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Mechanical, thermal and impedance properties of oil-extended EPDM/MWCNT nanocomposites: Efficacy of MWCNT reinforcement

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The systematic appraisal of mechanical, thermal and impedance characteristics of oil-extended ethylene propylene diene monomer (EPDM) rubber nanocomposites was conducted through incorporating different concentrations of multiwalled carbon nanotube (MWCNT). Morphology and dispersion of MWCNT concentration in EPDM elastomer nanocomposites have been analyzed through both tools, transmission electron microscopy (TEM) as well as scanning electron microscopy (SEM). Nanofiller impact on the mechanical features of prepared EPDM elastomer nanocomposites are improved as compared to neat EPDM elastomer owing to the reinforcing effect of MWCNT into EPDM matrix. The analysis of thermal stability of EPDM/MWCNT nanocomposites was also conducted through differential thermal analysis (DTA) and thermogravimetric analysis (TGA). It shows the capability of nanofiller in hindering the heat diffusion into elastomer matrix. Spectra of impedance analysis of EPDM/MWCNT nanocomposites were also accomplished in the 10^0 Hz to 10^5 Hz frequency range at various concentrations of MWCNT. Study of impedance parameters revealed the significant changes in real impedance as well as imaginary part of impedance and also provides elucidations that will depend on the interfacial polarization and relaxation aspects of EPDM elastomer matrix. The magnitude of real impedance decreases with increasing frequency and MWCNT concentrations due to augmented conduction in EPDM elastomer nanocomposites and also the imaginary part of impedance shows relaxation peak which shifts towards higher frequency.

Keywords: Ethylene propylene diene monomer, impedance, MWCNT, relaxation.

Introduction

The broad research work have been done on exclusive grouping of low density materials with the materials of high strength and stiffness leads to the enhanced properties of several composites and hence led to developed technologies. Rubber nanocomposites are more popular and mostly used due to their light weight, stretchable design and process ability. Present investigations are centered on carbon nanofillers such as carbon black[1], carbon nanotubes[2], and nanographite[3]. There are many applications of these nanocomposites are found in the field of electronics and antistatic devices, gas sensors, electromagnetic shielding devices etc.[4].

Oil-extended ethylene propylene diene rubber has been used as an elastomer with reinforcing MWCNT to prepare polymer nanocomposites. The present research work studied the thermal properties and frequency dependent impedance analysis of EPDM elastomer nanocomposites after adding different concentrations of MWCNT into rubber matrix.

Materials and methodology

Materials:

The rubber that has been used to formulate elastomer nanocomposites was oil-extended ethylene propylene diene monomer (EPDM) with 20% oil and 7.5 wt% of ethylene-norbornene, prepared by DSM elastomers, Singapore. MWCNT having purity ≥ 99% was supplemented as reinforcing nanofiller phase and procured through Nanoshel LLC, USA. Dicumyl peroxide (DCP) manufactured through Aldrich Chemical Company, USA was used as curative (with purity 98%). Also zinc oxide as well as stearic acid of chemically pure grade was obtained from common sellers.

Mixing and sample preparation:

An oil-extended EPDM elastomer was used to formulate required sample and mixed with other ingredients in laboratory size two roll mixing mill. Mixing components are listed in Table 1. During the process of mixing, temperature was maintained around 60–70°C and nip gap, mixing time and cutting operations were also maintained. The obtained samples were then heated electrically and then the Moore Hydraulic press was used to mould the prepared samples at constant casting environment.

Table 1. Components of EPDM elastomer nanocomposites with MWCNT nanofiller as reinforcing agent

Ingredients	Parts per hundred parts of rubber (phr)
Oil-extended EPDM Rubber (with 20% oil)	120.0
Zinc oxide	5.0
Stearic acid	1.5
Dicumyl peroxide (DCP)	1.0
MWCNT	0.0, 2.0, 4.0, 6.0

Results and discussion

Morphology:

SEM images of unfilled (0% MWCNT) and 2%, 4%, 6% MWCNT reinforced EPDM elastomer nanocomposites are represented in Fig. 1. The figure evidently shows the proper distribution of nanofillers into the EPDM matrix. Fig. 2 illustrates the TEM pictures of EPDM/MWCNT nancomposites. The figure evidently shows the homogeneous dispersion of MWCNT into EPDM matrix at low concentration of nanofiller, while at higher amount, conversely agglomeration takes place.

Mechanical properties:

The impact of MWCNT reinforcement on the statistics of mechanical performances of EPDM elastomer nanocomposites are illustrated in Table 2. The given data clarifies that the modulus, toughness and tensile strength rises with MWCNT concentrations. However, elongation at break declines with filler concentration. Improvement are mainly because anisotropic nanofillers have strong aligning capability under strain and also due to the foundation of filler network even at low level of concentration due to high aspect ratio of nanofillers[5].

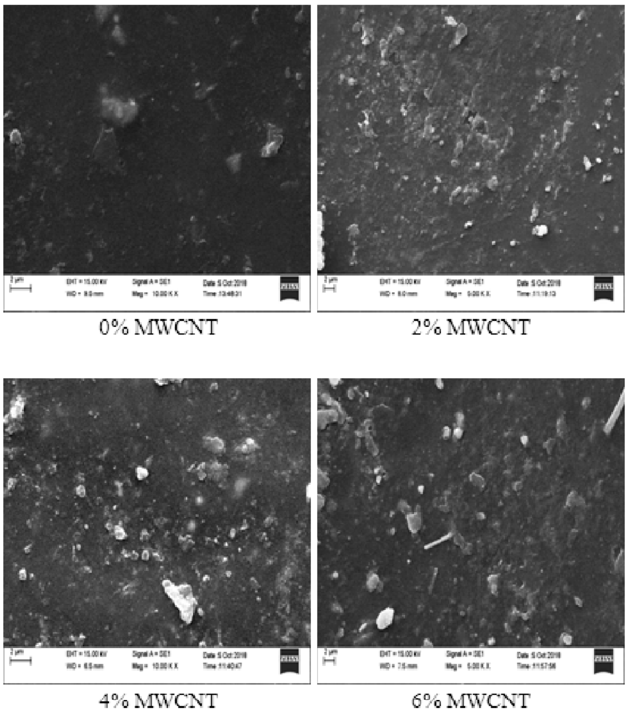
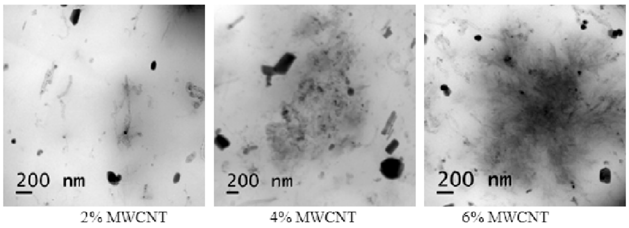

0% MWCNT 2% MWCNT 4% MWCNT 6% MWCNT

Fig. 1. SEM photomicrographs at different concentrations of MWCNT in EPDM nanocomposites.



2% MWCNT 4% MWCNT 6% MWCNT

Fig. 2. TEM photomicrographs at different concentrations of MWCNT in EPDM nanocomposites.

Table 2. Statistical data of mechanical properties of EPDM nanocomposites with various concentrations of MWCNT

MWCNT concentrations (%)	Tensile strength (MPa)	Modulus (MPa)	Elongation at break (%)	Toughness (MPa)
0	1.033	1.694	988.125	7.052
2	1.332	1.708	759.375	7.704
4	1.742	1.952	697.255	7.781
6	1.971	1.985	656.875	8.481

Thermal characteristics:

Thermogravimetric analysis (TGA) and differential thermal analysis (DTA):

Graph for both TGA and DTA analysis of EPDM/MWCNT nanocomposites are presented in Fig. 3 and Fig. 4, respectively with various concentrations of MWCNT. According to the TGA thermogram, thermal stability increases with increasing concentrations of MWCNT. As a result of which diffusion of volatile decomposition products of polymer nanocomposites are delayed[6].

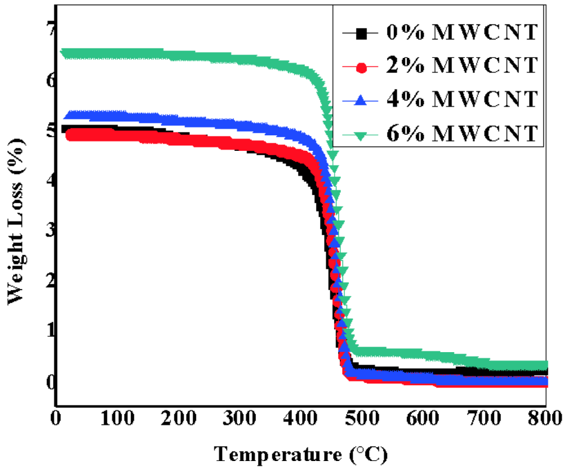


Fig. 3. TGA curves of EPDM/MWCNT with different concentrations of MWCNT.

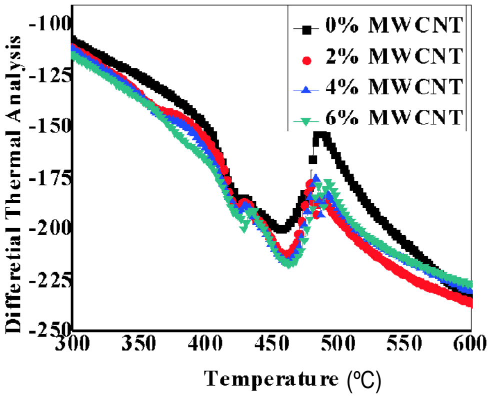


Fig. 4. DTA curve of EPDM/MWCNT with different concentrations of MWCNT.

Impedance analysis:

Real part of impedance:

The real impedance of EPDM nanocomposites with varying frequency at different concentrations of MWCNT is shown in Fig. 5. Regardless of filler loadings, there is a continuous reduction in real part of impedance as the frequency increases and it becomes constant at high frequency (above 10^4 Hz). The reason behind this trend in impedance is the conveyance of current in conductive elastomer nanocomposites through continuous conductive network which forms due to the homogeneous distribution of agglomerated and aggregated conductive fillers like MWCNT within the insulating EPDM matrix[7].

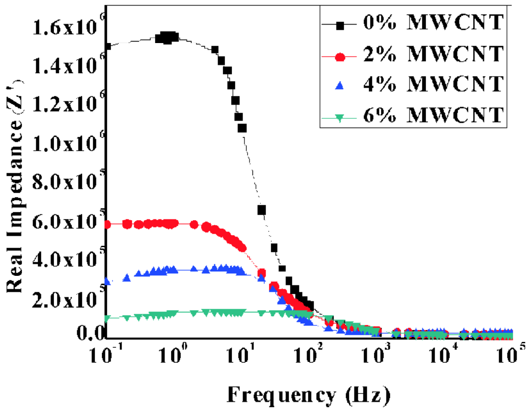


Fig. 5. The graph of real impedance of MWCNT reinforced EPDM nanocomposites with varying frequency.

Imaginary part of impedance:

The dependence of imaginary part of impedance spectra of EPDM/MWCNT nanocomposites on frequency and filler concentrations is signified in Fig. 6. The peak shown in frequency region reveals the existence of dipolar relaxation phenomenon and shows better capacitive and lower resistive conduct of nanocomposites with increasing concentrations of MWCNT. In the proximity of dispersed phase surface stiffness of polymer layer is advanced than that of the whole polymer as a result of controlled molecular mobility due to interactions between phases[8]. Hence, relaxation process becomes more difficult because of high adsorption of elastomer on the filler exterior with increasing filler loadings.

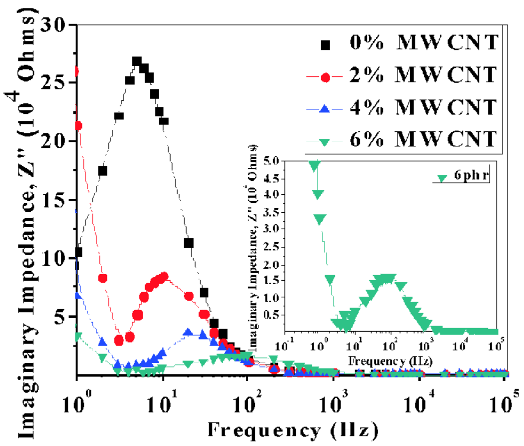


Fig. 6. Graph of imaginary impedance of MWCNT reinforced EPDM nanocomposites with varying frequency.

Conclusions

The incorporation of MWCNT nanofiller into the matrix of EPDM considerably changes the whole performances of prepared elastomer nanocomposites as compared to conventional elastomeric systems. Uniform distributions of MWCNT in EPDM matrix was obtained through morphological studies. The study confirms the homogeneous distribution of nanofiller upto 4% of MWCNT concentration after which agglomeration of nanofillers takes place. Also the reason behind the enhanced thermal stability of nanocomposites is the frame-up of degraded products of EPDM inside the assembly of EPDM/MWCNT nanocomposites. Characteristic peaks are shown in complex impedance with varying frequency and also the value of real part of impedance decreases as the frequency increases which shows better capacitive and decreased resistive behaviour of prepared nanocomposites.

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