STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 1, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Study on Thermal and Electrical Performance of Pani Doped Graphene Composites under Solar Light Irradiation

M. Dhanalaxmi[1], Domala Suresh[2,*], B. Sanjeeva Rao[3], A. Shirisha[4], J. Rajendra Prasad[5]

Abstract

Here in the research work focusses on the study of thermal and electrical performance of PANI doped graphene composites fabricated by chemical way. A sequence of conducting polymer oxidative method done using the polymerization of aniline in the presence of graphene was deliberate under solar light irradiation. The composites were inspected and characterized using spectroscopy and microscopy studies. The thermal/ electrical performance of PANI and PANI doped graphene were evaluated under solar light irradiation for different time of exposure duration likely 12, 24 and 36 hrs respectively. The results suggest a great enhancement in thermal and electrical behavior due to presence of graphene a contributed to higher conductivity and very good response to electrical behavior after exposure to sun light on the composites. Further the electrical conductivity measurements and impedance analysis gives a insight behavior of the materials. Pure PANI shows a conductivity of 20.18 S/cm measured at room conditions (298 K) and as prepared composites initiate to be greater performance and increased activity with higher magnitude of conductivity of 89.12 S/cm, 112.1 S/cm and 149.5 S/cm respectively. As the time of exposure increases the performance of conductivity of the nanocomposites increased by an order of three folds related to pure PANI which is accredited to significant surge in the carrier flexibility in the company of graphene sheets. The results show a synergetic effect and directly proportional to the time of exposure to solar light radiation.

Keywords: PANI, graphene nano composites, spectroscopic, morphological, thermal, conductivity and electrical properties

***Author for Correspondence**
Domala Suresh
suresh.domala@gmail.com

[1]Research Scholar, Department of Physics and Electronics, Chaitanya Deemed to be University, Hyderabad, Telangana, India
[2]Professor, Department of Physics and Electronics, Chaitanya Deemed to be University, Hyderabad, Telangana, India
[3]Professor, Department of Physics, Government Degree College, Rangasaipet, Warangal, Telangana, India
[4]Assistant Professor, Department of Mechanical Engineering, Kakatiya University College of Engineering and Technology, Warangal, Telangana, India
[5]Research Scholar, Department of Physics and Electronics, Chaitanya Deemed to be University, Hyderabad, Telangana, India

Received Date: November 19, 2025
Accepted Date: January 05, 2026
Published Date: February 06, 2026

Citation: M. Dhanalaxmi, Domala Suresh, B. Sanjeeva Rao, A. Shirisha, J. Rajendra Prasad. Study on Thermal and Electrical Performance of Pani Doped Graphene Composites under Solar Light Irradiation. Journal of Polymer & Composites. 2026; 14(Special Issue 1): S1134–S1146p.

INTRODUCTION

Conducting polymer composites have gained a great impact and potential interest in advancing with their extensive special features and physicochemical properties in many potential applications [1]. These unique properties facilitated interest especially in towards electronics and electrochemical activities. Conducting polymers are well knows as intrinsically conducting polymers (ICPs) that can be defined as organic polymer which behaves different from the general insulator.

These ICP additionally possess extensive physical and chemical properties that makes them to behave or perform characteristic like metal or semiconductor to open a wide range of research in many potential applications [2, 3]. The physical and chemical properties of the desired conductive

polymer can be altered to generate a fine conducting polymer of choice while adapting the concept of doping. The CPC nature of conducting or physicochemical characteristics can be tuned by various kinds of metals, semiconductors, nonmetal and oxide materials to intrigue the special phenomena of CPC. The nature of CPC can adjusted by level of doping percentage and materials intake to fabricate a special materials of polymer of chains with high level of electrical and electronical properties [4–6]. Additionally, the mechanical and thermal stability of CPC can be altered by different kinds of materials and level of doping percentages. The CPC generated by different kinds of doping or hybridization with various materials can generate different shapes and structure of CPC adapting different process of fabrication or synthesizes. Variety of CPC can be fabricated using physical and chemical method as such as regular thin films, tubes, neural forms, and various shapes and morphology. In recent years generating a CPC with special physical and chemical properties are inherited by using carbon materials, polymer oxides, oxides/sulphides of metals and metal hydroxides that created a special route in increasing and enhancing the physical feature and electrical behavior of the materials for various potential applications [7–9].

PANI is popular polymer because of its unique features like proton dupability (specially with acids groups), excellent redox recyclability, chemical stability, variable electrical conductivity electrochemistry, and environmental stability (which can be varied by changing the pH at which it is prepared), In general PANI is fabricated by protonic acid doping was performed via oxidation, either chemically or electrochemically. PANI can be easily synthesized under any favourable conditions, cost effective method and easy reproducible situations in physical and chemical method of preparation of PANI has proven to be the best and eco-friendly materials [10–13]. Polyaniline (PANI) is a promising material that exists in many forms of polymeric chains of oxidation available for many technological applications in various areas like sensors [14], light-weight batteries [15], super capacitors, corrosion inhibitors and EMI shielding.

The nature and physical features of PANI differs in the oxidation chains and existing of base plane of chains of oxidation and conjuration of chains due to leucoemraldine/emeraldine interaction that creates a different orientation and hybridzed feature of physical and chemical tendering for many potential application special increase the physical behaviour like optical, thermal and mechanical characteristics of the materials. [16–17]. A deep inside characteristics of PANI can lead to disorder and irregular patterns of exhibiting the performance due to week formation of long chains and structural modification which encounter the problems of enhanced performance and stable activity in various potential application like as change in redox patterns, charge/discharge characteristics disorders and many electrical/electronics discriminations.

Thus keeping the feature in minds, the doping or performance of PANI has to improved by hybridization with advance physical/chemical stable materials to fabricate a very high standard composite. In recent era, the combination of carbon based materials with variety of carbons forms like CNT, hardcarbons, GO, rGO and graphene have facilitated many researcher with their unique physical feature that showed high performance with robust stability for long duration. Additionally, the carbon based materials have high mechanical/thermal stability, higher electron density and localized functional grouping on the large surface area are well advanced in developing generation new kinds of materials with utmost features [18]. Introducing carbon materials as host to PANI can fetch the physical behaviour of PANI to higher level and exhibit a robust nature of conductivity. After invention of graphene, the use of graphene has promised many researchers and industries for developing advanced functional materials for many potential application because of unique physical feature of graphene. It has a very high surface areas, high mobility ratio, higher stability and high mechanical strength that intrigues the host and works as matrix for different materials for develop a functional or composites materials. Thus, in current research areas graphene based materials are highly utilized for many potential application especially for supercapacitor, batteries, water purification, and many energy/environmental application due to their robust physiochemical properties. Composites generates by combining graphene based

materials with PANI has created a major role in developing a variety of materials with impressive performance as photocatalyst, electrocatalyst and many electrochemical works. Madhabi et al reported the improved in thermal and electrical properties of PANI introducing in situ reduction of graphene oxide plane that further reduced to rGO/PANI nanocomposites exhibiting a excellent performance and observed the enhancing in physical properties by varying concentration of graphene oxide in the composites [19–20]. Reduced graphene oxide could induce more prolonged coil configuration of polymer chains in the PANI are the strong stacking force of pi bonds that exists among the ring structural behaviour of PANI. Additionally, the existences of graphene plane at the base interaction with intermolecular structuring to generate rigid formation.[21, 22]. The improvement in the electrical performance is generated due to the change in volume occurring at the raise of functional groups of rGO which supports for higher performance in the composites.

In view of above studies, the authors focus on the following aspects

1. Fabrication of grapheme doped PANI nano composites and their characterization.
2. Study of their spectroscopic thermal, crystalline and electrical or study of chemical and Physical properties.
3. The nano composites are exposed to solar radiations during their use. Therefore effect of solar radiation on chemical and physical properties under different conditions is to be ascertained.
4. For this purpose, the authors have used FTIR (chemical effect), XRD (crystalline properties DSC (thermal behavior), SEM (morphological changes) and electrical properties (conductivity measurement & impedance analysis).

The present research work mainly focus on the fabrication of PANI and graphene doped PANI using chemical method and successfully tested for thermal and electrical behavior of the composites. Integrating of polymer and graphene can increase the physicochemical properties that can enhance the electrical and thermal conditions of the composites. The composites and pure sample were exposed to solar radiation for different duration of exposure to understand the thermal and electrical behavior.

MATERIALS AND METHODS

Synthesis of PANI Doped Graphene

The analytical grade polyaniline was purchased from lobe chemical and used for the experimental processing without any further purification. For the preparation of graphene (Grp), firstly GO was synthesised using chemical method as reported by Kashinath et al [23–26] and the prepared GO was treated with hydrazine hydrate according to report which influence of graphene reinforcement in conductive polymer: Synthesis and characterization. In the process of reduction with hydrazine hydrate a small amount of ammonia solution was also added to get stable dispersion of graphene and PANI [27–29]. A stable solution of PANI and graphene (2:1) separately softened in dimethyl formamide solution (10 mL; DMF) solvent stirring for 2 hrs and yield pure fine solution of PANI doped graphene was desiccated in vacuum oven at 80^0C for 24 hr, named as PANI/Grp.

CHARACTERIZATION TECHNIQUIES

The PANI and PANI/graphene nano composites were obtained from market is further used with no purification and alteration to examine the degradation efficiency. The functional investigation of the PANI were conducted using Bruker Alpha-II. Fourier transform infrared spectroscopy (FTIR) instrument using KBr pallet making process. The structure and surface morphology of composites were investigate using scanning electron microscope (SEM) and DSC was used to understand the thermal behaviour of the materials in nitrogen atmosphere with ramp rate of 20°C/min from 0–180°C. Electrical impedance was measure using four probe method using electrometer (Keithley 619).

RESULTS AND DISCUSSION

XRD Studies

The crystal patterns and phase transformation of PANI and PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr nano composites were investigated using XRD diffractograms as depicted in Figure

1(a). The PANI having the characteristic and indexing peak patterns of standard diffraction phase reported early in many research work and literature survey/data gives insight concepts of semi crystalline and small intensity peaks formation. PANI presented the chief distinguishing peaks at 15.03°, 20.31°, 22.46°, 25.34°, and 34.15° for corresponding planes of refraction observed at (011), (020), (021), (200), and (310), respectively from previous reported data [30-31]. PANI show diffraction peak centred around 25^0. Therefore, it is natural to expect diffraction around 25° were observed for as prepard materials [32–33].

The characteristic peak pattern of pure PANI presence at at 26° corresponds to major indexing that confirms semi-crystalline behaviour of the sample materials prepared. The existence of graphene in PANI is characterized at major indexing peak at 27° which gives a lead of hybridization between PANI and graphene for PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr. The signal of the graphene peaks at 27° and 45° in the composite the perfect blend and formation of the composite [34–36]. The XRD investigation confirms the perfect mixture of PANI and Graphene in the composites giving a new conducting polymer materials. Further the intensity of peaks and existence of peaks at various level suggest a change in crystal behaviour of pure PANI and as prepared composites have a very good crystal behviour.XRD studies reveals a increase in the physiochemical properties of materials before and after doping with graphene is perfectly onserved in the results of thermal and electrical performance of composites.

FTIR Analysis

The functional groups and surface-active sites of the as obtained PANI and PANI/Grp Nano composites at different exposure to solar radiation (PANI/Grp@12hr PANI/Grp@24hr and PANI/Grp@36hr) were explored using FTIR technique as shown in Figure 1(b). The degradation efficiency of PANI and PANI/graphene under solar light radiation was examined using FTIR analysis for the time duration of 12, 24 and 36 hrs respectively. From the results, it can be predicted that there is slight decrease in the intensity and lower shift in peaks value of around 3 cm indicates a reduction or degradation of phase change due to solar irradiation on the surface of PANI/Grp. PANI is reported to give characteristics absorption bands 3400–3000 cm^{-1} (NH/OH/Hydrogen bonding), 1600–1500 cm^{-1} (Quinoid), 1500–1400 cm^{-1} (benzoid), 1240–1200 cm^{-1} (C-N). While PANI is doped with grapheme-based composites execute absorption bands 3400-3000cm^{-1} (NH or OH or HH) 2900 cm^{-1} (CH), 1700–1600 cm^{-1} (quinoid), 1500-1400 cm^{-1} (benzoid) 1250–1200 cm^{-1} (CN and or COC), 1180–1000 cm^{-1} (COC) [32, 37]. The functional group and localized bonding of PANI are located at intensive alcohol group existence at a peak value of 3410 cm^{-1} (O-H), 3218 cm^{-1} is the shoulder group that exists for aniline at lower wavenumbers because of the stretching bonds of N-H monome [38]. A shift in peaks were observed with subordinate strength after solar irradiation on PANI/Grp composites at 1290 cm^{-1}, 1236 cm^{-1}, besides 1105 cm^{-1} in PANI move to 1299 cm^{-1}, 1244 cm^{-1}, and 1128 cm^{-1} exposed to sunlight for 12, 24 and 36 hrs respectively [39–40]. This change in the intensity and peaks nature gradually decreases due to longer exposure to sun light which confirms a water free bonding of composites and defects free self-arrangement of localised molecules on the surface of composites. These shifts cannister be elucidated by the communications between the Grp and PANI handcuffs, which restrict the vibrations within the PANI structure. The stretching vibrations of C=O and C=C groups are present at 1728 cm^{-1} and 1622 cm^{-1}, respectively for PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr [41]. Furthermore, the C-O and alkoxy widening vibrating groups are detected at around 1380cm^{-1} and 1064 cm^{-}1, individually. Displays distinguishing mountaintops conforming to equally Grp and PANI, confirming the positive fusion of the PANI/Grp nano composite can be seen in Figure 1(b).

From the FTIR results Figure 1(b) displays that when the unadulterated PANI and composites were exposed to solar light there some changes in purposeful groups and localised structural bonding of the

resources which thus results in leading degradation of polymer chain and rebuilding performance of defect free molecules.

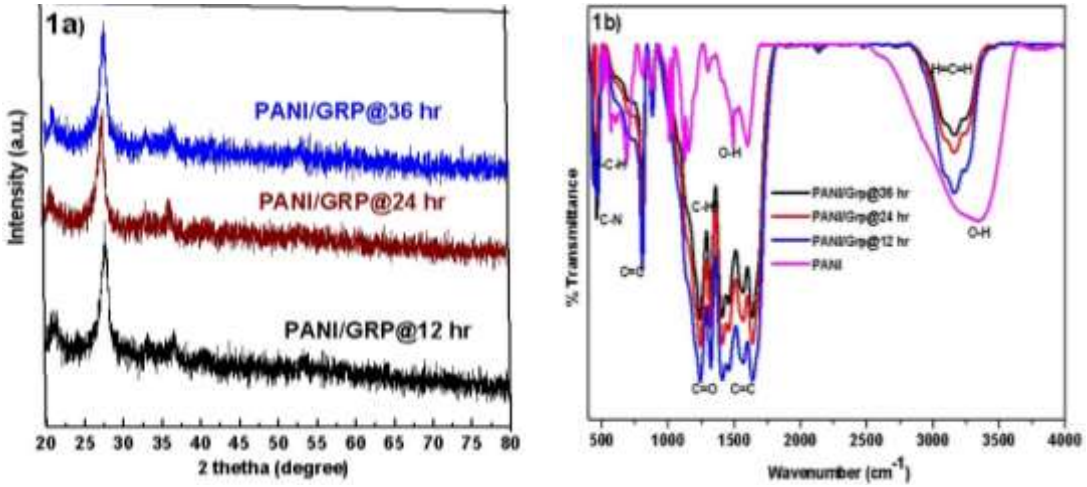

Figure 1. (a) XRD and (b) FTIR study of PANI and PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr of solar degradation respectively.

This exposure removed water bonding and free localised molecules on the surface which in turn made the materials very active to solar radiation and showing enhanced performance in thermal and electrical nature. A band at 1303 cm^{-1}, allied with C–N widening in the quinoid ring, and the gang at 1240 cm^{-1}, conforming to C–H meandering atmospheres, indicate the doped state of PANI in the PANI/Grp Nano composite (PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr) [42]. The presence of these bands confirms that PANI retains its electro and chemical activity. However, the overall structure of Grp remains largely intact, as evidenced by the FTIR spectrum, where the characteristic bands of GO are still present. This indicates that while some functional groups may interact with PANI, the core structure of Grp.

Scanning Electron Microscope

The microstructural properties of PANI and PANI@graphene, (PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr) was examined using SEM analysis shown in Figure 2. From SEM images it can be predicted that the PANI degradation shows a large humps or uncontrolled morphology or structure. A small piece of peddle or crushed paper like structure are confirmed for PANI/Grp@12hr, PANI/Grp@24hr and @36hr) respectively as shown in Figure 2 (b-d) [43–45]. The structure and morphology of PANI/Grp almost remains same but different size of crystal are higher in PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr which leads that a higher reduction of PANI/Grp under solar light. Due to exposure of sun light for longer duration on PANI and PANI@graphene that facilities in generating a higher dislocation and large gap between crystal planes which in turn generated the formation of higher or bigger crystalline size that are mostly crushed paper or crumbled like structure in nature can be seen in Figure 2.

The surface morphology of as prepared PANI confirms the presence of large grains of clusters which are depicted for chemically prepared PANI in common procedure way. A clear vision of morphology of PANI further depicts the irregular disc or large grains with distinct cluster structure. These irregular grains and cluster are larger and larger for the graphene doped PANI. These alteration and creation of higher cluster are more and more due to higher amount of graphene in PANI. High cluster and angulation of particles in the composites are employed due to physical interaction of PANI and graphene that generated to the hosting behaviour of PANI semi crystal behaviour intriguing the surface of composites more and more due to electrostatic and electron forces of hybridization can be clearly observed in SEM images [46–48]. The network and matrix nature of PANI and graphene physical behaviour compensate for higher grain boundary and clustering surface of composites and additionally

the longer duration of solar radiation additionally increase the surface area due to bulging nature of water oxidation in the composites.

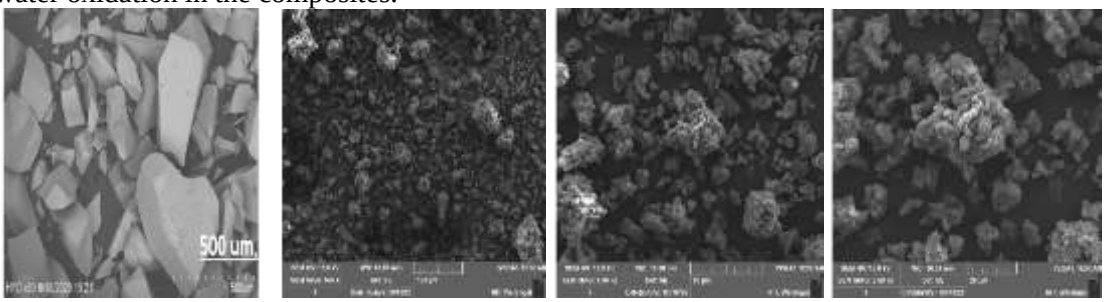

Figure 2. SEM images of (a) PANI, (b-d) PANI/Grp@12hr, PANI/Grp@24hr, and PANI/Grp@36hr respectively after solar degradation

From the other sides of surface behaviour indicates a higher flake like layers density in the composites due to presence of graphene at higher concentration and amount. The surfaee texture of composites shows non uniform patterns of nanoparticles and inbuilt flake layers [49].

DSC Analysis

The differential scanning calorimeter study was undertaken to understand the heating rate mechanism and decomposition of the PANI and PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr under nitrogen atmosphere at 10°C/min for of exposure respectively can be show in Figure 3. From the DSC curves, it can be examined that a clear changes in the energy as a function of temperature gradient of the expose was determined at 38°C for PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr respectively [50]. The temperature gradient decreases to higher level after the 36-hr degradation of PANI with decrease of 20°C of temperature gradient (Figure 3). The decrease in the transition temperature indicates that there is no cross linkage of any foreign interference but due to degradation of PANI and PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr in sunlight. This reduces some of active's sites and dislocation/break down of surface molecules that leads to ductile strength of PANI and PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr exposure and in turn interlocking of pure molecules dislocation leads to lower transition temperature. A two-step weight loss of the composites and pure PANI is observed in which the first weight loss is due to vaporization of water molecules and other surface impurities and second weight loss is due to breakdown of polymer chain and molecules on the surfaces is higher for higher exposure of sample. The reduce in gravity of composite is due to elevation of extra inhibiting particles and local settlement of moisture and unstable species on the surface were deeply eliminated which showed a degradation in thermal behaviour of composites and generating a secondary weight reduction breaking of polymer chains on the surface of graphene which leads to overall reduction in weight and thermal sensitivity. The thermal properties of pure PANI is very less compared to nanocomposites because of inherent various in the temperature gradient on different areas on the surface.

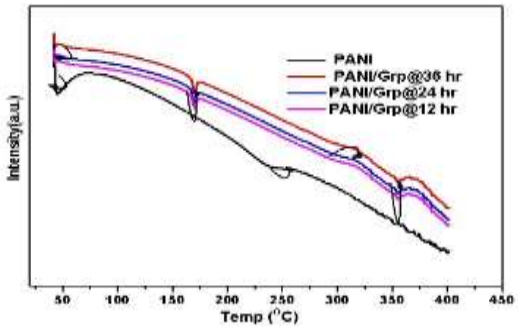

Figure 3. DSC thermogram of PANI, PANI/Grp@12hr, PANI/Grp@24hr, and PANI/Grp@36hr respectively after solar degradation

Increase in thermal stability of the composites can be attribute to network of graphene surface and its functionalized shield of non-flammable of polymer chains, Additionally, Grp controls and refrains the mobility of charge particles on the surface of PANI and decomposition of surface temperature leads to higher thermal stability of nanocomposites [51–53]. The company of shield constrains the rate of heat transfer and polymer dilapidation. The endothermic peaks cantered around 80ºC and 180ºCwith low enthalpy are assigned to transitions in polymer facilitated by release of water [54–56]. An endothermic reaction peak is located at 181ºC is accredited to the evolution of water in the method of vapour or moisture produced by the PANI and 349ºC for PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr under sunlight and the intensity of peaks is very high or higher value is observed for longer exposure that indicated a higher rate of surface degradation leading to the formation of water or release of water molecules due to degradation on the surface of PANI and in the composites. The first endothermic heat rate of PANI happens at the range of 30 for PANI/Grp@12hr. PANI/Grp@24hr and PANI/Grp@36hr PANI@24hr and 40^0C for PANI@12hr due to the elimination of moisture, which was more for PANI@24hr sample and first endothermic heat scan is decrease for PANI@24hr[57–58]. From the DSC curves, it can be examined that a clear changes in PANI/Grp@12hr, PANI/Grp@24hr and PANI/Grp@36hr the energy as a function of temperature gradient of the expose was determined at 389ºC for PANI/Grp@36hr and 349ºC for PANI/Grp@12hr, PANI/Grp@24hr respectively. The temperature gradient decreases to higher level after the 24hr degradation of PANI with decrease of 20ºC of temperature gradient (Figure 3).

Electrical Performance by Four-Probe Method

Electrical conductivities of the composites PANI doped graphene (PANI/Grp@12hr PANI/Grp@24hr and PANI/Grp@36hr) and pure PANI were measured using a four-probe method. For the investigation, a pellet of dimension 13 mm in diameter and 1mm thickness was prepared using 0.2 g was pelletized at 70 MPa using a hydraulic press. The I−V characteristics was conducted in the voltage ranging from -1 to 1 V with a difference of 0.01 V per measurement exhibiting a dual mode of sweep. To investigate the electrical properties of material were conducted a four different region on the surface of pellet prepared for four probe investigation. The region at center, and four edges at four corners are well defined with robust characteristic of electrical conductivity after many reputation [59–60].

Resistivity: $(\rho) = 4.5\ V/I$
Conductivity: $(S/cm) = 1/\rho$

Where V is the applied voltage, I is the measured current through the sample and S is the distance between the probes.

The result of resistivity and electrical behaviour of pure and composites were illustrated in Table 1 and a comparative illustration of electrical conductivity in shown in bar diagram method in Figure 4(a). The solar irradiated composites sample after 36 hr displayed the highest, good responsive conductivity followed by the PANI/Grp@24hr and PANI/Grp@12hr respectively. The conductivity the composites increased more and more due to continue exposure to solar irradiation which confirms a great influence of graphene in PANI and their exposure to solar light.

Table 1. Electrical conductivity of PANI and PANI/Graphene Nano composites Measured by four probe Technique.

		Resistivity(ohm-cm)				Conductivity(S/cm)			
Composition	**Thickness (mm)**	**RT**	**12 hr**	**24 hr**	**36 hr**	**RT**	**12 hr**	**24 hr**	**36 hr**
PANI	13	0.0624	0.0564	0.0489	0.0365	16.118	17.749	19.2	24.21
PANI/Grp@12hr	13	0.0102	0.0091	0.0072	0.0056	89.28	103.09	126.90	141.26
PANI/Grp@24hr	13	0.0085	0.0082	0.0067	0.0045	112.61	121.95	149.25	170.84
PANI/Grp@36hr	13	0.0027	0.0020	0.0016	0.0009	145.21	217.51	225.80	261.88

The composites exposed for less time gave higher electrical resistivity and lower stability. Unadulterated PANI displays a conductivity of 20.18 S/cm unhurried at apartment infection (298 K) and the electrical conductivity of the PANI doped graphene composites found to be greater performance and increased activity with higher magnitude of conductivity of 89.12 S/cm, 112.1 S/cm and 149.5 S/cm respectively for PANI/Grp@12hr, PANI/Grp@24hr, and PANI/Grp@36 hr. From the study, it is a clear evident that the presence of graphene in PANI showed a fivefold of better and enhanced conductivity at room temperature. This tendency of five folds enhanced behaviour is also identified in composites sample exposure to solar light but with higher and higher conductivity when compared to room temperature. The investigated data and results are in agreement with the reported values [61–64] where depicted in tabular form and bar graph of conductivity is illustrated in Figure 4a respectively. The improvement in the conductivity of composites is due to increase aspect ratio and surface area enlargement of graphene and PANI exposure to sunlight for longer time. Increase in surface area of composites played a vital role in electronic transportation and bridge between PANI and graphene that promotes for higher conductivity.

Additionally, the availability of higher concentration of mobile electrons inside and out the composite surface that face lifted in increasing conductivity. From the conductivity measurements, it can be concluded the conductivity of the pure PANI and PANI doped graphene composites showed a gradually increase in the conductivity for longer exposure to sunlight that stimulated the electrical behaviour similarity to the performance of composites at higher temperature. This result confirms the increase of conductivity is due solar exposure which the composites generate electrical behaviour under solar light irradiation thus acts a solar model electrical material. A gradual increase in conductivity is observed for longer exposure to sunlight which charge carrier transfer between Grp and PANI with raise in temperature in quilted by solar radiation. The thermal effect caused by the solar light migrated the arrangement of polymer chains of network and increase the conjugation between PANI and PANI doped graphene and subsequently resulted in rearrangement of molecules which contributed to delocalization of crystal lattice and increase in lattice space. The greater conductivity power be due to the great characteristic ratio and shallow zone of the graphene sheets due to high surface extent possibly served as effective permeated showing bridges. At developed attention of graphene, increase in conductivity may be due to the–loading between the graphene layers and polyaniline for which electron mobility inside the compound organization surges

Impedance Spectroscopy

To understand deeper insight behavior of pure and doped graphene composites sample electrical behavior was conducted using impedance spectroscopy analysis method**.** The affirmation from the reduction summits existence in real/imaginary share of the impedance spectroscopy is due to charge and space relaxation of the composites sample. The electrical conductivity of composite is inversely proportionally to impedance spectroscopy curve. From the EIS spectra, it can be conducted that the real part of impedance shows a critical hike in the frequency range and decrease in further and remain constant which shows the characteristic of grain resistance in the composites and pure sample. In the lower frequency region, a higher dissipation can be seen due to collective polarization mechanisms of dipoles that produces a higher amount of free radical and charge moving particles that directly support for higher movements and transportation of induced change particle and carriers.

A clear evident and confirmation that the composites exposed for longer duration in solar radiation (36 hrs.) showed a loss resistance, higher conductivity and good responses to electrical behavior compared to the sample exposed to less duration 24 and 12 hrs. The standards inputs from the impedance be contingent on the entire resistance in the circuit which is the total of grain /bulk resistance [65–67]. The presence of semicircular arc implies the dielectric response which signifies a combination of resistor and capacitor in parallel method and the area region of arc suggest the raise in conductivity, This behavior in composites is higher for 36 hr exposed sample when compared to 24 and 12 hr exposure and which direct us to understand a good responsive to thermal and electrical behavior of the composites were predicted and investigated for longer sun light better than less exposed samples were depicted in Figure 4.

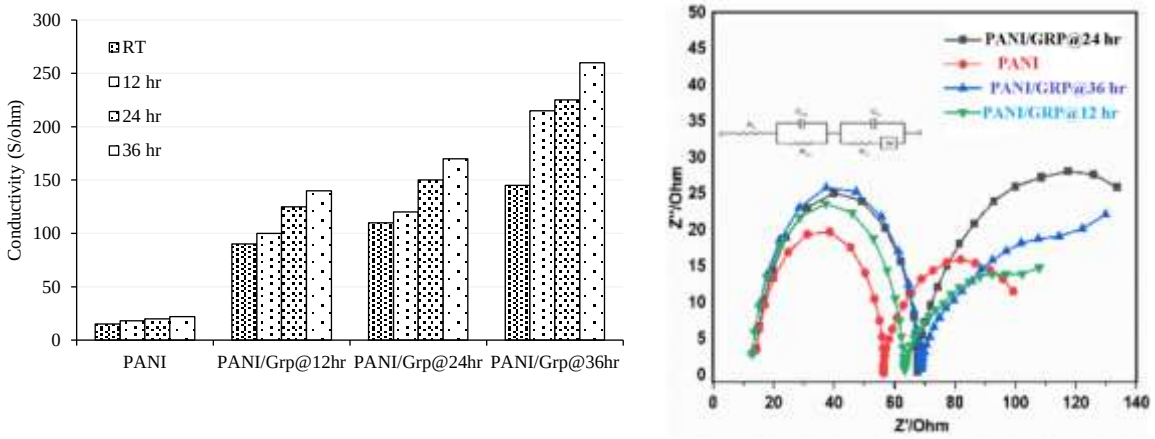

Figure 4. Conductivity bar graph and EIS spectra PANI, PANI/Grp@12hr, PANI/Grp@24hr, and PANI/Grp@36hr respectively after solar degradation.

CONCLUSION

In summary, PANI and PANI doped graphene composites were successfully fabricated using chemical method and investigated for thermal and electrical behavior. The composites and pure PANI were exposed to solar light and tested for changes in thermal and electrical conductivity characteristics. Our observation suggested that the composites showed an increased and higher rate of conduction and thermal behavior compared to pure sample even after the exposure to solar light radiation.

Pure PANI shows a conductivity of 20.18 S/cm measured at room temperature (298 K) and higher magnitude of conductivity of 89.12 S/cm, 112.1 S/cm and 149.5 S/cm respectively for composites sample which nearly fivefold higher and enhanced performance. The results give insights concept of higher responsive of composites exposed to longer sun light and this method generating the conductivity is a newest concept which can be further developed for any conducting polymer-based materials.

Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES

1. Kim M, Lee C, Jang J, Fabrication of Highly Flexible, Scalable, and High-Performance Supercapacitors using Polyaniline/Reduced Graphene Oxide Film with Enhanced Electrical Conductivity and Crystallinity. Adv. Funct. Mater. 2014; 22: 2489–2499p.
2. Kumar NA, Choi H J, Shin YR, et al. Polyaniline-grafted reduced graphene oxide for efficient electrochemical supercapacitor. ACS Nano. 2012; 6: 1715–1723p.
3. Rao C N R, Sood A K, Subrahmanyam K S, et al. Graphene: The New Two-dimensional Nanomaterial. Angew. Chem. Int. Ed. 2009; 48: 7752–7777p.
4. Zhang K, Zhang LL, Zhao X.S, et al. Graphene/Polyaniline Nanofiber Composites as Supercapacitor Electrodes. Chem. Mater 2010; 22 (4): 1392–1401p.
5. Manvi Sharma, D. Veerabhadra Babu, Mamta Gour, et al. Design and Characterization of High-Performance Polymer Nanocomposites for Aerospace Applications. Stm. Jopc. 2025; 13(4): 178–193p.
6. Fowler JD, Allen MJ, Tung V C, Yang Y, Kaner RB, Weiller BH. Practical chemical sensors from chemically derived graphene. ACS Nano. 2009; 3(2): 301–306p.
7. Wang C, Li Dan, Too Chee O, et al. Electrochemical Properties of Graphene Paper Electrodes Used in Lithium Batteries. Chem. Mater. 2009; 21(13): 2604–2606p.

8. J. Lurdhumary, Suguna B. Rao, S. Nooray Sashmi, et al. Electroactive Graphene–Polymer Nanocomposites for Self-Sustaining and Multifunctional Flexible Devices. Stm. Jopc. 2025; 13(6): 260–271p.
9. Eda G, Chhowalla M. Graphene-based Composite Thin Films for Electronics. Nano Lett. 2009; 9(2): 814–818p.
10. Vickery JL, Patil AJ, Mann S. Fabrication of Graphene–Polymer Nano composites with Higher Order Three-Dimensional Architectures. Adv. Mater. 2009; 21(21): 2180–2184p.
11. Mazzeu MAC, Faria LK, Baldan M.R, et al. Influence of reaction time on the structure of polyaniline synthesized on a pre-pilot scale. Braz. J. Chem. Eng. 2018; 35: 123–130p.
12. Ashok Kumar Suluguru, Brunda Ungarala,B. Vamsi Krishna. Enhanced Durability and Performance of Reinforced Concrete Beams through CFRP Wrapping: An Experimental Investigation. Stm. Jopc. 2024; 12(4): 37–49p.
13. Ghorbel E, Hadriche I, Casalino G, et al. Characterization of Thermo-Mechanical and Fracture Behaviours of Thermoplastic Polymers. Materials. 2014; 7: 375–398p.
14. Hamlaoui FZ, Naar N. Improvement of the structural and electrical properties of PMMA/PANI-MA blends synthesized by interfacial in situ polymerization in a continuous organic phase. Polym. Bull. 2020; 79: 37–63p.
15. Khan MDA, Akhtar A, Nabi SA, Investigation of the electrical conductivity and optical property of polyaniline-based nanocomposite and its application as an ethanol vapou sensor. New J. Chem. 2015; 39: 3728–3735p.
16. Waware US, Hamouda AMS, Majumdar D. Synthesis, Characterization Physicochemical Studies of Copolymers of aniline and 3-nitroaniline. Polym. Bull. 2020; 77: 4469–4488p.
17. Shikalgar Niyaj Dilavar, Ashwin Sailesh, Manas Ranjan Sahoo, et al. Enhancing Mechanical Properties by Parameter Optimization in Fiber and Particle Reinforced Composites. Stm.Jopc. 2025; 13(2): 75–85p.
18. Gkourmpis T, Karolina G, David T, et al. Melt-mixed 3D Hierarchical Graphene/Polypropylene Nanocomposites with Low Electrical Percolation Threshold. Nanomaterials. 2019; 9(12): 1766p.
19. Madhabi, Devi, Kumar, et al. electrical and dielectrical properties of reduced grapheme oxide – polyaniline nanotubes hybrid nano composites synthesized by in situ reduction and varying grapheme oxide concentration. Jou. Appli. Poly. 2018; 135: 45883p.
20. Kashinath Lellala, Namratha K, Byrappa K. Ultrasonication Assisted mild Solvothermal Synthesis and Characterization and Morphology Study of Few-Layered Graphene by Colloidal Suspensions of Pristine Graphene Oxide. Microporous and Mesoporous Materials. 2016; 226: 522–529p.
21. Kashinath K, Namratha K, Byrappa, Microwave-assisted synthesis and Characterization of Cerium Oxide-Graphene Oxide Nanocomposites For Significant Efficiency Of Photodegradation Performance Of Dyes, reduction of Cr (VI) and its antibacterial effect. Journal of Environmental Science. 2019; 76: 65–79p.
22. Lellala K, Chaliyawala HA, Mukhophadhyay I. A Novel Graphene as an Anodic Material for Lithium-Ion Battery, Fabrication of Graphene from Camphor: Emerging Energy Applications": Taylor and Francis group. SBN 9780367677237, by CRC Press; 2021.
23. Kashinath L. Sulphur Embedded On In-Situ Carbon Nano disc Decorated On in situ Graphene Sheets for efficient photocatalytic activity and Capacitive Deionization method for Heavy Metal Removal. Journal of Materials research and technology. 2021; 13: 1555–1566p.
24. Goodrum R, Hafton W, Huiyan Li, et al. Graphene-based nanostructure from green processes and their applications in biomedical sensors. Adv. Industrial Eng. Polym. Res. 2024; 7: 37–53p.
25. Devaraj S, Munichandraiah N, Effect of Crystallographic Structure of Mno2 on Its Electrochemical Capacitance Properties. J. Phys. Chem. C. 2008; 112: 4406–4417p.

26. Han.T H, Parveen N, Ali S A, et al. Electrochemically synthesized sulfur-doped grapheme as a superior metal-free cathodic catalyst for oxygen reduction reaction in microbial fuel cells. RSC Adv. 2016; 6: 103446–103454p.
27. Verma S, Pandey V K, Verma B. Facile synthesis of grapheme oxide-polyaniline-copper cobaltite (GO/PANI/CuCo204) hybrid nanocomposite for supercapacitor applications. Synth. Met. 2022; 286: 117036–117049p.
28. Wang H, Lin J, Shen Z X. Polyaniline (PANi) based electrode materials for energy storage and conversion. J. Sci. Adv. Mater. Dev. 2016; 1: 225–255p.
29. Stankovich S, Dikin DA, Piner RD, et al. Synthesis of graphene-based nanosheets via chemical reduction of exfoliated graphite oxide. Carbon. 2007; 45(7): 1558–1565p.
30. Wang T, Yi Zhu G, Li Y S, et al. Synthesis of Polyaniline/Graphene Nano composites and Its Optical, Electrical and Electrochemical Properities. Sci. China Chem. 2011; 54: 1645p.
31. Majumadar D, Baskey M, Saha SK. Epitaxial growth of crystalline polyaniline on reduced grapheme oxide. Macro Macromol Rapid Com. 2011; 32: 1277p.
32. Ajeel K, Kareem Q S. Synthesis and Characteristics of Polyaniline (PANI) Filled by Graphene (PANI/GR) nano-films. IOP Conf.ser.2019; 1234 012020p.
33. Mustafa Z, Ranjn Kuma Ghadai, B.B.Pradhan, et al. Resent Advances in Polyaniline/grapheme nanocomposites for supercapacitor application: Synthesis properties, and future direction. Results in Surfaces and Interfaces. 2024; 17: 100316p.
34. Muralikrishna S, Nagaraju D H, Balakrishna R G. et al. Hydrogels of polyaniline with graphene oxide for highly sensitive electrochemical determination of lead ions. Anal. Chim. Acta. 2017; 990: 67–77p.
35. Mutalib T N A B. T A, Soojin J, Kai L F, et al. Properties of polyaniline/graphene oxide (PANI/GO) composites: effect of GO loading. Polym. Bull. 2021; 78: 4835–4847p.
36. Rahman Md M, Mahtab T, Bin Mukhlish M Z, et al. Enhancement of electrical properties of metal doped polyaniline synthesized by different doping techniques. Polym. Bull. 2021; 78: 5379–5397p.
37. Rehana Rasool, Kowsar Majid. Synthesis, characterization, thermal and electrical properties of composie of polyaniline with cobaltmonethanolamine complex. Bull Mater Sci. 2014; 37: 1811–1184p.
38. Tchova M, Stejskal J. Polyaniline: The infrared spectroscopy of conducting polymer nanotubes (IUPAC Technical Report). Pure.Appl.Chem. 2011; 83: 1803–1817p.
39. Du S M X, Xu Y, Xiong L et al. Polyaniline with High Crystallinity Degree Synthesis, Structure, and Eeectrochemical Properties. J. Appl. Polym. Sci. 2014; 131(9).
40. Yang S, Zhu S, Hong R. Graphene Oxide/polyaniline Nanocomposites Used in Anticorrosive Coatings for Environmental Protection. Coatings. 2020; 10: 1215
41. Gemeay, Elsharkawy R G, Aboelfetoh E F. Graphene Oxide/Polyaniline/Manganese Oxide ternary nanocomposites, Facile Synthesis, Characterization, and Application for Indigo Carmine Removal. J. Polym. Environ. 2018; 26: 655–669p.
42. Xiong S RW, Zang X I, Yu Wu et al. Covalent Bonding of PANI and p-Phenylenediamine-Functionalized GO Using N, N′-Dicyclohexylcarbodiimide as Dehydrating Agent for Electrochromic Applications. Chemistry Select 2019; 4: 543–550p.
43. Riaz A, Usman A, Muhammad F, et al. Shahid S, Effect of polymerization of Aniline on Thermal Stability, Electrical Conductivity and Band Gap of Graphene Oxide/Polyaniline Nanocomposites. Int. J. Electrochem. Sci. 2017; 12: 1785–1796p.
44. Hanafi N N. et al. Solar-driven Degradation of 2-Chlorophenol using PANI/GO as Photocatalyst. Orbital, Electron. J. Chem. 2020; 205–212p.

45. Xu G, Nan Wang, Junyi W, et al. Preparation of Graphene Oxide/Polyaniline Nanocomposite with Assistance of Supercritical Carbon dioxide for Supercapacitor Electrodes. Ind. Eng. Chem. Res. 2011; 51: 14390–14398p.
46. Li H, Zang Q, Liu L, et al. Covalently-grafted polyaniline on graphene oxide sheets for high performance electrochemical supercapacitors. Carbon. 2014; 71: 257–267p.
47. Miao J, Li H, Qu H, et al. Graphene/PANI hybrid film with enhanced thermal conductivity by in situ polymerization. J. Mater. Sci. 2018; 53: 8855–8865p.
48. Kumar R, Sahoo S, Joanni Eet al. A review on synthesis of graphene, h-Bn and MoS2 for energy storage applications: Recent progress and perspectives. Nano Res 2019; 12 (11): 2655–2694p.
49. Kumar R, Sahoo S, Joanni E, et al. A Recent progress in the synthesis of graphene and derived materials for next generation electrodes of high-performance lithium-ion batteries. Prog. Energy Combust Sci .2019; 75: 100786p.
50. Ragupathy D.H, Park G, Campet H N, et al. Remarkable capacity retention of nanostructured manganese oxide upon cycling as an electrode material for supercapacitor. J. Phys. Chem. C 2009; 113: 6303–6309 p.
51. Ragupathy P, Vasan H N, Munichandraiah N. Implication of change transfer properly on the super capacitive performance of manganese oxide originated through different synthesis-routes. J. Electrochemical Soc. 2008; 155: A34–A40p.
52. Varghese A, Devi K R S, Kausar F, et al. Evaluative study on supercapacitance behavior of polyaniline/polypyrole metal oxide-based composites electrodes: a review. Mater. Today Chem. 2023; 29: 101424–101444p.
53. Mutalib T N A B T A, et al. Properties of polyaniline /grapheme oxide (PANI/GO) composites, effect of GO loading. Polm. Bull. 2021; 78: 4835–4847p.
54. Moon Gyu Han, Yong Jin Lee, Sung Woen Byun, et al. Physical properties and thermal transition of polyaniline film. Syn. Met. 2001; 124: 337–343p.
55. Yen Wei, Guang-Way Jang, Kesyin F, et al. Thermal transitions and mechanical properties of films of chemically prepared polyaniline. Polymer. 1992; 33: 314–322p.
56. Luis Claudio Mendes, Ana Paula Santiago Falco, Magali Silveira Pinho, et al. Sulfonated Polyaniline: Influence of Sulfonation Routes on its Thermal and Structural Characteristics. Material Research. 2011; 14(4): 466p.
57. Meena P L, Jitendra S, Ajay K S, et al. Fabrication of polyaniline-coated porous fibrous nanocomposite with granular morphology using tea waste Corban for effective removal of rhodamine B dye from samples. Biomass Convers and Biorefinery. 2022; 14(1): 17711–1730P.
58. Tene T, Gabriela T U, Macro G, et al. Toward large-scale production of oxidized grapheme. Nanomaterials 2020; 10: 279p.
59. Parveen N M, Han J I, et al. Newly Design Porous/Sponge Red Phosphorus@ Graphene and Highly Conductive Ni2P Electrode for Asymmetric Solid State Super capacitive Device with Excellent Performance. Nano-Micro Lett. 2020; 12: 1–16p.
60. Wang T, Zhu Y, Gai Li, et al. A novel Hydrogen peroxide biosensor based on the BPT/AuNPs/grapheme/HRP. Sci. China Chem. 2011; 54; 1645p.
61. Crowan D L, Priest V, Marrero T R, et al. Electrical conductivity in Polyaniline. Journal of Physics and Chemistry of solid. 1990; 51: 307p.
62. Sahar Abdalla A, Telfah H, Ferjani. Electrical conductivity enhancement in polyaniline films via. Mixed ion-electron conductive fillers. Journal of Applied Polymer Science. 2024; 141(41).
63. Oleh Khamar, Volodymyr dutka, Mykhaylo Yastyshyn, et al. Electrical conductivity and thermal stability of polyaniline and water-soluble Polymer nanocomposites. Molecular Crystal and Liquids Crystals. 2024; 768: 265–275p.

64. Kareema Alfahed, Ajeel K I. Effect of Cobalt's Chloride on the electrical Properties of Poly(O-Toluidine). Energy Procedia 2012; 322–324p.
65. Israel Rubinstein and Eyal Sabatani, Electrochemical Impedance Analysis of Polyaniline films on Electrodes. Jou. Electro. Chem. Soc. 1987; 134–3078p.
66. Serguei D, Mikhailenko Macro A S, Rodrigues, et al. Impendence Analysis of Polyaniline in Comparison with Some Conventional Solid Electrolytes. J. Phy Chem.2018; 122: 7764–7774p.
67. Mutabar shah, Noman Khan, Zaid Imran, et al. Structural, Optical and Impendence spectroscopy study of thin film of Polyaniline (PANI/ZnO) Nano composite. Material Research Express 2020; 7: 015314.

