# Influence of Graphene Oxide and Multiwalled Carbon Nanotubes on Electrical, Tribological, Mechanical and Thermal Properties of Poly (methyl methacrylate) Nanocomposites

Khurram Liaqat,1 Srosh Fazil,1 Saba Mumtaz1 and Syed Asim Hussain Shah2\*

<sup>1</sup>Department of Chemistry, University of Poonch Rawalakot, Rawalakot 12350, Azad Kashmir, Pakistan <sup>\*2</sup>Department of Physics and Chemistry, University Tun Hussein Onn Malaysia (UTHM) Pagoh Campus, Pagoh Higher Education Hub, KM 1, Jalan Panchor, 84600 Muar, Johor, Malaysia

\*Corresponding author: asimshah8896@gmail.com

Published online: 21 April 2025

To cite this article: Liaqat, K. et al. (2025). Influence of graphene oxide and multiwalled carbon nanotubes on electrical, tribological, mechanical and thermal properties of poly (methyl methacrylate) nanocomposites. *J. Phys. Sci.*, 36(1), 37–54. https://doi. org/10.21315/jps2025.36.1.4

To link to this article: https://doi.org/10.21315/jps2025.36.1.4

**ABSTRACT:** A series of nanocomposites were synthesised by combining polymethyl methacrylate (PMMA) with low-loading percentages of multi-walled carbon nanotubes (MWCNTs) and graphene oxide (GO), while keeping the total weight fraction of MWCNTs/GO constant at 0.01 wt.%. The coexistence of MWCNTs and GO resulted in the formation of a bridging network within the PMMA matrix, greatly reinforcing the properties of the nanocomposites. These nanocomposites were then analysed for surface and volume resistivity, friction coefficient and mechanical properties. The results showed a significant decrease in friction coefficient, surface and volume resistivity. Furthermore, nanocomposites with higher MWCNTs and lower GO contents exhibited improved friction coefficients compared to pure PMMA, even within the first 900 s. Moreover, the thermal stability, tensile strength and Young's modulus increased, while the elongation at break decreased, as the MWCNTs content increased from 0.001 wt.% to 0.009 wt.% and GO content decreased from 0.009 to 0.001.

**Keywords:** surface and volume resistivity, friction coefficient, multiwalled carbon nanotubes (MWCNTs), graphene oxide (GO)

© Penerbit Universiti Sains Malaysia, 2025. This work is licensed under the terms of the Creative Commons Attribution (CC BY) (http://creativecommons.org/licenses/by/4.0/).

#### 1. INTRODUCTION

Polymeric materials have limitations for effective industrial use, prompting ongoing research to develop new materials with enhanced capabilities. One approach is the use of fillers added to the polymeric matrix to achieve desired characteristics.<sup>1</sup> However, achieving the desired performance requires significant filler loading, resulting in increased cost and processing difficulties. The use of nanofillers has the potential to address the challenges associated with conventional fillers. The properties of nanocomposites are influenced by the size, type, shape, dispersion and loading ratio of nanofillers.<sup>2,3</sup> Carbon nanotubes (CNTs) have been a focus of research in polymer nanocomposites since their discovery in 1991 due to their covalently bonded structure, stiffness, strength and flexibility.<sup>4,5</sup> They surpass conventional fillers in terms of thermal and electrical conductivity and are known for improving anti-wear and load-carrying capability. Their superior tribological properties are attributed to their unique structure and dimension, making them agile in the contact area and reducing interfacial friction.<sup>6,7</sup> However, their use is limited due to complicated manufacturing and limited solubility.

Subsequently, graphene oxide (GO), a derivative of graphene, has been proven to be an effective nanofiller.<sup>8</sup> Its hexagonal carbon structure has oxygen-based functional groups, which confer advantages such as increased solubility and the possibility for surface functionalisation.<sup>9,10</sup> The large specific surface area and aspect ratio of GO or CNTs respectively accelerate the agglomeration, making it challenging to effectively blend them with the matrix when used individually.<sup>11</sup> Recent research has also shown that GO may facilitate the dispersion of CNTs through noncovalent interaction.<sup>12,13</sup>

Polymethyl methacrylate (PMMA) is a significant transparent polymeric material with excellent properties, including good chemical stability, relatively balanced physical and mechanical properties, good processing properties, weather resistance and electrical insulation properties, excellent optical properties, low density and good toughness. It is widely used in aviation, construction, agriculture, optical instruments and other fields due to its outstanding electrical insulation and processing qualities. PMMA finds application in bulletproof glass, window glass, instrument accessories, optical appliances and construction materials.<sup>14–20</sup> However, it does have some drawbacks such as poor heat resistance, poor tribological performance, resistance to organic solvents, low usage temperature, high water absorption and ease of burning.<sup>21</sup> The tribological properties of a polymer nanocomposite materials are critical for its reliable performance as a viable substitute for metallic materials, thanks to its enhanced optical, mechanical and electrical properties.<sup>22</sup>

Kadambinee et al., prepared hybrid composite by blending reduced graphene oxide (rGO), multiwalled carbon nanotubes (MWCNTs) and PMMA. They investigated how the varying weight percentages rGO wt.% affected the electrical and thermal properties of MWCNTs/PMMA composite. The inclusion of rGO in the composite led to improve electrical and thermal properties attributed to to the formation of continuous path by rGO in MWCNTs/PMMA composite. Specifically the composite with 6 wt.% rGO demonstrated an electrical conductivity of  $1.546 \times 10^{-1}$  Scm<sup>-1</sup>. Moreover, the thermal stability of the MWCNTs/PMMA composite increased as the rGO wt.% increased.<sup>23</sup>

A nanocomposite, inspired by nacre and composed of GO and PMMA was developed. For this purpose GO was grafted with ethylenediamine to serve as a platform for creating the covalent bond between ethylenediamine grafted GO and PMMA. This nanocomposite was vacuum filtered due to which it adopted brick and mortar microstructure, leading to enhanced interfacial strength. Notably, it demonstrated a tensile strength of  $261 \pm 7$  MPa and toughness of  $5 \pm 0.2$  MJm<sup>-3</sup> representing a 55% and 42% improvement respectively compared to conventional GO/PMMA.<sup>24</sup>

PMMA/GO nanocomposites were fabricated using pickering emulsion polymerisation of methyl methacrylate (MAA) with GO acting as a stabilising agent. Transmission electron microcopy revealed that the average particle diameter of the nanocomposites was 150 nm. Transparent GO flakes effectively covered the particle surface and exhibited excellent dispersion. Thermal gravimetric analysis and differential scanning calorimetry were utilised to examine the impact of GO on the thermal stability of PMMA. Thermal gravimetric results demonstrated a significant increase in T10 and T50 for all the composites as compared to PMMA.<sup>25</sup>

3D mixing approach followed by injection molding was used for fabrication of multiwalled CNTs/PMMA nanocomposites, three different types of multiwalled CNTs: pristine, hydroxyl and carboxyl functionalised were used for this purpose. These nanocomposites displayed lower friction coefficient and reduced wear rates compared to pure PMMA, with the optimal performance observed at MWCNTs contents of 0.5 wt.%. Coefficient of friction and wear rate was significantly influenced by the amount of MWCNTs, average load and track diameter. The improved tribological performance of the MWCNT-reinforced PMMA nanocomposites can be attributed to the effective transfer of load between the MWCNTs and the PMMA matrix, as well as the reinforcement effect of the MWCNTs.<sup>26</sup>

The PMMA/MWCNTs composites were synthesised using in situ polymerisation. The effect of change in reaction time, polymerisation temperature and change in MWCNTs contents on the process of composite fabrication were studied. The results demonstrated an increase in tensile strength by 24% and bending strength by 233% respectively, additionally the composite with 3 wt.% MWCNTs exhibited 138% increase in thermal conductivity and achieved an electrical conductivity of 3.94 S/m. Furthermore, significant improvement was observed in the thermal stability of composite.<sup>27</sup>

We have explored the potential of GO to enhance the dispersion of CNTs through non-covalent interaction. In this study, we have fabricated nanocomposites thin films using PMMA with different weight ratios of MWCNTs and GO while keeping the total weight fraction of MWCNTs and GO constant. These nanocomposites were characterised using various characterisation techniques to study the combined effect of MWCNTs and GO on their thermal, mechanical, electrical and tribology properties of PMMA based nanocomposite films.

## 2. EXPERIMENTAL

### 2.1 Materials

Sulfuric acid (H<sub>2</sub>SO<sub>4</sub>, 99.9%), sodium nitrate (NaNO<sub>3</sub>, >99.5%), potassium permanganate (KMnO<sub>4</sub>, 99.9%), graphite (fine powder), PMMA (MW  $\geq$  120,000), highly conductive multiwalled carbon nanotubes (MWCNTs) and N, N-dimethylformamide (DMF) were bought from Sigma-Aldrich, USA.

### 2.2 Characterisation Methods

ESCA Lab 220i-XL by VG scientific from United States of America (USA), equipped with a hemispherical electron analyser was used for X-ray photoelectron spectroscopy (XPS) analysis. The infrared (IR) spectrum was recorded in 4,000 cm<sup>-1</sup>–500 cm<sup>-1</sup> range with a spectral resolution of 4 cm<sup>-1</sup> using a Thermo Scientific Nicolet 6700 Fourier transform infrared spectroscopy (FTIR) spectrometer by Thermo fisher Scientific from USA. X-ray diffractometer (XRD) by Rigaku from Japan with a scanning rate of  $2^{\circ}$  min<sup>-1</sup> was used to record XRD patterns in the 2 $\theta$  range of  $5^{\circ}$ –50°. Scanning electron microscopy (SEM) (JMS-6480) by JEOL from Japan at 5.0 kV was used for scanning electron microscopic investigations. Volume and surface resistivity were measured by EST121 resistance microcurrent by Beijing Huajinghui Technology Co., Ltd. from China. Abrasion characteristics were examined by the friction and wear tester UMT-2MT by Bruker CETR from USA. Universal testing machine H50KS

by Hounsfield from United Kingdom (UK) was used to mechanically analyse the samples according to the ASTM D-638 standards having an efficiency of  $\pm 1\%$  with a crosshead speed of 1 mm/min. Samples were cut into dumbbell shape and placed into the machine having gauge length and applied load of 7.62 mm and 500 N, respectively. TA 2000 by TA instruments from USA was used to study the thermal stability of the PMMA based nanocomposites with varying GO and MWCNTs contents in the temperature range of 25°C–600°C with the heating rate of 10°C/min in nitrogen environment.

### 2.3 Synthesis of GO

The process of synthesising GO involved two steps. First, a modified Hummer's process was used to synthesise graphite oxide. This involved adding 2.50 g of graphite and 5 g of sodium nitrate (NaNO<sub>3</sub>) to cold-concentrated  $H_2SO_4$  while continuously stirring. At a steady temperature of 20°C, 7.5 g of KMnO<sub>4</sub> was added to this mixture. The mixture was then kept at 35°C ± 3°C for 30 min. Deionised water was added progressively to the mixture, causing its temperature to rise to 98°C which was maintained for 15 min. Later, 5% hydrogen peroxide was added into it. Graphite oxide was obtained by filtering and washing the mixture three times.<sup>28</sup>

The synthesised graphite oxide was then converted into GO by sequentially sonicating and stirring it in N, N-dimethylformamide (DMF).<sup>29</sup>

### 2.4 Synthesis of MWCNTs / GO/ PMMA Nanocomposite Films

Solution of PMMA was prepared by dissolving 1 g of PMMA in 15 mL of N, N-dimethylformamide (DMF) through stirring. Different dispersions of GO in DMF were obtained by dispersing varying weight ratios of GO ranging from 0.009 wt.%-0.001 wt.% through sequential stirring and sonication for 30 min each. These dispersions were then individually added to the solution of PMMA and the resultant mixture was subjected to sequential stirring and sonication for 30 min each. Subsequently various dispersions of MWCNTs in DMF were obtained by dispersing different weight ratios of MWCNTs ranging from 0.001 wt.%-0.009 wt.% through sequential stirring and sonication for 30 min each, were added separately to the GO/PMMA dispersion. The weight ratios of GO and MWCNTs were adjusted to maintain a constant combined weight ratio of 0.01 wt.% in the PMMA matrix. The MWCNT/GO/PMMA mixture was then subjected to stirring and sonication for 24 h before being transferred to a petri dish and allowed to dry at room temperature. Additionally, 0.005 wt.% MWCNT/ PMMA and 0.005 wt.% GO/PMMA nanocomposite films were also synthesised for comparison.

#### 3. RESULTS AND DISCUSSION

#### 3.1 Characterisation of GO

The XPS spectra of GO and graphite were analysed to confirm the successful synthesis of GO. In Figures 1(a) and Figure 1(b), the XPS survey scans of GO and graphite, respectively, were compared, revealing an additional peak attributed to O1s in GO. This additional peak confirms the successful synthesis of GO.



Figure 1: XPS survey scan of (a) GO and (b) graphite.

Furthermore, the XPS C1s spectrum of GO (see Figure 2[a]) was compared to that of graphite (see Figure 2[b]) to investigate the oxidation process. The analysis revealed that XPS C1s spectrum of GO exhibits four peaks representing carbon atoms attached to different oxygen-containing functional groups (hydroxyl, epoxy, carbonyl and carboxyl groups) and non-oxygenated carbon, while XPS C1s spectrum of graphite displays only one peak at 284.4 eV. This finding aligns with previous studies and confirms the successful oxidation of graphite.<sup>30</sup>

The synthesis of GO was further confirmed by the FTIR (see Figure 3) indicating the presence of various oxygen-containing functional groups by the appearance of the peak, at 1,224 cm<sup>-1</sup> (C-OH stretching), at 1,620 cm<sup>-1</sup> (C=C stretching of the unoxidised graphitic domain) and at 1,720 cm<sup>-1</sup> (C=O stretching of carboxyl). Peaks at 2,849 cm<sup>-1</sup> and 2,927 cm<sup>-1</sup> (asymmetric and symmetric stretching of CH<sub>2</sub> of GO respectively).<sup>31</sup>



Figure 2: XPS C1s spectrum of (a) GO and (b) graphite.



Figure 3: FTIR spectra of PMMA, 0.005 wt.% GO/PMMA/, 0.005 wt.% MWCNTs/ PMMA and 0.005 wt.% MWCNTs/0.005 wt.% GO/PMMA nanocomposite.

#### 3.2 Characterisation of Nanocomposite

Formation of nanocomposite was confirmed by comparing FTIR spectrum of MWCNTs/GO/PMMA nanocomposite film with those of PMMA, GO/PMMA and MWCNTs/PMMA. FTIR spectrum of PMMA (see Figure 3) has peaks, at 2,995 cm<sup>-1</sup> (asymmetric stretching), at 2,951 cm<sup>-1</sup> (symmetric stretching), at 1,478 cm<sup>-1</sup>, 1,437 cm<sup>-1</sup>, 1,388 cm<sup>-1</sup> (twisting) and at 1,188 cm<sup>-1</sup> (wagging) due to methyl group whereas, peak at 1,724 cm<sup>-1</sup> is due to stretching of carbonyl (C=O) group.<sup>32</sup> FTIR spectrum of 0.005 wt.% GO/PMMA nanocomposite has peaks of both PMMA and GO. When spectra of GO and 0.005 wt.% GO/ PMMA are compared it appears that the peak corresponding to the OH group of GO and that of the C=O group of PMMA has moved to a lower wave number in the latter case. This shifting of peaks indicates the existence of hydrogen bonding between polymer matrix (PMMA) and filler (GO).<sup>33</sup> FTIR spectrum of 0.005 wt.% MWCNTs/PMMA shows peaks of both MWCNTs and PMMA. Which is in accordance with the previous studies. Some typical peaks are, at 3,360 cm<sup>-1</sup> and 2,927 cm<sup>-1</sup> (C-H stretching), at 1,596 cm<sup>-1</sup> (C=C stretching), at 1,444 cm<sup>-1</sup> (C-H bending) other peaks are similar to those that appears in the FTIR spectrum of PMMA.<sup>34</sup> FTIR spectrum of MWCNTs/GO/ PMMA nanocomposite has all the peaks of GO/PMMA spectrum and also has the peaks in the range of 750 cm<sup>-1</sup>–840 cm<sup>-1</sup> and 840 cm<sup>-1</sup>–900 cm<sup>-1</sup> corresponding to the meta distribution process undergone in most of the benzene rings of MWCNTs.<sup>35,36</sup>



Figure 4: X-ray diffractograms of GO, PMMA, MWCNTs and MWCNTs/GO/PMMA with varying concentrations of GO and MWCNTs.

Figure 4 shows XRD diffraction patterns with peaks at  $2\theta = 12.5^{\circ}$ ,  $14.5^{\circ}$ ,  $17.5^{\circ}$  and  $26.5^{\circ}$ , corresponding to GO, MWCNTs, PMMA and MWCNTs/GO/PMMA, respectively. Diffraction pattern of MWCNTs/GO/PMMA have a single spike

which appears at  $2\theta = 17.5^{\circ}$ . The relative intensity of nanocomposite peaks rises as the amount of GO/MWCNTs in the nanocomposites increases, indicating that MWCNTs/GO are present. According to this Figure, the diffraction patterns of PMMA/GO/MWCNTs nanocomposites do not show any pattern that corresponds to GO (12.5°), PMMA (14.5°) or MWCNTs (26.5°) indicating exfoliation, as reported earlier.<sup>37,38</sup>



Figure 5: SEM images of (a) PMMA, (b) 0.005 wt.% MWCNTs/PMMA, (c) 0.005 wt.% GO/PMMA and (d) 0.009 wt.% MWCNTs/0.001 wt.% GO/PMMA.

Surface morphology of the polymer and the nanocomposites was examined using the SEM. In Figure 5(a), SEM image reveals the smooth surface of pristine polymer. In Figure 5(b), aggregates of MWCNTs are visible in the SEM image of PMMA based nanocomposite containing 0.005 wt.% MWCNTs. Conversely, Figure 5(c) shows the SEM image of 0.005 wt.% GO/PMMA nanocomposite displaying uniform distribution of GO with rough surface. In Figure 5(d), the SEM image of PMMA based nanocomposite containing 0.009 wt.% MWCNTs and 0.001 wt.% GO reveals a homogeneous dispersion of MWCNTs. This may be attributed to the non-covalent interaction of GO, which facilitates the uniform dispersion of MWCNTs.<sup>12,13</sup>



Figure 6: Effect of varying concentrations of MWCNTs and GO on surface and volume resistivity of PMMA based nanocomposites.

Figure 6 shows a relationship between surface and volume resistivity of the PMMA based nanocomposites and varying contents of nanofillers (MWCNTs and GO). It appears from this figure that surface and volume resistivity gradually reduces as the weight ratio of MWCNTs increases from 0.001 wt.% to 0.009 wt.% in the presence of GO whose weight ratio decreases from 0.009 wt.% to 0.001 wt.%. There is 90% and 70% decrease in surface and volume resistivity respectively as the weight ratio of MWCNTs increases up to 0.009 wt.% and weight ratio of GO decreases up to 0.001 wt.%. This reduction is likely due to the presence of both GO and MWCNTs. MWCNTs are electrical conductive in nature and their presence with GO has led to improved exfoliation resulting in reduced surface and volume resistivity. This improvement can be attributed to the use of multiple fillers with different aspect ratios in polymer nanocomposite which creates bridges between them.<sup>38,39</sup> This bridging forms a well-distributed conducting network, leading to increased conductivity and affecting the percolation threshold. Consequently, the coexistence of MWCNTs and GO leads to bridging between them, resulting in increased PMMA conductivity.



Figure 7: Effect of varying concentrations of MWCNTs and GO on average frictional coefficeint of PMMA based nanocomposites.

Figure 7, shows a relationship between average frictional coefficient and varying contents of nanofillers (MWCNTs and GO). It appears from this figure that the average frictional coefficient of the nanocomposites decreases consistently as the weight ratio of MWCNTs increases from 0.001 wt.%–0.009 wt.% in the presence of GO whose weight ratio decreases from 0.009 wt.%–0.001 wt.%. The average frictional coefficient of pure PMMA is 0.6, which decreases to 0.18 as the MWCNT content increases to 0.009 wt.% and the GO contents decreases to 0.001 wt.%. The presence of GO has helped in the uniform distribution of MWCNTs and has also improved the interaction between PMMA and fillers, resulting in a reduction in the average frictional coefficient of the composites.

Figure 8 illustrates the relationship between friction coefficient and time. It reveals that, for pure PMMA, friction coefficient experiences a rapid increase within the first 400 s. On the other hand, for nanocomposites with higher MWCNTs and lower GO contents, the friction coefficient is lower than pure PMMA within the first 900 s. This improvement can be attributed to the smooth surface of the nanocomposites, which enhances their wear resistance. This enhanced smoothness is likely the result of the coexistence of MWCNTs and GO, leading to the formation of a uniform graphite layer on the surface of the PMMA matrix. This layer reduces the shear force between the contact surfaces and acts as a solid lubricant, effectively reducing the friction and enhancing the friction and wear properties of the nanocomposites.



Figure 8: Effect of varying concentrations of MWCNTs and GO on friction coefficient as a function of time of PMMA based nanocomposites.

Table	e 1:	Mec	hanical	prop	erties	of	nanocomposites.
				Prop		~	indire e e imp e breeb.

Sample	Tensile Strength	Young's Modulus	Elongation at Break
PMMA	$4.1\pm0.01$	$69.49\pm0.03$	$0.059\pm0.01$
0.001 wt.% MWCNTs/0.009 wt.% GO/ PMMA	$13.8\pm0.03$	$394.28\pm0.01$	$0.035\pm0.05$
0.003 wt.% MWCNTs/0.007 wt.% GO/ PMMA	$16 \pm 0.02$	$500\pm0.05$	$0.032\pm0.02$
0.005 wt.% MWCNTs/0.005 wt.% GO/ PMMA	$20.4\pm0.01$	816 ± 0.02	$0.025 \pm 0.03$
0.007 wt.% MWCNTs/0.003 wt.% GO/ PMMA	$22\ \pm 0.02$	$977.77\pm0.03$	$0.022 \pm 0.04$
0.009 wt.% MWCNTs/0.001 wt.% GO/ PMMA	22.7 ± 0.05	1,261.11± 0.01	$0.018 \pm 0.03$

Stress and strain behaviour of PMMA and PMMA nanocomposites with varying weight ratios of MWCNTs and GO was studied and data was compiled in Table 1 which was utilised to construct the graphs between weight ratios of GO and MWCNTs and properties such as tensile strength, Young's modulus and elongation at break. It is evident that with the increase in loading of MWCNTs in the presence of GO, the tensile strength and Young's modulus values also increases. For example, the nanocomposite of PMMA with weight ratios of MWCNTs in the range of 0.001 wt.%–0.009 wt.% and GO in the range of

0.009 wt.%–0.001 wt.% tensile strength (Figure 9[a]) and Young's modulus (Figure 9[b]) increase by 81.94% and 94.49%, respectively. Conversely, the elongation at break (Figure 9[c]) decreases by 227% as compared to pure PMMA. This improvement in the mechanical strength with the increase in the weight ratio of MWCNTs in the presence of GO, likely attributed to the GO's synergistic effect, promoting uniform distribution of MWCNTs. Both GO and MWCNTs form a bridged network in the PMMA matrix providing the larger contact area for stress transfer at the PMMA matrix and nanofiller interface as well as improved contact between the PMMA matrix and MWCNTs/GO hybrid nanofiller.<sup>23,40</sup>



Figure 9(a): Effect of varying concentrations of MWCNTs and GO on tensile strength of PMMA based nanocomposites.



Figure 9(b): Effect of varying concentrations of MWCNTs and GO on Young's modulus of PMMA based nanocomposites.



Figure 9(c): Effect of varying concentrations of MWCNTs and GO on elongation at break of PMMA based nanocomposites.

Pure PMMA is thermally unstable, which limits its use in high-temperature applications. The thermal stability of synthesised nanocomposites was analysed in temperature range of 25°C-600°C at a heating rate of 10°C/min, in the presence of nitrogen. The results illustrated in Figure 10 indicates that thermal stability of the nanocomposites increases steadily with the MWCNTs content in the presence of GO. Residual weight percentage of PMMA nanocomposite with 0.001 MWCNTs in the presence of 0.009 wt.% GO increases by 40%. As the weight ratio of MWCNT content increases from 0.001 wt.%-0.003 wt.% and the weight ratio of GO decreases from 0.009 wt.%-0.007 wt.% in the PMMA nanocomposite, the residual weight percentage further increases by 48%. Continuing an increase in the weight ratio of MWCNTs from 0.003 wt.%-0.005 wt.% and decrease in weight ratio of GO from 0.007 wt.%-0.005 wt.% leads to the 55% increase in residual weight percentage. Notably, the maximum residual weight percentage increases by 68% when the MWCNTs weight ratio increases to 0.009 wt.% and GO weight ratio decreases to 0.001 wt.%. This enhancement in thermal stability is likely due to the interaction between MWCNTs, GO and PMMA.<sup>41</sup> The coexistence of MWCNTs and GO forms a combined barrier that inhibits the transfer of the thermal decomposition products. Consequently, these decomposition products must traverse a convoluted path thereby elevating the temperature required for degradation.<sup>42</sup>



Figure 10: Thermal gravimetric analysis of (a) PMMA, (b) 0.001wt.% MWCNTs/ 0.009 wt.% GO/PMMA, (c) 0.003 wt.% MWCNTs/0.007 wt.% GO/ PMMA, (d) 0.005 wt.% MWCNTs/0.005 wt.% GO/PMMA, (e) 0.007 wt.% MWCNTs/0.003 wt.% GO/PMMA and (f) 0.009 wt.% MWCNTs/0.001 wt.% GO/PMMA nanocomposites.

#### 4. CONCLUSION

A simple method has been developed for producing MWCNTs/GO/PMMA nanocomposites. The successful synthesis of the nanocomposite was confirmed by FTIR analysis. XRD and SEM analysis verified that GO has facilitated in the evenly distribution of MWCNTs throughout the PMMA. When nanocomposites contained MWCNTs ranging from 0.001 wt.%-0.009 wt.% and GO ranging from 0.009 wt.%–0.001 wt.%, surface resistivity decreased from 1E + 016 to 1E+ 015, volume resistivity decreased from 1E + 018 to 3E + 017. Additionally, friction coefficient decreased from 0.55 to 0.17 with the value being lower than pure PMMA in the initial stage and in the first 900 s. This suggested that the MWCNTs has improved the surface smoothness of the PMMA nanocomposites, thereby enhancing the wear resistance of the material. With an increase in the MWCNTs contents from 0.001 wt.% to 0.009 wt.% and decrease in GO content s from 0.009 wt.% to 0.001 wt.% there was 81.94% increase in tensile strength and a 94.49% increase in Young's modulus along with 68% increase in thermal stability as compared to pure PMMA. This enhancement in the properties of nanocomposites is attributed to the coexistence of MWCNTs and GO resulting in the formation of bridged network structure.

### 5. **REFERENCES**

- Qazi, R. A. et al. (2021). Effect of MWCNTS functionalization on thermal, electrical and ammonia-sensing properties of MWCNTS/PMMA and PHB/ MWCNTS/PMMA thin films nanocomposites. *Nanomater.*, 11(10), 2625. htts:// doi.org/10.3390/nano11102625
- Ibrahim, A. M. M. et al. (2019). Enhancing the tribological properties of NiAl based nanocomposites for aerospace bearing applications. *Mater. Res. Express.*, 6, 085067. https://doi.org/10.1088/2053-1591/ab2028
- 3. Jordan, J. et al. (2005). Experimental trends in polymer nanocomposites-a review. *Mater. Sci. Eng. A.*, 393(1–2), 1–11. https://doi.org/10.1016/j.msea.2004.09.044
- 4. Iijima, S. & Ichihashi, T. (1999). Single shell carbon nanotube of 1 nm diameter. *Nature*, 363, 603–605. https://doi.org/10.1038/363603a0
- 5. Iijima, S. (1991). Helical microtubules of graphitic carbon. *Nature*, 354, 56–58. https://doi.org/10.1038/354056a0
- 6. Yoo, B. M. et al. (2014). Graphene and graphene oxide and their uses in barrier polymers. *J. Appl. Polym. Sci.*, 131(1), 1–23. https://doi.org/10.1002/app.39628
- Vyavhare, K. & Aswath, P. B. (2019). Tribological properties of novel multiwalled carbon nanotubes and phosphorus containing ionic liquid hybrids in grease. *Front. Mech. Eng.*, 5, 15. https://doi.org/10.3389/fmech.2019.00015
- Saputra, A. M. A. et al. (2022). Synthesis and characterisation of graphene oxide/ chitosan composite membranes from natural waste. J. Phys. Sci., 33(3), 63–79. https://doi.org/10.21315/jps2022.33.3.5
- 9. Cheng, C. et al. (2017). Functional graphene nanomaterials based architectures: Biointeractions, fabrications and emerging biological applications. *Chem. Rev.*, 117(3), 1826–1914. https://doi.org/10.1021/acs.chemrev.6b00520
- Pendolino, F. & Armata, N. (2017). Graphene oxide in environmental remediation process. Switzerland: Springer Briefs in Applied Sciences & Technology. https:// doi.org/10.1007/978-3-319-60429-9
- Han, D. et al. (2022). Effect of the ratio of graphene oxide (GO) and multi-walled carbon nanotubes (MWCNTS) on metal friction and wear during mixing. *Polym. Test.*, 106, 1–13. https://doi.org/10.1016/j.polymertesting.2021.107441
- 12. Zhang, C. et al. (2010). Graphene oxide-assisted dispersion of pristine multiwalled carbon nanotubes in aqueous media. *J. Phy. Chem. C.*, 114(26), 11435–11440. https://doi.org/10.1021/jp103745g
- 13. Gómez-Navarro, C. et al. (2008). Elastic properties of chemically derived single graphene sheets. *Nano Lett.*, 8(7), 2045–2049. https://doi.org/10.1021/nl801384y
- 14. Reddy, M. R. et al. (2016). XRD, SEM, FTIR, DSC studies of polymer blend films of PMMA and PEO. *Mater. Today Proc.*, 3(10), 3713–3718. https://doi.org/10.1016/j.matpr.2016.11.018
- Sun, J. et al. (2007). Characterization and optical properties of sol-gel processed PMMA/SiO<sub>2</sub> hybrid monoliths. J. Non-Cryst. Solids, 353(29), 2807–2812. https:// doi.org/10.1016/j.jnoncrysol.2007.05.158

- 16. Xiong, Y. et al. (2006). Methyl methacrylate homopolymerization and copolymerization with styrene by rare earth catalyst in ionic liquids. *Chem. Lett.*, 35(5), 524–525. https://doi.org/10.1246/cl.2006.524
- Wu, Li. et al. (2013). Development of AgCl /poly (MMA-co-AM) hybrid pervaporation membranes containing AgCl nanoparticles through synthesis of ionic liquid microemulsions. *Sep. Purif. Technol.*, 114, 117–125. https://doi. org/10.1016/j.seppur.2013.04.010
- Chatterjee, U. & Jewrajka, S. K. (2007). Synthesis of block copolymer-stabilized Au–Ag alloy nanoparticles and fabrication of poly (methyl methacrylate)/Au– Ag nanocomposite film. J. Colloid Interface Sci., 313(2), 717–723. https://doi. org/10.1016/j.jcis.2007.05.028
- Gu, S. et al. (2011). Preparation and characterization of visible light-driven AgCl / PPy photocatalyst. J. Alloys Compd., 509(18), 5677–5682. https://doi. org/10.1016/j.jallcom.2011.02.121
- Huang, X., & Brittain, W. J. (2001). Synthesis and characterization of PMMA nanocomposites by suspension and emulsion polymerization. *Macromolecules*, 34(10), 3255–3260. https://doi.org/10.1021/ma001670s
- 21. Dong, B. et al. (2005). Preparation and tribological properties of poly (methyl methacrylate)/multi-walled carbon nanotubes composites. *J. Mater. Sci.*, 40, 4379–4382. https://doi.org/10.1007/s10853-005-0739-z
- 22. Patnaik, A. et al. (2021). *Tribological in materials and manufacturing- wear, friction and lubrication*. United Kingdom: Intechopen. http://doi.org/10.5772/ intechopen.87674
- Sa, K. et al. (2017) Investigation of electrical and thermal properties of reduced graphene oxide-multiwalled carbon nanotubes/PMMA hybrid nanocomposite. *Phys. Status Solidi A*, 215(5), 1700476. https://doi.org/10.1002/pssa.201700476
- 24. Chathuranga, H. et al. (2021). Preparation of bioinspired graphene oxide/PMMA nanocomposite with improved mechanical properties. *Compos. Sci. Technol.*, 216, 109046. https://doi.org/10.1016/j.compscitech.2021.109046
- 25. Huang, Y. et al. (2014). Study on the PMMA/GO nanocomposites with good thermal stability prepared by in situ pickering emulsion polymerization. *J. Therm. Anal. Calorim.*, 117, 755–763. https://doi.org/10.1007/s10973-014-3794-3
- Patel. V. et al. (2023). Multi-walled carbon-nanotube-reinforced PMMA nanocomposites: An experimental study of their friction and wear properties. *Polymers*, 15(13), 2785. https://doi.org/10.3390/polym15132785
- Shang, M. et al. (2023). Fabrication and characterization of PMMA/MWCNTs composite materials. J. Wuhan Univ. Technol.-Mat. Sci. Edit., 38. 1190–1197. https://doi.org/10.1007/s11595-023-2809-y
- Hummers Jr, W. S. & Offeman, R. E. (1958). Preparation of graphitic oxide. J. Am. Chem. Soc., 80(6), 1339. https://doi.org/10.1021/ja01539a017
- 29. Paredes, J. I. et al. (2008). Graphene oxide dispersions in organic solvents. *Langmuir*, 24(19), 10560–10564. https://doi.org/10.1021/la801744a
- 30. Stobinski, L. et al. (2014). Graphene oxide and reduced graphene oxide studied by the XRD, TEM and electron spectroscopy methods. *J. Electron. Spectros. Relat. Phenomena.*, 195, 145–154. https://doi.org/10.1016/j.elspec.2014.07.003

Influence of Graphene Oxide and CNTs on PMMA Nanocomposites

- Valencia, C. et al. (2018). Synthesis and application of scaffolds of chitosangraphene oxide by the freeze-drying method for tissue regeneration. *Molecules*, 23(10), 1–16. https://doi.org/10.3390/molecules23102651
- Soman, V. V. & Kelkar, D. S. (2009). FTIR studies of doped PMMA PVC blend system. *Macromol. Symp.*, 277, 152–161. https://doi.org/10.1002/masy.200950319
- 33. Shah, R. et al. (2015). Characterization and properties of poly(methyl methacrylate)/graphene, poly(methyl methacrylate)/graphene oxide and poly(methyl methacrylate)/ p-phenylenediamine-graphene oxide nanocomposites. *Polym.-Plastics Technol. and Eng.*, 54(13), 1334–1342. https://doi.org/10.1080/0 3602559.2015.1010220
- Ali, S. H. R. et al. (2010). Morphology and properties of polymer matrix nanocomposites. *Int. J. Metrol. Qual. Eng.*, 1(1), 33–39. https://doi.org/10.1051/ ijmqe/2010009
- 35. Xu, L. et al. (2022). Preparation and study on the flame-retardant properties of CNTs/PMMA microspheres. *ACS Omega*, 7(1), 1347–1356. https://doi. org/10.1021/acsomega.1c05606
- Rahim, A. et al. (2021). Synthesis and characterization of covalently grafted graphene oxide – poly (vinyl alcohol)/ carbon nanotubes nanocomposites. *Digest J. Nanomat. Biostruct.*, 16, 1147–1155 https://doi.org/10.15251/djnb.2021.163.1147
- 37. Fazil, S. et al. (2023). Synthesis and characterization of electrical and thermal conductive vinyltriethoxysilane functionalized graphene oxide/poly (methyl methacrylate) nanocomposite films. *Membranes*, 13(6), 609. https://doi.org/10.3390/membranes13060609
- Zhang, S. M. et al. (2012). Synergistic effect in conductive networks constructed with carbon nanofillers in different dimensions. *Express Polym. Lett.*, 6, 159. https://doi.org/10.3144/expresspolymlett.2012.17
- Deng, H. et al. (2014). Progress on the morphological control of conductive network in conductive polymer composites and the use as electroactive multifunctional materials. *Prog. Polym. Sci.*, 39, 627–655. https://doi. org/10.1016/j.progpolymsci.2013.07.007
- 40. Amr, I. T. et al. (2011). Effect of acid treated carbon nanotubes on mechanical, rheological and thermal properties of polystyrene nanocomposites. *Compos. B Eng.*, 42(6), 1554–1561. https://doi.org/10.1016/j.compositesb.2011.04.013
- Tripathi, S. N. et al. (2013). Electrical and mechanical properties of PMMA/ reduced graphene oxide nanocomposites prepared via in situ polymerization. *J. Mater. Sci.*, 48, 6223–6232. https://doi.org/10.1007/s10853-013-7420-8
- 42. Ayanoğlu, Z. G. & Doğan, M. (2020). Characterization and thermal kinetic analysis of PMMA/modified-MWCNT nanocomposites. Diam. *Relat. Mater.*, 108, 107950. https://doi.org/10.1016/j.diamond.2020.107950