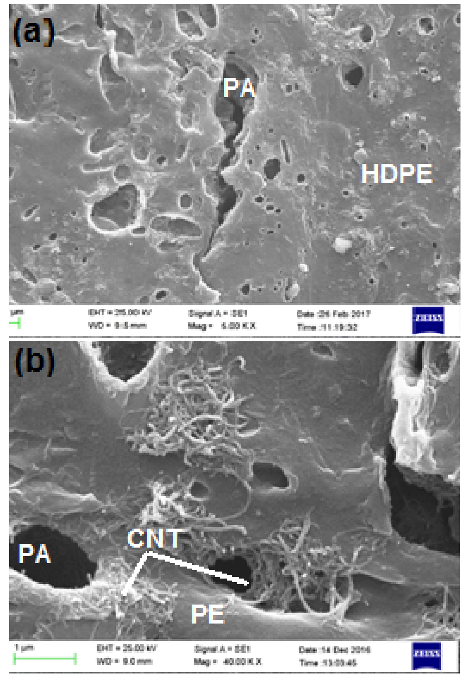

Fig. 2. SEM micrograph of the conductive PA6/PE/CNT nanocomposite filled with 3% CNT; 2a)5 kx and 2b)40 kx.

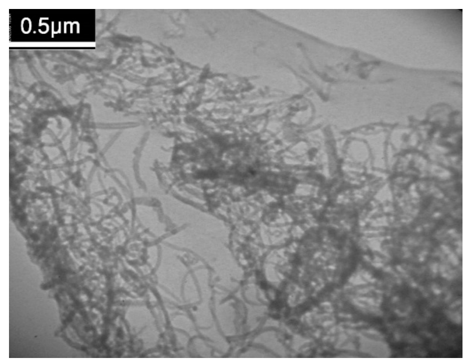

Fig. 3. TEM micrograph of the conductive PA6/PE/CNT nanocomposite.

cm^{-3} which is close to 1.04 g cm^{-3} for the soft tissue.

IV. CONCLUSIONS

For creating electrical conductivity in PA6/PE blend as a tissue equivalent material, CNT is used as a conductive filler. PA6/PE/CNT nanocomposite filled with 3% CNT showed electrical conductivity in the range of semi-conductive materials. High aspect ratio of CNTs facilitate the formation of conductive network in continuous PA phase, built the double percolation structure in PA6/PE/CNT nanocomposite which reduces the percolation threshold value. The similarity of composite density with soft tissue represents the tissue equivalency of the PA6/PE/CNT nanocomposite.

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