Structural and DC-electrical properties of novel PMMA-PVA nanocomposites reinforced with graphene nanosheets

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Abstract. Polymer-graphene nanocomposites offer interesting opportunities to enhance the properties of polymer nanocomposites. In this study, new nanocomposites with polymethyl methacrylate and polyvinyl alcohol were successfully fabricated for the first time with various loading ratios of graphene oxide nanosheets (GO), with dimethylformamide-co-distilled water used as the developing solution. Fourier-transform infrared spectroscopy (FTIR), optical microscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM), and DC electrical conductivity tests were conducted to investigate the structure and DC electrical properties of the resulting PMMA-PVA/GO nanocomposites. The OM and SEM images recorded a fine homogenous matrix and good distribution of GO in the nanocomposites, while the FTIR spectra displayed functional groups of all polymers and GO in the nanocomposites, with strong interfacial interaction between GO nanosheets and polymers, as confirmed by shifts in the XRD spectra of the PMMA. The results for conductivity in the DC electrical systems showed improvement after the addition of GO. The value of DC conductivity for PMMA-PVA/GO nanocomposites was 7.86 x 10⁻¹⁵ per ohm-cm at a GO ratio of 0.09%, while an increase in GO loading ratio to 0.27% caused an increase in conductivity to 4.53 x 10⁻⁷ per ohm-cm. The values of the activation energy of the nanocomposites were ~6.8% to -24.8% and -66.91% eV for 0.09%, 0.18%, and 0.27% GO, respectively. These results suggest that such inclusions could allow for the development of better and wider applications for nanocomposites, including solar cells, electrical devices, IR-windows, microwave absorption panels, and sensors.

Keywords: nanocomposites, graphene, PMMA, DC electrical properties, PVA.

1- Introduction

Polymer technology has progressed rapidly in recent decades, and nearly 200 million tons of plastic materials per year are now generated worldwide [1]. Polymers have many positive characteristics, such as ease of configuration, low cost, high resistance, and flexibility, supported by a range of useful properties that make them particularly useful in various applications of electronic strategy [2,3]. Polymer science is currently developing rapidly in several interesting directions, with scientists seeking to produce high-quality polymers that can be used in various applications and fields [4,5]. PVA has many useful properties that distinguish it from other polymers such as its strength, corrosion resistance, and good thermal stability [6]. It features a carbon chain backbone fastened to methane carbons with hydroxyl functional groups. These OH groups facilitate the hydrogen bonding that forms effective polymer mixtures [4,7,8]. PMMA is a thermoplastic polymer of an amorphous type [9] that has multiple useful optical properties based on its transparency. PMMA is thus used in many applications, including lenses, car signals and internal and external lighting [10,11]. It also has good resistance to harsh cutting.
conditions and is stable in the presence of acids and alkalis; however, its resistance to scratching is weak, which is one of the main drawbacks of this polymer [11,12].

Polymer-nanocomposites have attracted research and engineering attention in recent years, based on the high performance of their matrices [13], which allow manipulation and enhancement of structure that can improve the resulting material properties [14,15], assuming that interaction takes place between the dispersed particles and the relevant matrix [16,17]. Carbon materials are generally considered the most significant nanofillers enabling notable enhancement of material properties, with graphene emerging as the best option for a broad range of uses. Its inherent characteristics make graphene an excellent nanofiller [18], and graphene and its derivatives are thus frequently used in this role. Graphene oxide (GO) in the form of carbon nanosheets is often used as a functional graphene material [19,20]. GO is a single atomic-layered material with base oxygen groups with identical graphene structures. These oxygen groups make GO hydrophilic and thus easy to disperse in water and range of solvents; it can thus also be deposited over a larger surface area. The conductivity of the GO is improved as it undergoes treatment with heat, light, and chemical reduction, and the majority of graphene characteristics can be restored in this manner [14,21]. This makes GO useful for the precision electronics used in various industries [22], including hydrogen storage and solar cells [23].

Rajendran (2001) [24] used a solvent casting technique to prepare composites of PMMA and PVA in the presence of LiCl104 to create blended polymer electrolytes; dimethylformamide (DMF) was used as a solvent, and the matrix was a plasticizer. The results exhibited stable mechanical properties inflexible, free-standing films. T.Al-Saadi and Jihad (2015) [25] synthesized graphene/PMM nanocomposite films by using 20 ml of chloroform to dissolve PMMA with graphene in various loading ratios (0, 0.1, 0.3, 0.5, 1, and 2 wt. %). The matrix was controlled under temperatures of 80 °C for 30 minutes, then cast in a mould. The results for FT-IR, XRD, and SEM showed that the resulting material had a highly agglomerated state, with multiple wrinkles of graphene flakes in the matrix of the PMMA. This increase in the concentration of graphene flakes increased the absorption of the PMMA and generated a reduction in the energy gap from 4 to 2.8 eV. Additionally, the incorporation of graphene-enhanced both the mechanical and optical properties of the nanocomposites, offering promise for various applications such as solar cells, IR-windows and microwave absorption. Kashyap et al. (2016) [26], investigated the effect of adding different proportions of GO on the electrical and mechanical properties of polyvinyl alcohol (PVA), with composites fabricated by applying the casting method. The finding of that study showed that the modulus of elasticity and tensile strength increased by up to 150% at appropriate proportions. The results also showed improvements in electrical conductivity from -30 to -35. Several different measuring devices were used to determine these findings, including UV-vis, XRD and SEM. Kandhol et al. (2019) [27] similarly reported the preparation of PVA with various loading ratios of RGO (1, 1.5, and 2 wt. %), using a solution mixing method and evaporative casting techniques to synthesis the nanocomposites. The study focused on the influence of frequency in the range between 100 Hz and 1.5 MHz. The findings showed improvements in AC conductivity and dielectric constant as the loading ratio of the RGO in the nanocomposites increased.

Although there have been several previous investigations [24–28], no researchers have reported on the effect of graphene on PMMA with PVA, potentially because their different solvents make these materials difficult to mix. The current investigation is thus the first study to investigate fabricated PMMA-DMF and PVA-DW-co-DMF with the addition of GO-DMF as new nanocomposites. A solution-sonication method was applied to achieve fine homogeneous mixtures from the components in the matrix, and graphene oxide was used to improve the structural and DC electrical properties of PMMA-PVA/GO nanocomposite. Nanocomposites were thus successfully prepared, and the structure and electrical properties characterized using FTIR, OM, and DC electrical properties testing. The findings indicated significant enhancement in the characteristics under investigation.
2. Experimental work

2.1. Materials

Poly (methyl methacrylate) (PMMA) with a molecular weight of $20,000$ to $18,000$ g mol$^{-1}$ was utilized with graphene oxide nanosheets with a $213$ °C melting point and $99\%$ purity, as purchased from the Tuttlingen Company. Poly (vinyl alcohol) with a molecular weight of $18,000$ to $12,000$ g mol$^{-1}$, a melting point of $230$ °C and $99\%$ purity was provided by the Panreac Company, Spain.

2.2 Graphene oxide (GO) as additive nanofiller

Graphene oxide (GO) was prepared as in the authors’ previous publications [29,30].

2.3. Purification of nanocomposites

Various ratios of PMMA-DMF and PVA-DW/DMF were applied to determine the most appropriate way to mix these two polymers, with different solvents being applied as required. A method was thus developed that not only mixed the materials into a fine homogeneous matrix but which also offered good GO dispersion, using the following steps: One gram of PVA was dissolved in $50$ ml DW, then stirred for $1$ h at $80 \pm 3$ °C; meanwhile, the PMMA was dissolved in DMF at a ratio of $6$ g to $50$ ml using a magnetic stirrer for $3$ h at $80 \pm 3$ °C, and GO nanosheets were dispersed in $50$ ml DMF at the required concentrations ($0.09$ to $0.27$ wt.%) using a magnetic stirrer, with a sonication bath added as an acoustic method to promote good dispersion of GO in the solvent. After the PVA was completely dissolved in DI, $10$ ml of DMF was added to $30$ ml of the PVA-DI solution and mixed using a magnetic stirrer for $0.5$ hr at $80 \pm 3$ °C to promote homogeneity. After that, $5$ ml of the PVA-DI-DMF was added to $25$ ml of the PMMA-DMF solution and mixed for $4$ hours using a magnetic stirrer at $80 \pm 3$ °C; the polymer matrix developed further fine homogeneity during this time. The next step was to reduce the temperature of the PVA-PMMA matrix to about $35 \pm 3$ °C before adding the three ratios of GO-DMF to separate portions to prepare the three nanocomposites for testing. After the addition of the GO, the mixing-sonication methods used for the GO nanosheets were reapplied, with the mixing of the PVA-PMMA/GO matrix continued for another $3$ h prior to sonication for $15$ minutes. This procedure was repeated four times to ensure fine homogeneity and good dispersion of GO in the polymer matrices. Table 1 summarises the fabrication method.

![Table 1. Synthesis method.](image-url)
Figure 1. Schematic of synthesis of GO, PM-PV1, and PM-PVGO nanocomposite.

2.4 Characterisation
A Nikon Olympus model 73346 was used to record the optical microscope (OM) images. A Fourier transforms infrared (FTIR) spectra (Vertex 701) from Bruker, Germany, was used to characterizing the nanocomposites in the region between 4000 and 400 cm⁻¹. The DC electrical conductivity was measured at temperatures ranging between 40 and 80 °C, with samples placed in the oven at the required temperature and the electrical resistance recorded after three to six minutes.

3. Theoretical work
The electrical conductivity (σ) (DC) of the samples can be considered based on the measurements of a regular body with a section of length (L), electrical resistance (R), and a constant area (S) by applying equation 1 [13,31,32]:

\[ \sigma_{dc} = \frac{L}{RS} \]  

Equation 2 is then used to calculate the sample’s dielectric constant (ε).

\[ \varepsilon = \frac{C_p}{C_o} \]  

Where \( C_p \) is parallel capacitance and \( C_o \) is the vacuum capacitor, calculated by applying equation (3):

\[ C_o = \frac{\varepsilon_o M}{\varepsilon} \]  

Where \( \varepsilon_o \) is vacuum permittivity, \( M \) is the area of the capacitance plate, and \( t \) is the distance between two plates. Dielectric loss, \( \varepsilon'' \), is given by equation (4):

\[ \varepsilon'' = \varepsilon D \]  

Where D is the dispersion factor.

The Arrhenius equation is used to calculate the electrical conductivity, which varies exponentially with temperature (T) [33].

\[ \sigma_{dc} = \sigma_o \exp \left( \frac{-E_a}{kT} \right) \]
Where $K$ and $E_a$ refer to the Boltzmann constant and the activation energy, respectively.

4. Results and discussion

Figure 2 illustrates the FTIR spectra for GO, the PMMA-PVA blend, and the PMMA-PVA/GO nanocomposites, all of which lie in the range 4000 to 500 cm$^{-1}$. In figure 2, (a) shows the FT-IR spectrum of GO has a broadband peak at 3,220 cm$^{-1}$ related to the hydroxyl group’s (O–H) stretching vibrations. The peak at 1,723 cm$^{-1}$ reflects an adsorption functional group matching the stretching carbonyl groups (C=O) [30]. At 1,604 cm$^{-1}$, a peak occurs that represents a skeletal ring (C=C), a stretching vibration functional group of the sp2 carbon domain related to un-exfoliated GO sheets. The functional groups at 1,374 and 1,040 cm$^{-1}$ are related to the carbonyl and epoxy groups [34], respectively.

The PMMA-PVA blend spectrum (b) indicates several peaks at 1646, 1604, 1361, and between 1260 and 1000 cm$^{-1}$, which are attributed to CH$_2$, C-H stretching, O-H bending, and C-O (ester bond) stretching vibrations, respectively. These functional peaks are related to functional group peaks of both PMMA [35] and PVA [36]. The contribution of GO also creates a new functional peak in the nanocomposites, as displayed in (c), (d), and (e), with new strong bands at 2,904, 1,604 and 887 cm$^{-1}$. Additionally, an increase in the intensity of other peaks is shown to accompany increases in the contribution of GO to nanocomposites. Increasing the ratio of the GO to 0.27 wt. %, the highest ratio in this investigation, resulting in shifting the functional peaks of PM-PVGO4 by up to 10 cm$^{-1}$ for most functional groups, with increases in the intensity of peaks due to the addition of the nucleating agent GO/PMMA-PVA. Examining the infrared spectra shows that the variation of GO nanoparticle ratios causes significant changes and strong interfacial interactions in the PMMA-PVA spectrum, potentially related to the creation of hydrogen bonds between the O-H in the GO and the C=O in the PMMA-PVA. However, this could also be related to the charge from the other atoms being separated from the C=O.
function group. The property of C=O of having a double bond leads to a reduction in absorption and shifts the functional peaks to a lower wavelength [37].

The XRD patterns for GO, PM-PV1, PM-PVGO2, PM-PVGO3 and PM-PVGO4 nanocomposites are shown in figure 3. A strong diffraction peak at 2θ = 11.1° is shown in the XRD spectra; this peak, with 001 diffractions, is related to GO nanosheets with an interlayer spacing of 0.79 nm, calculated by applying the Bragg equation. The GO peak is thus shifted from the 2θ = 26.5° of graphite, confirmed by the oxidation of flakes and production of GO nanosheets in other research [38,39]. PMV1 exhibits two broad peaks at 2θ = 14.1° and 30°, related to the (111) and (112) diffractions of PMMA, in agreement with the literature [38][40].

Both patterns, GO at 2θ = 11.1° and PVA at 2θ = 19.8°, were located in the wide and high-intensity area of PMMA between 7° and 23°. The peaks of GO and PVA thus overlap with those of PMMA. The distribution of GO nanosheets in the matrix is illustrated clearly in the OM images, being potentially related to the orientation, in agreement with the literature [41], making it more difficult to determine from XRD patterns. However, the influence of increasing the ratio loading of GO nanosheets in the matrix shows in the shifting of peaks of the PMMA, with the PMMA peak shifted from 2θ = 14.1° to 14.2°, and from 15° to 16.1° with increases in the loading ratio of GO nanosheets from 0 wt. % to 0.09, 0.18 and 0.27 wt. % in the matrices of PM-PVGO2, PM-PVGO3, and PM-PVGO4, respectively. This shift may reflect an increase in the spacing of the interplanar crystals and a volume expansion in the macrostructure [42]. The XRD findings thus support the FTIR spectra, which showed strong interactions between the nanosheets and matrix; it also highlights that the GO nanosheets do not change the polymer crystal structures in the nanocomposites, in agreement with other investigations [42].

Figure 3. XRD patterns for GO, PM-PV1, and PM-PVGO nanocomposite.
Figure 4. Optical microscopy at 40X magnification: (A) PM-PV1, (B) PM-PVGO2, (C) PM-PVGO3, and (D) PM-PVGO4

Figure 4 shows optical images of PMMA-PVA and PMMA-PVA/GO samples with various loading ratios of GO at a magnification power of 40X. These images illustrate the fine homogeneity of the matrices, with a good distribution of GO throughout the polymer composites. The OM images thus confirm the successful preparation of the PMMA-PVA/GO nanocomposites using the selected method, in comparison to polymer blending films with PMMA-PVA/GO nanocomposites films, which displayed a notable modification with increases in the ratio of GONS. The contribution of these GONs caused several changes in the films without any aggregation or negative effect on the transparency of the films. The fine distribution was also improved with increases in the ratio of GONs, especially for PM-PVGO4, as illustrated in figure (4 D), in agreement with the previous literature [13,43].
Figure 5. SEM images of (A) PM-PV1, (B) PM-PVGO2, (C) PM-PVGO3, (D) PM-PVGO4 nanocomposites. E, F and H present the nanosize calculations of GO in nanocomposites.

A scanning electron microscope was used to characterize the surface morphology of samples to investigate the dispersion of GO in the nanocomposites. Figure 5 shows SEM micrographs of the surface of the PMMA-PVA blend and PMMA-PVA/GO nanocomposites films. Image A in figure 5 shows the blended polymers creating a uniform morphology revealing a rather soft surface, while B, C, and D show how the increase in the ratio of GO nanosheets in the PMMA-PVA/GO nanocomposites leads to surface morphology variations. The nanocomposite films with multiple GO nanosheets demonstrate fine dispersion without aggregates on the surface. These results agree with the optical microscopy images and with results from the previous investigation [44]. The SEM images (E, F and
H) in figure 5 illustrate the measurements of GONS size from between a few nanometres and a few microns.

![Figure 5](image)

**Figure 5.** GONS size measurements from a few nanometres to a few microns.

**Figure 6.** DC electrical conductivity with increases in the concentration of GO for PMMA-PVA/GO nanocomposite at 30 °C

Figure 6 shows the DC surface electrical conductivity at a temperature of 30 °C for increasing loading ratios of graphene oxide nanosheets (GO) in nanocomposites samples. The results show improvement in the electrical conductivity with increasing concentrations of GO, with this being enhanced from $7.86 \times 10^{-15}$ to $4.53 \times 10^{-9}$ for PMMA-PVA/GO nanocomposites with GO concentration growth from 0.09% to 0.27%.

Figure 7 illustrates the electrical conductivity for PMMA-PVA and PMMA-PVA/GO nanocomposites with increasing temperature of samples at low concentrations as the polymer chains and graphene oxide nanosheets (GO) interact to “trap” and move carrier charges through the hopping process based on temperature increases. The contribution of GO is to increase the motion of the polymer chains so that the trapped charge carriers are released, and the conductivity of the PMMA-PVA/GO nanocomposite increases as a consequence of increases in the mobility and the number of carriers of these charges available [45]. Figure 7 also shows that the electrical conductivity of the nanocomposite with 0.09% GO reduced with the increase in temperature; this material exhibited resistance to the positive thermal coefficient, in agreement with the literature [46,47].
Figure 7. DC electrical conductivity with increases in the range of temperature for PMMA-PVA/GO nanocomposites.

Figure 8. DC electrical conductivity vs. inverse absolute temperature for PMMA-PVA/GO nanocomposite.
Table 2. Summary of activation energy results with increases in the concentration of graphene oxide nanosheets.

| GO wt.% nanosheets | $E_a$ (eV) |
|--------------------|------------|
| 0                  | 2.36       |
| 0.09               | 2.22       |
| 0.18               | 1.9        |
| 0.27               | 1.42       |

Figure 9. The activation energy for DC conductivity vs. GO nanosheet concentration of nanocomposites.

The relationship between $\text{Ln}\sigma_{dc}$ and the inverse absolute temperature of nanocomposites is shown in Figure 8. Equation 5 was used to characterize the activation energy, and the results showed high values of activation energy ranging from 2.36 to 1.42 eV for the PMMA-PVA/GO nanocomposite. Table 2 summarises the existence value of activation energy in the polymer nets. Adding low ratios of graphene oxide nanosheets (GO) results in a reduction of the activation energy values of samples due to the influence of the space charge. Moreover, it also creates local energy levels in the forbidden energy gap that interact to trap charge carriers that move by hopping among levels. Increasing the loading ratio of GO thus reduces the activation energy as an outcome of increasing the local centers of the nanocomposite, as shown in figure 9; in these samples, the conduction mechanism reduces the concentration of hopping.

The activation energy shows low values for PMMA-PVA/GO nanocomposites at -6.8%, -24.8%, and -66.91% eV for 0.09%, 0.18% and 0.27% GONS, respectively. This is due to the creation of a graphene oxide nanosheet continuous network that includes paths inside the nanocomposite that help the charge carriers to pass through, resulting in a decrease of activation energy with growth in the loading ratio of the GO [48], as displayed in Figure 9.

5- Conclusions
Novel PMMA-PVA/GO nanocomposites were successfully fabricated for the first time in this study; these were then investigated using solution-sonication methods. The contribution of GO nanosheets created strong interfacial interactions with polymers in the polymer matrix nanofillers as determined
using FTIR and by examination of shifts in the XRD peaks. The GO offered significant enhancement in the optical properties that increased with increases in the loading ratio of GO nanosheets in the nanocomposites. The fabrication of the new nanocomposites was successfully achieved such that homogenous and fine dispersion of the GO nanosheets was observed in the samples, and both the contribution of GO and increases in the loading ratio considerably improved the electrical properties based on DC Electrical Conductivity testing. The DC electrical conductivity results increased from 7.86 \times 10^{-15} to 4.53 \times 10^{9} \text{ ohm-cm}^{-1} with an increase in the concentration of GO from 0.09\% to 0.27\%. Similarly, the values of the activation energy of PMMA-PVA/GO nanocomposites were - 6.8\%, - 24.8\%, and - 66.91\% eV for 0.09\%, 0.18\%, and 0.27\% GO nanocomposites, respectively.

These nanocomposites were successfully prepared using the described method for the first time in this study. The test results suggest promising uses for these films in various applications such as gas or humidity sensors and similar applications such as ultraviolet filters, solar cells, light diffusers, and various items required by the automotive and smartphone industries.

References

[1] Carrara Jr C E 2003 Seymour/Carraher’s polymer chemistry (CRC Press)
[2] Busfield W K and O'Donnell J H 1975 Effects of gamma radiation on copolymers of styrene and methyl methacrylate in the solid state Journal of Polymer Science: Polymer Symposia vol 49 (Wiley Online Library) pp 227–37
[3] Abdulridha A R, Al-Bermawy E, Hashim F S and Alkhayatt A H O 2020 Synthesis and characterization and pelletization pressure effect on the properties of Bi1.7Pb0.3Sr2W0.2 Ca2Cu3 O10+δ superconductor system Intermetallics 127 1–8
[4] Jawad E, Khudhair S H and Ali H N 2011 A thermodynamic study of adsorption of some days on Iraqi Bentoniet modified clay European Journal of Scientific Research 60 63–70
[5] Al-nesrawya S H, Mohseenb M J and Al-Bermawy E 2020 Reinforcement the Mechanical Properties of (NR50/SBRs50/ OSP) Composites with Oyster Shell Powder and Carbon Black IOP Conference Series: Materials Science and Engineering 871
[6] Rajendran S, Sivakumar M and Subadevi R 2004 Investigations on the effect of various plasticizers in PVA-PMMA solid polymer blend electrolytes Materials Letters 58 641–9
[7] Lee J H, Lee H B and Andrades J D 1995 Blood Compatibility Of Polyethylene Oxide Surfaces Elsevier 20 1043–79
[8] Robeson L M, Hale W F and Merriam C N 1981 Miscibility of the poly (hydroxy ether) of bisphenol A with water-soluble polyethers Macromolecules 14 1644–50
[9] Mallick P K, NEWMAN S and U R E D S 1990 Composite materials technology: Processes and properties New York/Munich, Oxford University Press/Hanser Publishers, 1990, 400
[10] Clyne T W and Hull D 2019 An introduction to composite materials (Cambridge university press)
[11] Cascini G and Rissone P 2004 Plastics design: integrating TRIZ creativity and semantic knowledge portals Journal of engineering design 15 405–24
[12] Al-Bermawy A-K J, Al-Bermawy E and Kadem B Y 2011 A Study of Some Mechanical Properties of Iraqi Palm Fiber-PVA Composite by Ultrasonic European Journal of Scientific Research 61 203–9
[13] Abdelamir A I, Al-Bermawy E and Hashim F S 2019 Enhance the Optical Properties of the Synthesis PEG/Graphene- Based Nanocomposite films using GO nanosheets Journal of Physics: Conference Series 1294 1–13
[14] Hashimi R, Hashimi F S and Al-bermawy E 2020 Enhance the Optical Properties of the Synthesis PS- PMMA blend using ZnO/ Fe2O3 nanoparticles Test Engineering and Management 83 21939–50
[15] Al-Rubayy S, Al-bermawy E, Habeeb M and Rajagopalan R 2020 Electrochemical Performance Evaluation of Ni foam/NiCo2O4-CNTs for Energy Storage Applications.pdf Test Engineering and Management 83 12828–41
[16] Deng F, Zheng Q-S, Wang L-F and Nan C-W 2007 Effects of anisotropy, aspect ratio, and nonstraightness of carbon nanotubes on thermal conductivity of carbon nanotube composites Applied Physics Letters 90 21914

[17] Al-Owaedi O A, Khalil T T, Karim S A, Said M H, Al-Bernamy E and Taha D N 2020 The promising barrier: Theoretical investigation Systematic Reviews in Pharmacy 11 110–5

[18] Tung V C, Allen M J, Yang Y and Kaner R B 2009 High-throughput solution processing of large-scale graphene Nature Nanotechnology 4 25–9

[19] Stankovich S, Dikin D A, Dommett G H B, Kohlhaas K M, Zimney E J, Stach E A, Piner R D, Nguyen S T and Ruoff R S 2006 Graphene-based composite materials. Nature 442 282–6

[20] Abdul M and Al-Bernamy E 2020 Enhance the Electrical Properties of the Novel Fabricated PMMA-PVA/ Graphene Based Nanocomposites Journal of Green Engineering 10 3465–83

[21] Ivey K N, Muth A, Arnold J, King F W, Yeh R-F, Fish J E, Hsiao E C, Schwartz R J, Conklin B R and Bernstein H S 2008 MicroRNA regulation of cell lineages in mouse and human embryonic stem cells Cell stem cell 2 219–29

[22] Eda G, Fanchini G and Chhowalla M 2008 Large-area ultrathin films of reduced graphene oxide as a transparent and flexible electronic material Nature nanotechnology 3 270

[23] Wang X, Zhi L and Müllen K 2008 Transparent, conductive graphene electrodes for dye-sensitized solar cells Nano Letters 8 323–7

[24] Rajendran S and Mahendran O 2001 Experimental Investigations on Plasticized PMMA/PVA Polymer Blend Electrolytes Ionics 7 463–8

[25] Al-Saadi T M and Jihad M A K 2015 Preparation and characterization of graphene/PMMA composite International Journal of Advanced Research in Science Engineering and Technology 2 902–9

[26] Kashyap S, Pratihar S K and Behera S K 2016 Strong and ductile graphene oxide reinforced PVA nanocomposites Journal of Alloys and Compounds 684 254–60

[27] Kandhol G, Wadhwa H, Chand S, Mahendra S and Kumar S 2019 Study of dielectric relaxation behavior of composites of Poly (vinyl alcohol) (PVA) and Reduced graphene oxide (RGO) Vacuum 160 384–93

[28] Sa K, Mahakul P C, Nanda K K and Mahanandia P 2018 Effect of ionic liquid functionalized carbon nanotubes on mechanical, thermal and electrical properties of carbon nanotubes-reduced graphene oxide/PMMA nanocomposites Chemical Physics Letters 706 76–81

[29] Al-Bernamy E and Chen B 2020 Preparation and Characterization of Poly(ethylene glycol)-Adsorbed Graphene Oxide Nanosheets Polymer International 01 October

[30] Abdelamir A I, Al-Bernamy E and Hashim F S 2020 Important factors affecting the microstructure and mechanical properties of PEG/GO-based nanographene composites fabricated applying assembly-acoustic method AIP Conference Proceedings 2213 1–13

[31] Pankove J I 1971 Optical Processes in Semiconductors (New York, USA: Dover Publications, Inc.)

[32] Ingham J D and Lawson D D 1965 Refractive Index-Molecular Weight Relationships Journal of Polymer Science A3 2707–10

[33] Ravi M, Pavani Y, Kumar K K, Bhavani S, Sharma A K and Rao V V R N 2011 Studies on electrical and dielectric properties of PVP: KBrO4 complexed polymer electrolyte films Materials Chemistry and Physics 130 442–8

[34] Rajabi M, Mahanpoor K and Moradi O 2019 Preparation of PMMA / GO and PMMA / GO-Fe 3 O 4 nanocomposites for malachite green dye adsorption: Kinetic and thermodynamic studies Composites Part B 167 544–55

[35] Vijayakumari G, Selvakumaran N, Jeyasubramanian K and Mala R 2013 Investigation on the electrical properties of polymer metal nanocomposites for physiological sensing applications Physics Procedia 49 67–78

[36] Luo Q, Shan Y, Zuo X and Liu J 2018 Anisotropic tough poly(vinyl alcohol)/graphene oxide nanocomposite hydrogels for potential biomedical applications RSC Advances 8 13284–91

[37] Zheng L and Zhen W 2018 Surface Functionalization of Graphene Oxide via Activators
Regenerated by Electron Transfer for Atom Transfer Radical Polymerization and Its Effect on the Performance of Poly(lactic acid) \textit{Polymer (Korea)} \textbf{42} 581–93

[38] Yang J, Yan X, Wu M, Chen F, Fei Z and Zhong M 2012 Self-assembly between graphene sheets and cationic poly (methyl methacrylate)(PMMA) particles: preparation and characterization of PMMA/graphene composites \textit{Journal of Nanoparticle Research} \textbf{14} 717

[39] Rameshkumar C, Sarojini S, Naresh K and Subalakshmi 2017 Preparation and characterization of pristine PMMA and PVDF thin film using solution casting process for optoelectronic devices \textit{Journal of Surface Science and Technology} \textbf{33} 12–8

[40] Wang C, Feng L, Yang H, Xin G, Li W, Zheng J, Tian W and Li X 2012 Graphene oxide stabilized polyethylene glycol for heat storage \textit{Physical Chemistry Chemical Physics} \textbf{14} 13233–13238

[41] Fu Y, Xiong W, Wang J, Li J, Mei T and Wang X 2017 Polyethylene Glycol Based Graphene Aerogel Confined Phase Change Materials with High Thermal Stability \textit{Journal of Nanoscience and Nanotechnology} \textbf{18} 3341–7

[42] Indolia A P and Gaur M S 2013 Optical properties of solution grown PVDF-ZnO nanocomposite thin films \textit{Journal of Polymer Research} \textbf{20} 1–8

[43] Feng Y, Zhang X, Shen Y, Yoshino K, Feng W, YiyuFeng, XuequanZhang, YongtaoShen, KatsumiYoshino, Fengab W, Feng Y, Zhang X, Shen Y, Yoshino K and Feng W 2012 A mechanically strong, flexible and conductive film based on bacterial cellulose/graphene nanocomposites \textit{Carbohydrate Polymers} \textbf{87} 644–9

[44] Al-Bermany E, Qais D and Al-Rubaye S 2019 Graphene Effect on the Mechanical Properties of Poly (Ethylene Oxide)/ Graphene Oxide Nanocomposites Using Ultrasound Technique \textit{Journal of Physics: Conference Series} \textbf{1234} 1–12

[45] Khaleel R I 2004 Electrical and Optical properties modification of Poly (Vinyl Chloride) by Zinc, Copper and Nickel Ethyl Xanthate chelate Complexes \textit{M. Sc., College of Sci., Mustansiryah}

[46] Kryszewski M 1974 Electrical Conductivity of Semicrystalline and Amorphous Polymers and Related Problems \textit{J Polym Sci Polym Symp} vol 50 (Wiley Online Library) pp 359–404

[47] El-Tawansi A, Kinawy N and El-Mitwally M 1989 Free volume conduction and magnetic solitons in polystyrene composites containing transition metals \textit{Journal of materials science} \textbf{24} 2497–502

[48] Ahmad M S, Zihilif A M, Martuscelli E, Ragosta G and Scafora E 1992 The electrical conductivity of polypropylene and nickel-coated carbon fiber composite \textit{Polymer composites} \textbf{13} 53–7