

STUDY ON IMPACT STRENGTH AND EFFECT OF ACCELERATED WEATHER TESTING ON SOME PROPERTIES OF POLYOXYMETHYLENE/SILICA NANOCOMPOSITES[#]

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Abstract. The impact strength, some properties and morphology of nanocomposites based on polyoxymethylene (POM) and nano-silica (NS) with different content before and after accelerated weather testing are discussed in this paper. The impact strength of all POM/NS nanocomposite samples is larger than that of POM but decreased when the content of NS is more than 0.5 wt.%. The greatest value is 70.43 J/m at 5 wt.% of NS content (POM/0.5NS). The FTIR spectra of POM and POM/NS nanocomposites show the appearance of characteristic peaks of POM and NS in the nanocomposites. Carbonyl index (CI) for POM and POM/NS nanocomposites are changed after testing responding to the increase of C=O group content. The change of CI of POM before and after testing is 0.34, while that of all POM/NS nanocomposites is only around 0.15. The results of the tensile properties of POM/NS nanocomposites indicate that samples are decomposed by ultraviolet (UV) radiation and photo-oxidation degradation of POM. The tensile properties of POM/NS nanocomposites are larger than those of POM, and they are increased when rising NS content (from 0 to 1.5 wt.%). The retention of tensile strength and elongation at break of all POM/NS nanocomposites are reduced significantly while their Young modulus is less decreased after accelerated weather testing. The dielectric constant and dielectric loss tangent of the nanocomposites after testing are increased with rising NS content (from 0 to 2 wt.%). Contrary, volume resistivity of POM/NS nanocomposites after testing is reduced from $5.9 \times 10^{+11}$ to $6.4 \times 10^{+10}$ with rising NS content (from 0 to 2 wt.%). SEM images of the nanocomposites display the appearance of cracks on the surface of samples after testing. The number of the crack is decreased and the size of crack becomes smaller and fewer deeps when increasing NS content to 2 wt.%.

Keywords: polyoxymethylene, nano-silica, carbonyl index, dielectric properties, morphology.

Classification numbers: 2.4.4, 2.9.3, 2.9.4.

[#]Dedicated to the 40th Anniversary of Institute for Tropical Technology.

1. INTRODUCTION

Polymer composites used in the automotive industry are mostly affected by the photochemical reaction when subjected to severe weather conditions [1 - 2]. The photochemical reaction is also referred to as photo-degradation. In the photo-degradation process, the strength of the polymers is being affected which may be due to excessive UV penetration and thermal oxidation [3 - 4].

Polyoxymethylene (POM) is known as polyacetal (acetal), a highly crystalline high-performance engineering thermoplastic polymer. Its advantages are the low coefficient of friction, excellent wear resistance, high modulus, high strength, stiffness coupled with good impact strength and resistance to many solvents and automotive fuel [5]. POM is widely used in mechanic, automotive, and electric-electronic industries [6 - 8]. To maximize its practical use, stabilizers and antioxidants are added to polyacetal to enhance its resistance against oxidation, UV irradiation, ozone, etc.

Nanosilica (NS) is an inorganic additive, which has outstanding properties for some polymers such as high tensile strength, small expansion coefficient, high reflexes of UV light, high surface activity and so on. It is popularly used in the preparation of paints, coatings, plastic, rubber, adhesives [9 - 13].

Recently, the studies on the nanocomposites of POM/carbon nanotubes and POM/hydroxyapatite showed that the tensile, thermal and electric properties of the nanocomposites were improved by these nano additives [14 - 16]. Wacharawichanant *et al.* [17] studied the influence of particle size of ZnO on morphology, mechanical and thermal properties of POM/ZnO nanocomposites which were prepared by a melt mixing technique in a twin-screw extruder. Zakaria and Shelesh-Nezhad investigated the tensile behavior of POM/CaCO₃ nanocomposites and the mechanisms of the plastic deformation of nanocomposites [18]. Zhao and Ye indicated that the nano graphite well dispersed into the POM matrix. The effect of the type and the content of the graphite, the nature of the coupling agents used in the graphite modification on the properties of the composites were studied [19]. From the literature review, it can be seen that the above works did not concern the influence of the NS content or/and accelerated weather testing on some properties and morphology of POM/NS nanocomposites.

Our previous research mentioned the nanocomposite based on POM and NS was prepared by the melt-mixing method [20]. The results of some properties like tensile, thermal, dielectric and morphology indicated that the properties of POM/NS nanocomposite were increased when compared with neat POM.

In this work, we present the effect of NS content and accelerated weather testing on impact strength, other properties, and morphology of POM/NS nanocomposites. The change of their characteristics, properties based on FTIR spectra, retention tensile properties, dielectric properties, and morphology after accelerated weather testing were investigated and discussed.

2. EXPERIMENTAL

2.1. Materials

Polyoxymethylene (code F20-03) was supplied by Korea Engineering Plastics Co., Ltd (Korea) with a density of 1.41 g/cm³, melt flow index (MFI) of 9 g/10 min. The average

molecular weights are presented in Table 1. Nanosilica powder with a particle size of about 12 nm was supplied by Sigma-Aldrich Co. (USA).

Table 1. The average molecular weight for POM copolymers.

Sample	Mn	Mw	Mw/Mn (PDI)
POM F20-03	8 614	74 727	8.67

2.2. Preparation of POM/NS nanocomposites

POM and NS particles were dried at 80 °C in a vacuum for about 4-6 hours. Then, nanocomposites based on POM and 0.5 - 2 wt. % NS (compared with a total weight of two components) were prepared by melt mixing in the Haake Rheomixer (Germany) at 190 °C for 6 minutes and rotor speed of 60 rpm. After melt mixing, the nanocomposites were molded by a hot pressured machine (Toyoseiki, Japan) at 190 °C, pressing pressure of 12 - 15 MPa. The sample in sheet sharp was allowed to cool and be stored at room temperature for 48 hours before determining its properties and morphology. These samples were denoted as POM, POM/0.5 NS, POM/1 NS, POM/1.5 NS and POM/2 NS correspondingly to NS content of 0, 0.5, 1, 1.5 and 2 wt.%.

2.3. Accelerated weather testing

Accelerated weather testing of POM and POM/NS nanocomposites were carried out on UV condensation weather device (Atlas UVCON model UC-1, USA) at Institute for Tropical Technology, Vietnam Academy of Science and Technology (VAST) according to ASTM D4329-99 as follows: UV ray lighting is for 8 hours at 60 °C and then moisture condensation is for 4 hours at 50 °C. The time total of ultraviolet (UV) radiation – humidity heat test for all samples is 168 hours [21 - 22]. The source of UV radiation is 8 lamps UVB – 313 (maximum wavelength of 313 nm). After finishing, the samples were stored at room temperature for at least 24 hours before determining their properties and morphology.

2.4. Determination of nanocomposite morphology and characteristics

Izod impact strength test of nanocomposites was performed according to the ASTM D256 standard at room temperature. Each sample was measured five times, and reported represents the average of five measurements. A Nicole/Nexus 670 Fourier Transform Infrared (FTIR) spectrometer (USA) was used for recording the FTIR spectra of samples at room temperature as follows: 16 scan with 8 cm⁻¹ resolution and wave number ranging from 400 to 4000 cm⁻¹. Tensile properties (Young modulus, tensile strength, and elongation at break) of the nanocomposites were determined on Zwick Tensile 2.5 Machine (Germany) according to the ASTM D638. Dielectric properties (dielectric constant, dielectric loss tangent and volume resistivity) of the nanocomposites were evaluated on Agilent instruments model E4980A (Malaysia) with the 16451B test fixture for solid materials according to ASTM D150. Scanning electron microscopy (SEM) was used to study the morphology of the impact fracture surfaces for the POM and POM/NS nanocomposites. All specimens were coated with platinum before SEM image recording. UV radiation – humidity heat durability of the nanocomposites was calculated by the retention percentage of their tensile properties after accelerated weather testing (UV radiation – humidity heat testing).

3. RESULTS AND DISCUSSION

3.1. Impact strength

Impact strength expresses energy absorbed by the materials during the destruction process when materials are subjected to sudden impact loads. Figure 1 presents the impact strength of the POM/NS nanocomposites with various NS content before and after accelerated weather testing (UV radiation - humidity heat testing). The impact strength of POM/NS nanocomposites is higher than that of neat POM. For example, the impact strength of POM/NS nanocomposite at the NS particles content of 0, 0.5, 1, 1.5 and 2 wt.% are 60.09, 70.43, 63.75, 64.05 and 64 J/m, respectively. This may be because NS particles are well dispersed into POM, interacted with polymer matrix by hydrogen bonding between hydroxyl groups in POM and silanol groups on the surface of NS particles, thus, POM reinforced by NS nanoparticles is more durable and the POM/NS nanocomposites become tighter. Although the impact strength of POM/NS nanocomposites is higher than that of POM, it has a trend to decrease slightly when the content of NS nanoparticles is higher than 0.5 wt.%. This is explained by not regular dispersion of NS particles in the POM matrix. Therefore, the NS particles are easily clustered which form some defects in the POM matrix leading the structure of POM/NS nanocomposites to be less uniform, and decrease their impact resistance.

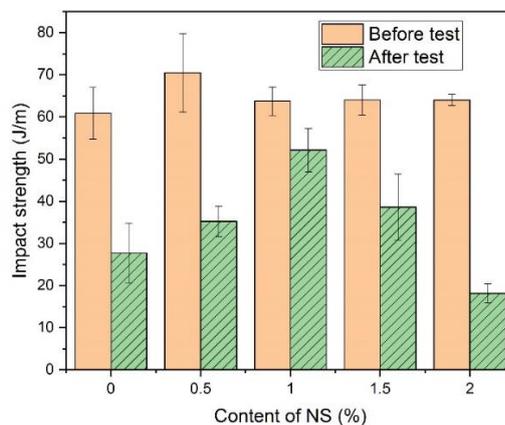


Figure 1. Impact strength of the POM/NS nanocomposites before and after accelerated weather testing.

After testing, POM and POM/NS nanocomposite experienced a significant reduction in the impact strength compared with that before testing. This proved that the nanocomposites have been decomposed due to the effects of accelerated weather testing conditions, especially, the effects of UV radiation. Despite the decrease of the impact strength after testing with all samples, the nanocomposite has an increase of impact strength (from 35.22 to 52.09 J/m) when rising gradually the content of NS from 0.5 to 1 wt.%. This indicates that the NS particle plays a role as the barrier which limits the effects of the factors such as UV radiation, temperature, and oxygen permeation into the POM matrix. However, the impact strength of POM/NS nanocomposite with NS content more than 1 wt.% is lower than that of POM. This may be explained by assumption that the clustering and agglomeration of NS at these contents (1.5 and 2 wt.%) are more than other NS contents. It leads to the formation of more holes inside the polymer matrix, and these holes are placed where many stresses are concentrated.

3.2. FTIR spectra

FTIR spectra of POM and POM/NS nanocomposite before and after accelerated weather testing are displayed in Figure 2. In the FTIR spectrum of POM, before and after testing, some peaks characterized for stretching and bending vibrations of C=O, C-O, C-H₂, O-H groups are found (Figure 2a). For example, C=O group stretching at 1736.6 cm⁻¹, C-O group stretching at 1280.3 cm⁻¹, C-H₂ group bending at 1470 cm⁻¹ and O-H group at 3744 cm⁻¹ [6].

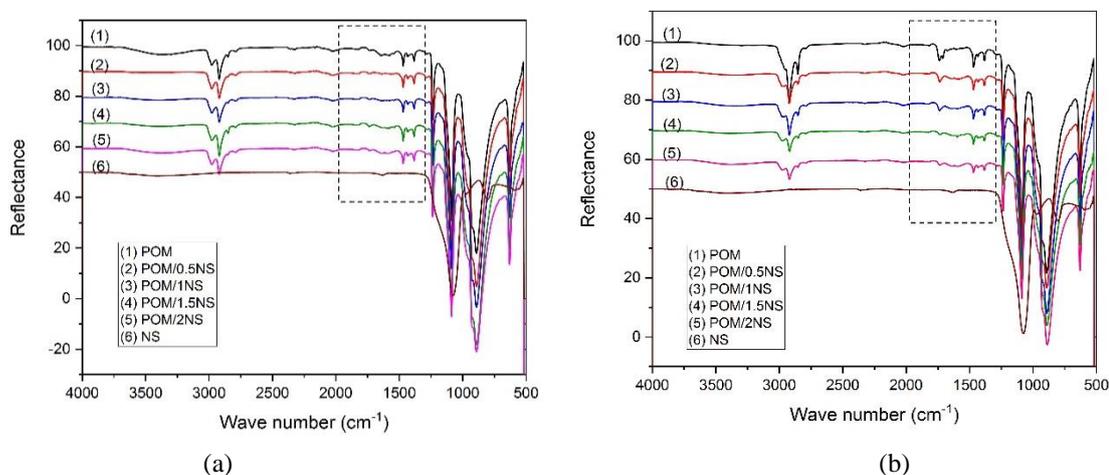


Figure 2. FTIR spectra of POM and POM/NS nanocomposite before (a) and after (b) accelerated weather testing.

The FTIR spectra of POM/NS nanocomposite before and after testing also show the characteristic peaks of POM and NS such as the peaks of C-H and C=O groups in POM at 917 cm⁻¹ and 1736 cm⁻¹, respectively (as mentioned above), asymmetric and symmetric stretching of Si-O group at 1082.11 and 795 cm⁻¹, O-H group at 3442 cm⁻¹ and Si-OH group at 955.1 cm⁻¹ [12]. Observing the Figure 2b, the FTIR spectra of POM and POM/NS nanocomposites after the test is an appearance of the absorption peak in the 1500-1800 cm⁻¹ regions. This peak is corresponding to the C=O group which expressed the photo-oxidation degradation process. However, the intensity of this peak decreased when rising the NS contents from 0 to 2 wt.%, meanwhile the POM samples have the highest intensity.

Figure 3 shows the bend region corresponding to the carbonyl group and the methylene bending in the FTIR of POM and POM/1.5NS nanocomposite. Interestingly, the absorption peak around 1735 cm⁻¹ characterized for the stretching vibrations of the carbonyl (C=O) group is seen clearly in the FTIR spectra of POM after accelerated weather testing (Figure 3). The band indicates a more obvious absorption expressing that the photo-oxidation degradation process takes place corresponding to the carbonyl group (C=O). Previous studies have assigned these carbonyl groups to formyl radical (-OCHO), yielding by B-scission of -O-CH- groups in the main chain as thermo-oxidation proceeds in testing [23]. The intensity and width of this peak are slightly decreased as shown in Figure 3. This is caused by the formation of the carbonyl groups such as ketone (at 1766 cm⁻¹), vinyl (at 1697 cm⁻¹), etc. From the Figures 2 and 3 it proves that POM chains and POM/NS nanocomposites are decomposed by photo-oxidation degradation reactions to form formic aldehydes, vinyl, ketone, etc. (Figure 4) [24].

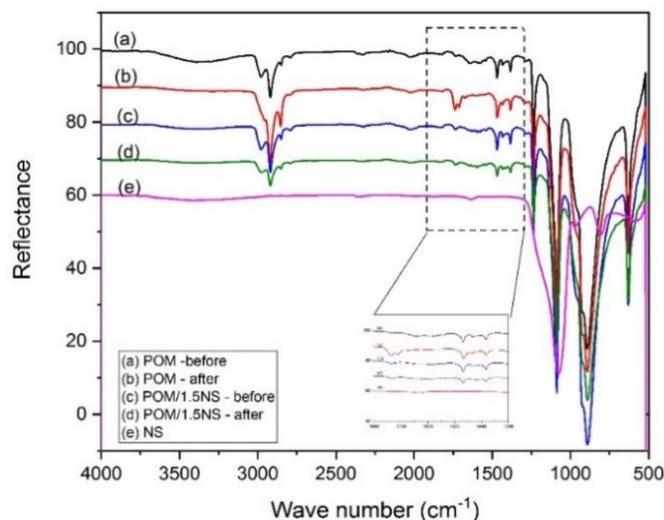


Figure 3. FTIR spectra of POM and POM/1.5 wt.% NS nanocomposite before and after accelerated weather testing in the band region corresponding to the carbonyl aldehyde group and the methylene bending.

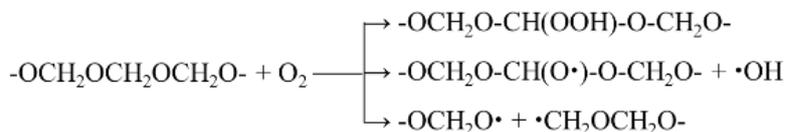


Figure 4. Decomposed reactions of POM chains [23].

Carbonyl index (CI) is a parameter to quantify relatively the carbonyl group content existed in the tested samples, it is calculated using the following equation [25]:

$$CI = \frac{I_{1735}}{I_{2800}}$$

where, I_{1735} and I_{2800} are absorption peak intensity at 1735 cm^{-1} and 2800 cm^{-1} of the ketone carbonyl stretching vibration and methylene symmetrical stretching vibration, respectively.

The CI for POM and POM/NS nanocomposites using different NS content before and after testing is performed in Table 2. In general, the CI for POM and POM/NS nanocomposites using 0 to 2 wt. % NS are changed after testing. It can be seen that the CI of all samples is increased after testing responding to the increase of C=O group content. The extending of CI of POM demonstrates that the hydrocarbon chain of POM polymer is decomposed by the photo-oxidation process. However, the results from Table 2 also display that the CI increase of POM/NS nanocomposites is less than that of neat POM. For example, while the change of CI for POM before and after testing is 0.34, the CI change of all POM/NS nanocomposites is only around 0.15. Especially, the change of CI for POM/NS nanocomposite at 1.5 and 2 wt.% NS are around 0.07.

After testing, the CI of nanocomposites is less than that of neat POM. The content of the C=O group in POM macromolecules is descended. This can be explained by NS particles that

disperse and interact with POM macromolecules and NS particles play a role as shielding, barriers and limit oxygen permeation into the POM matrix. Thus, POM is inclined to break down dominant from aldehyde terminal groups in POM macromolecules leading to reduce C=O groups. As can be seen, the CI of nanocomposites tends to decrease with rising NS content (from 0.5 to 1.5 wt. %). This expressed the NS particles to reduce the photo-oxidation degradation of POM macromolecules in nanocomposites during testing.

Table 2. Carbonyl index (CI) of POM and POM/NS nanocomposites before and after accelerated weather testing.

Sample	CI Before test	CI After test	Δ CI*
POM	0.57	0.91	0.34
POM/0.5NS	0.56	0.71	0.15
POM/1NS	0.45	0.68	0.14
POM/1.5NS	0.53	0.60	0.07
POM/2NS	0.54	0.52	0.07

* Δ CI: the change of carbonyl index before and after accelerated weather testing.

3.3. Tensile properties

Table 3a demonstrates tensile properties (tensile strength, elongation at break and Young's modulus) of POM and POM/NS nanocomposites using different NS content before and after accelerated weather testing. It is clear that the tensile properties of the POM/NS nanocomposites before and after testing are higher than those of neat POM. As mentioned in our previous study, the tensile properties of POM/NS nanocomposites are larger in comparison with that of POM and increased with rising NS content (from 0.5 to 1.5 wt. %) before testing. For example, the tensile strength and elongation at break are climbed from 60.88 MPa and 18.47 % (neat POM) to 65.77 MPa and 21.43 % (POM/NS 1.5 wt.%), respectively [20]. Likewise, the tensile properties of POM/NS nanocomposite after testing are also larger than those of neat POM. The tensile strength and Young's modulus of POM/NS nanocomposites after testing have an upward tendency with rising NS content (from 0.5 to 1.5 wt.%). They are from 22.15 to 25.84 MPa and from 1548.75 to 1850.9 MPa, respectively. The elongation at break of POM/NS nanocomposites after testing reaches the maximum value (1.45 %) at 1 wt. % NS. This may be explained by photo-oxidation degradation of POM chains caused by factors such as UV radiation, humidity, and heat. According to Gardette *et al.* [26], the degradation mechanism for photo-oxidation taken place in POM is described as the following: the oxidation of the carbon atoms with the formation of secondary hydroperoxides that decomposes into two radicals: an alkoxy-macroradical and a hydroxy radical. The alkoxy-macroradical can react in two possible ways: a cage reaction may occur leading to the formation of carbonate and water, and a b-scission which leads to forming terminal formaldehyde groups and an alkoxy-macroradical.

Table 3a. Tensile properties of the POM/NS nanocomposites before and after accelerated weather testing.

Content of NS (%)	Tensile strength (σ) (MPa)		Elongation at break (ϵ) (%)		Young' modulus (E) (MPa)	
	Before	After	Before	After	Before	After
0	60.88 \pm 3.3	21.27 \pm 2.5	18.47 \pm 4.9	1.15 \pm 0.21	1736.44 \pm 106.6	1488.38 \pm 394.7
0.5	63.04 \pm 1.4	22.15 \pm 3.9	21.83 \pm 3.9	1.5 \pm 0.16	1798.56 \pm 107.8	1548.75 \pm 104.4
1	65.38 \pm 0.9	23.05 \pm 3.6	21.66 \pm 2.3	1.45 \pm 0.10	1899.93 \pm 122.9	1649.38 \pm 141.3
1.5	65.77 \pm 1.9	25.84 \pm 1.8	21.43 \pm 1.2	1.39 \pm 0.16	2001.33 \pm 114.9	1850.9 \pm 166.7
2	61.33 \pm 2.5	21.42 \pm 0.85	14.98 \pm 1.4	0.96 \pm 0.06	1653.06 \pm 32.16	1596.82 \pm 114.9

The tensile properties of POM/NS nanocomposites using different NS content after testing are larger than those of POM due to the NS particle as inorganic additive reflecting UV radiation and oxygen permeation limitation into the POM matrix. They are important reasons to improve the tensile properties of POM/NS nanocomposites after testing.

Table 3b. Retention of tensile properties.

Content of NS (%)	Retention of σ (%)	Retention of ϵ (%)	Retention of E (%)
0	34.94	6.23	85.71
0.5	35.14	6.87	86.11
1	35.25	6.69	86.81
1.5	39.29	6.49	92.48
2	34.92	6.47	96.60

Table 3b shows the retention of tensile properties of POM and nanocomposites after testing. The retention of Young's modulus of POM/NS nanocomposites has maximum values, while the retention of elongation at break of that is minimum. It can be seen that the retention of tensile properties of the nanocomposites is larger than that of POM. This proves that POM is affected by UV radiation - humidity heat testing more than the nanocomposites. This is explained by the regular dispersion of NS particles into POM and good adhesion with POM macromolecules. Therefore, the NS particles can be effective barriers that limit oxygen permeation into the POM matrix as well as reduction of photo-oxidation degradation, thermo-oxidation degradation, and scission reaction of POM macromolecules.

As in Table 3b, the retention of tensile strength and Young's modulus of the above nanocomposites reaches a maximum value at 1.5 wt.% NS. When the NS content higher than 1.5 wt.%, the tensile properties of POM/NS nanocomposites after testing are decreased. Maybe, at the NS content higher than 1.5 wt.%, the NS particles are easy to agglomerate to form defects as micro-size pores in the POM matrix that oxygen air can penetrate into the nanocomposites.

Although the retention of elongation at break of POM/NS nanocomposites is larger than that of POM, the retention of elongation at break of nanocomposites is reduced with rising NS content. These results prove the weather stability of POM/NS nanocomposites is higher than that of neat POM.

3.4. Dielectric properties

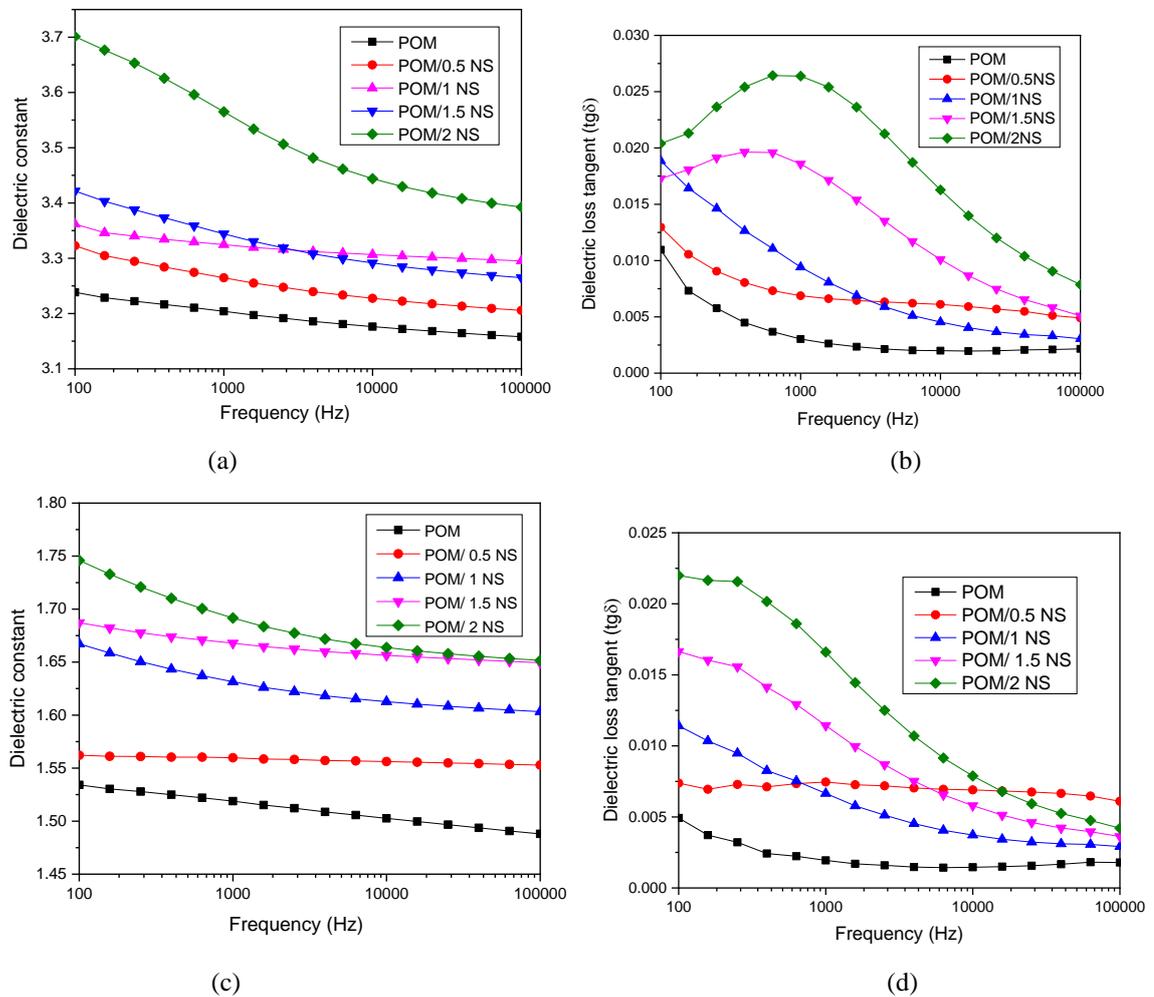


Figure 5. The dielectric constant and dielectric loss tangent of POM and POM/NS nanocomposites before (a-b) and after (c-d) accelerated weather testing as a function of frequency.

The variation of dielectric constant and dielectric loss tangent of POM and POM/NS nanocomposites using different NS content before and after accelerated weather testing is expressed in Figure 5. It is clear that the dielectric constant and dielectric loss tangent of POM/NS nanocomposites at every frequency are larger than those of neat POM in both before and after testing. The dielectric constant of POM/NS nanocomposites is increased with rising NS content. This can be explained by POM less polarized than NS particles, so the polarization of nanocomposites is grown up when adding NS particles into the POM matrix. Besides, when the

NS is dispersed well into the polymer matrix, there is little space left between the NS particles. Thus, the dielectric constant of each NS particle is equal to the NS value (3.7 - 3.9 at 1000 Hz), which is higher than that of neat POM (3.28 at 1000 Hz) as mentioned in our previous research, so the dielectric constant of nanocomposites is increased with rising NS content [20, 27]. As shown in Figure 5, the dielectric constant and dielectric loss tangent of POM/NS nanocomposites are decreased with rising frequency. This can be explained that the material becomes more polarized at a lower frequency, while the polarity in the material can be reduced at a higher frequency.

In other issues, Figure 5 also displays that the dielectric properties are affected by accelerated weather testing. For example, the dielectric properties of all nanocomposites have been reduced after accelerated weather testing. They are decreased with rising the frequency and the dielectric properties of POM/NS nanocomposite are more dropped than those of neat POM (Figures 5c-d). This may be due to the presence of NS particles tends to agglomerate to form the hole in the POM matrix and photo-oxidation degradations of POM chains by factors such as UV irradiation and humidity are easily happened (as mentioned above). The reduction of dielectric properties according to the frequency can be explained by the contribution of electric dipoles in nanocomposites (such as C=O, C-O, and C-H groups) at low frequency. With rising the frequency, the electric dipoles in nanocomposites reduce the ability to oscillate according to the external electric field, thus the dielectric properties of nanocomposites are decreased. The electric loss tangent is a parameter denoting the quantitatively dissipation of the electrical energy [28]. In Figures 5b, d performs the dielectric loss tangent of nanocomposites before and after accelerated weather testing. It grows up with rising NS content. This is explained by the presence of silanol groups on the surface of NS particles, which has the ability to absorb moisture so it is able to reduce the resistance of POM.

Table 4. Dielectric constant, dielectric loss tangent and volume resistivity of POM and POM/NS nanocomposites using different NS content before and after accelerated weather testing.

Samples	Dielectric constant (ϵ)		Dielectric loss tangent ($\tan\delta$)		Volume resistivity (ρ_v) ($\Omega\cdot\text{cm}$)	
	Before	After	Before	After	Before	After
POM	3.20 ± 0.08	1.51 ± 0.06	0.0260 ± 0.007	0.0019 ± 0.0001	9.55 × 10 ⁺¹⁰	5.9 × 10 ⁺¹¹
POM/0.5NS	3.26 ± 0.04	1.56 ± 0.02	0.0140 ± 0.005	0.0067 ± 0.0001	7.69 × 10 ⁺¹⁰	1.62 × 10 ⁺¹¹
POM/1NS	3.32 ± 0.03	1.63 ± 0.02	0.0101 ± 0.004	0.0075 ± 0.0005	5.44 × 10 ⁺¹⁰	1.56 × 10 ⁺¹¹
POM/1.5NS	3.34 ± 0.05	1.67 ± 0.07	0.0057 ± 0.006	0.0114 ± 0.0005	3.88 × 10 ⁺¹⁰	9.65 × 10 ⁺¹⁰
POM/2NS	3.56 ± 0.06	1.69 ± 0.01	0.0070 ± 0.0007	0.0166 ± 0.0003	1.91 × 10 ⁺¹⁰	6.4 × 10 ⁺¹⁰

Table 4 presents the dielectric constant (ϵ), dielectric loss tangent ($\tan \delta$) and volume resistivity (ρ_v) of POM and POM/NS nanocomposites using different NS content before and after testing which are measured at 1 kHz. It can be seen that the dielectric constant and dielectric loss tangent of the nanocomposites after testing are increased with increasing NS content from 0 to 2 wt.%, these are corresponding to from 1.51 to 1.69 and from 0.0019 to 0.0166, respectively. The volume resistivity (ρ_v) of POM/NS nanocomposites after accelerated

weather testing is reduced from $5.9 \times 10^{+11}$ to $6.4 \times 10^{+10}$ with rising NS content (from 0 to 2 wt.%). The ρ_v of nanocomposites after testing is dropped due to the NS particles dispersed uniformly and distributed across the entire volume of the material. Therefore, the charged particles of NS can easily move in the electric field through inter-phase regions with better conductivity [29 - 30]. From Table 4, the dielectric constant and dielectric loss tangent of all samples after testing are smaller compared with the samples before testing. Contrary, the volume resistivity of samples after testing is larger than that of the samples before testing. This may be explained by supposing that the NS has silanol groups on the surface which has the ability to absorb moisture as aforementioned, leading to the formation of polar interactions and hydrogen bonds in the inter-phase regions of nanocomposites. Thus, the movement of molecule dipole in nanocomposites is limited.

3.5. SEM images

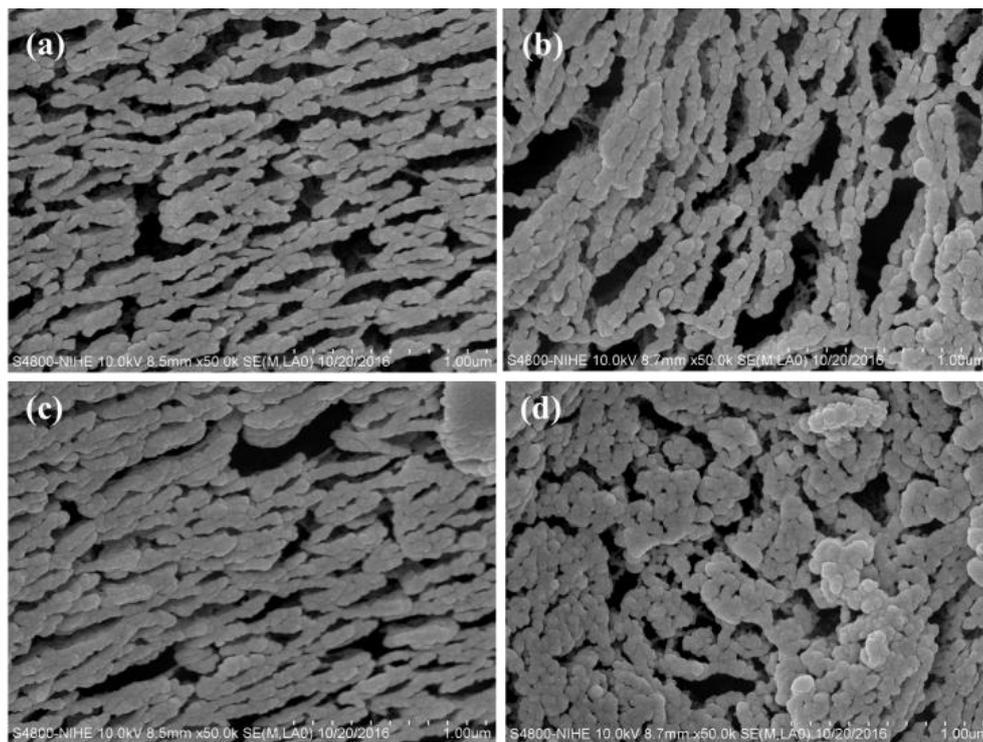


Figure 6. SEM images of POM (a), POM/NS nanocomposites using 1 wt. % (b), 1.5 wt. % (c) and 2 wt. % NS (d) after accelerated weather testing.

The photo-degradation of a polymer material usually begins from the surface and then develops along with the depth gradually [31]. Like our previous study, the structure and morphology of POM/NS nanocomposite had also been observed [20]. This study showed that the POM had a homogeneous structure with a continuous phase, while the POM/NS had a heterogeneous structure with two phases. The surface of POM is smooth without cracks, holes and free of any kind of defects. The surface of POM/NS nanocomposites with different NS content has a structure with two phases as matrix phase (POM) and dispersed phase (NS). The NS particles were dispersed most regularly into the polymer matrix at 1.5 wt.% NS with at least the smallest crack, hole, and defects. They are dispersed into POM with the size from 100 nm to

500 nm. In POM/2 wt.% NS nanocomposite, the dispersion of NS particles is more difficult than that in the nanocomposites using other investigated NS contents.

Figure 6 shows SEM images of the fracture surface of POM and POM/NS nanocomposites using 1, 1.5 and 2 wt.% NS after testing. It can be seen that the morphology of nanocomposites is significantly changed with the appearance of cracks on the surface of samples. The cracks are seen all over the surface, indicating a preferential propagation of micro-cracks with further ramifications in other directions. The POM sample is highly degraded and the cracks formed with no preferential propagation tendency (Figure 6a). The number of cracks and the size of the cracks on the surface of POM/NS nanocomposites are decreased and the cracks become smaller and less deep with increasing NS content from 0.5 to 2 wt.% (Figures 6b, c, and d). As expressed in figures 6.c and 6.d, the surface damage of samples is somehow slighter. Only a few cracks with small size are found on the surface of the samples. The surface of POM and nanocomposites using NS content less than 1.5 wt.% has more cracks with the bigger size of cracks (Figures 6.a and 6.b). This is explained by the fact that the formation of the hydrogen bond between the C=O groups of POM and O-H groups of NS particles which limits photo-degradation and photo-oxidation degradation of POM chains and nanocomposites. This is consistent with the observed FTIR spectrum after the test (Figure 2b).

4. CONCLUSION

Overall, the impact strength of POM/NS nanocomposites is increased when adding NS into POM, and it reaches the maximum value of 70.43 J/m at 5 wt.% in NS contents. The FTIR spectra of nanocomposites indicate some characteristic peaks of POM and NS. The increase of carbonyl index C=O group (CI) in nanocomposites after UV radiation – humidity heat testing compared with that before testing is performed via the change of CI (Δ CI). The CI of nanocomposites has a trend to drop with rising NS content from 0.5 to 2 wt.%, which is corresponding to the reduction of the CI change from 0.15 to 0.14. For instance, POM/NS nanocomposites containing 1 and 1.5 wt.% NS have a change of CI of 0.07. The tensile properties of all samples after testing are sharply decreased compared with those before testing. The results indicate that tensile strength and elongation at break of POM/NS nanocomposites are reduced significantly while their Young modulus is less decreased in comparison with before testing. The dielectric properties of POM/NS nanocomposites after testing are reduced in comparison with those before testing. The dielectric constant and dielectric loss tangent of the nanocomposites are risen after testing, while the volume resistivity of nanocomposites is reduced from 5.9×10^{11} to 6.4×10^{10} corresponding the increase of NS content from 0 to 2 wt.%. The SEM images on the surface of nanocomposites after testing show the preferential propagation of micro-cracks with further ramifications in another direction. The number of cracks and size of cracks of nanocomposites are decreased with rising NS content from 1 to 2 wt.%.

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