

Synthesis and characterization of Carbon-inserted phenolic resin nanocomposites

Ranjana Goswami, Yogesh Chandra Goswami*, Jyoti Kaundal, Chaitanya Sekhar

Nano Research Lab, School of Sciences, ITM University, Gwalior MP, 474001, India

Received 07 July 2023;

revised 09 October 2023;

accepted 14 October 2023;

available online 19 October 2023

Abstract

This paper presents the synthesis and characterization of nanocomposites made from Activated Carbon and Phenol-Formaldehyde, known for their exceptional thermal properties, chemical stability, and affinity for graphite and other forms of carbon. These composites are primarily designed for high-temperature applications that demand strength retention. X-ray diffraction (XRD) analysis reveals a distinct carbon peak in the nanocomposites, while Fourier-transform infrared (FTIR) spectroscopy indicates the presence of functional group peaks in their respective regions. The aim of this study is to provide a detailed account of the chemical synthesis and characterization of activated carbon/Phenol-Formaldehyde nanocomposites. The results of the XRD and FTIR analyses demonstrate the presence of a sharp carbon peak and functional group peaks in their respective regions. These properties render the composites suitable for high-temperature applications requiring strength retention.

Keywords: Bakelite; Carbon; Charcoal; Phenol Formaldehyde Nanocomposites; XRD.

How to cite this article

Goswami R., Chandra Goswami Y., Kaundal J., Sekhar Ch. Synthesis and characterization of Carbon-inserted phenolic resin nanocomposites. *Int. J. Nano Dimens.*, 2023; 14(4): 331-338.

INTRODUCTION

Polymer nanocomposites are a class of materials that have garnered significant attention in recent years. These materials consist of a polymer matrix filled with nanoparticles or nanoscale fillers, which can impart unique properties to the resulting composite material. They have found applications in a wide range of areas, including microelectronics, biomaterials, drug delivery, fuel cell electrodes, mini-emulsion particles, polymer-bound catalysts, layer-by-layer self-assembled polymer films, electro-spun nanofibers, imprint lithography, polymer blends, nanocomposites, and catalysts [1-4].

Phenolic resins composed of phenol and formaldehyde, synthesized in various molecular weights and cross-linking densities, are well-known for their ability to withstand heat, electrical resistance, and chemical exposure. These resins have attracted considerable interest in polymer

science research due to their unique properties and their potential applications in various fields such as adhesives, coatings, composites, and electronics [5]. Studies have shown that adding nanoparticles, such as clay or alumina, can further enhance the scratch resistance of phenolic resins [6-7] and improve their mechanical properties, hard coatings, scratch resistance, and abrasive resistance

Phenolic resins are the preferred binders for manufacturing the carbon brushes used in electrical motors and starters. Depending on the manufacturing process, powdered or liquid solutions of novolac resin-hexa blends and liquid resol binding systems provide the desired binding properties of Phenol/formaldehyde resin, which is a highly cross-linked thermoset material [8]. It is produced through a condensation reaction between phenol and formaldehyde in the presence of either a primary or acidic catalyst. These applications are mainly chosen for their

* Corresponding Author Email: ycgoswami@gmail.com

excellent thermal and chemical resistance Phenol-formaldehyde resin is renowned for its electrical non-conductivity and heat-resistant properties in electrical insulators, radio and telephone casings. Its industrial applications include moulding compounds, coatings, structural adhesives, thermal insulation materials, and composites [9-12]. Due to their high cross-linking density, phenol resins are brittle, which is considered a challenge in their industrial applications. Efforts have been made to address this disadvantage by modifying phenolics with elastomers or thermoplastics [13-15].

In recent years, the incorporation of nanomaterials into polymer matrices has opened new avenues for improving not only the mechanical properties of composites but also their electrical and thermal properties. This involves adding a small number of strategically placed nanoparticles inside the polymeric matrix to produce composite materials with the desired properties [16-21]. Similarly, incorporating nanoparticles such as clay or silica into polymer matrices can enhance their stiffness, hardness, and scratch resistance [22-23].

Patton *et al.* conducted a study where they introduced carbon nanofibers (CNF) into carbon fiber-reinforced phenolic composites. This modification led to significant changes in heat transfer rates and influenced the combustion chemistry of the composite material [24].

Yu and Wan introduced novel flake graphite into barium-phenolic resin and created nanocomposites using roller-coating technology. These nanocomposites exhibited improved ablation performance when compared to the control system. Interestingly, the size of the graphite flakes was found to impact the ablation rate [25].

Liu *et al.* utilized POSS nanomodification in phenolic resin along with carbon fibre reinforcement. Their SEM analysis revealed that this approach resulted in the formation of a more charred surface on burnt samples, ultimately enhancing the material's ablation performance [26].

Bahramian & Kokabi compared the ablation performance, thermal decomposition, and temperature distribution of asbestos/phenolic composites modified with layered silicate to traditional asbestos/phenolic composites. They introduced nanofillers at 3, 4, and 6wt% loadings and found that the 6wt% nanocomposite samples

exhibited the best ablation performance [27].

Srikanth *et al.* prepared ablative nanocomposites by incorporating nano-silica into phenolic resin with carbon fibre reinforcement. The ablation resistance of these nanocomposites increased with the nano-silica content up to 2wt%, but beyond this point, the ablation resistance decreased [28].

Koo *et al.* prepared ablative nanocomposites using MMT organoclay, POSS, and carbon nanofibers (CNF) in a phenolic resin, both with and without carbon fibres. Their study demonstrated that the combination of high loading of MMT organoclay, carbon fibres impregnated with phenolic resin modified using low loading of POSS, and high loading of CNF in phenolic resin resulted in superior ablation performance compared to conventional carbon/phenolic composites [29].

Natali *et al.* produced two different mixtures, one with carbon black (CB) and the other with multi-walled carbon nanotubes (MWCNTs), both in a phenolic matrix. They observed better performance in nanomodified samples through various tests, including thermogravimetric analysis, heat capacity evaluation, oxy-acetylene testing, and post-burning morphology analysis [30-32].

Chonghai Wang *et al.* reported carbon fibre (CF) reinforced silica-phenolic resin (Si/PR) aerogel nanocomposite was prepared through a simple one-pot sol-gel polymerisation in a slurry of CF, PR, silane, hexamethylenetetramine and ethylene glycol [33].

Another advantage of nanomaterials in polymer matrices is their ability to enhance thermal properties. For instance, the addition of graphene can improve the thermal conductivity of polymers, rendering them suitable for heat dissipation applications [34-36]. Similarly, the incorporation of carbon nanotubes can enhance the thermal stability of polymers, enabling them to withstand high temperatures without significant degradation. The introduction of conductive nanoparticles, such as silver or copper, can confer electrical conductivity to polymers, making them suitable for use in sensors, actuators, and electronic devices [37]. Additionally, the integration of nanoparticles, such as quantum dots, can enhance the optical properties of polymers, rendering them valuable in displays and photovoltaic devices [38].

Huang *et al.* [39] presented a successful

modification of phenol-formaldehyde resins with carbon nanotubes, resulting in high-performance adhesives. This study provides valuable insights into how nanomaterials can be employed to enhance the properties of traditional adhesive materials, potentially benefiting various industries.

Cellulose or carbon nanofibers can enhance the dispersion of phenolic resins in solvents, leading to improved compatibility and reduced viscosity [40]. Yang *et al.* [41] reported the preparation and performance of porous carbon nanocomposites derived from renewable phenolic resin and halloysite nanotubes.

In summary, the addition of nanomaterials to phenolic resins holds significant potential for improving their properties and expanding their applications. Nonetheless, further research is necessary to optimize the preparation and processing methods of these nanocomposites to achieve the desired properties while ensuring their safety and environmental compatibility [42-44].

In this paper, we initially report the synthesis of Phenol-Formaldehyde Carbon Nanocomposites using a cost-effective method and their characterization.

EXPERIMENTAL DETAILS

Materials used

Formaldehyde (40 wt% solutions in water), Phenol, Conc. HCl, Glacial Acetic acid, and Activated Carbon were purchased by Ranbaxy and CDH and used as purchased without further purification.

Method

The whole process was divided into two steps (i) Synthesis of Phenol-Formaldehyde resin and (ii) Synthesis of Phenol-Formaldehyde resin-activated carbon nanocomposites.

Synthesis of Bakelite

Reaction Setup

2.5g of formaldehyde (formalin solution 40%) is taken in a beaker. To this, 5 ml of Glacial Acetic acid and 2g of phenol are added. The mixture is then heated to 60°C with continuous stirring. During heating, a few drops of concentrated HCl are added to the solution.

Microwave Irradiation

The solution is subjected to microwave irradiation for approximately 10 minutes. This step is likely aids in the polymerization of the Phenol-Formaldehyde resin, leading to the formation of Bakelite.

Reaction Completion

After microwave treatment, the reaction mixture is allowed to continue for a certain period. This is to ensure that the reaction reaches completion.

Washing and Drying

The resulting Phenol-Formaldehyde resin is washed several times with water to remove any unreacted chemicals or impurities. Finally, it is dried, likely to obtain a solid Phenol-Formaldehyde resin product.

Synthesis of Phenol-Formaldehyde resin activated carbon nanocomposites

Nanocomposite Formation

In this step, the objective is to create phenol-formaldehyde resin resin-activated carbon nanocomposites by incorporating activated carbon nanoparticles into the phenolic resin matrix. Different weight percentages of activated carbon are added to assess their impact on the properties of the resin.

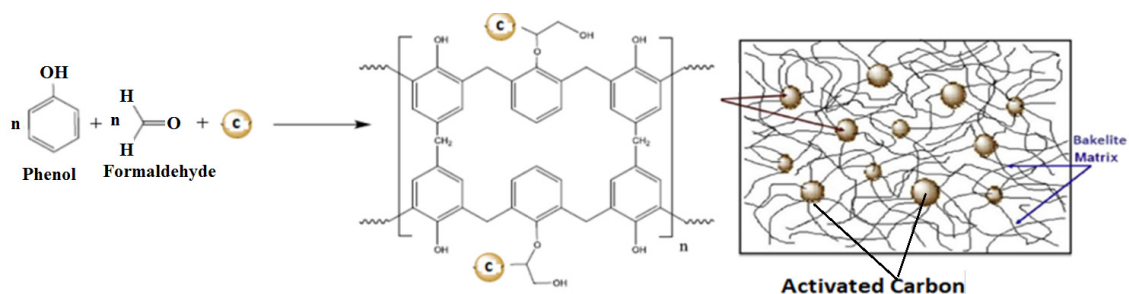


Fig. 1. Schematic diagram of Bakelite/Activated carbon nanocomposites.

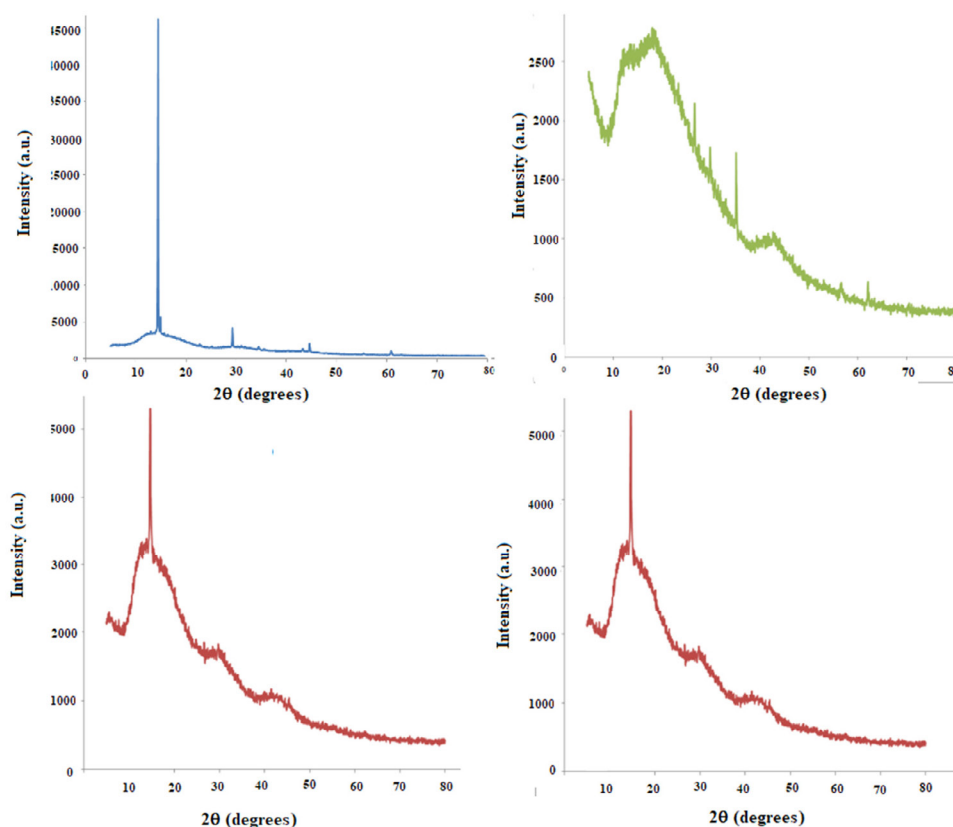


Fig. 2. X-ray diffractograms for (a) pure Phenol-Formaldehyde resin and (b), (c) (d) the Carbon nanocomposites containing 10, 20, and 30 wt.%.

Solvent Usage

Glacial Acetic acid is employed as a solvent to dissolve the phenolic resin for further processing.

Dispersing Activated Carbon

Activated carbon nanoparticles are first dispersed in formalin (formaldehyde solution) in various weight ratios (10%, 20%, and 30%). This dispersion likely involves thorough mixing to ensure a uniform distribution of activated carbon within the resin.

Reaction and Separation

The reaction is allowed to proceed to completion after the addition of activated carbon. Once the reaction is complete, the nanocomposites are separated from the reaction mixture.

Washing and Drying

Similar to the Phenol-Formaldehyde resin synthesis process, the Phenol-Formaldehyde resin activated Carbon nanocomposites are washed to remove any residual chemicals and impurities.

Finally, they are dried, presumably to obtain solid nanocomposite materials.

Characterisations

All the samples were characterised by x-ray diffraction studies using Bruker D8 Advance XRD Cu Ka (1.54\AA) radiation, generated at a voltage of 40 kV and current of 55mA was used as the X-ray source. The diffraction patterns were collected at a diffraction angle of 2 from 20 to 80. FESEM studies were carried out from IIT Mandi using Nova Nano SEM 450. FT-IR studies were analysed using a Perkin Elmer spectrophotometer at 350-4000nm in KBr pellets.

RESULTS AND DISCUSSION

X-ray diffraction (XRD) analysis

X-ray diffraction is employed to characterize the structure of nanoparticles within a polymer matrix. X-ray diffractograms of pure Phenol-Formaldehyde resin and its Carbon nanocomposites are presented in Fig. 2: (a) pure Bakelite, (b) 10 wt.%, (c) 20 wt.%, and (d) 30 wt.%.

Being a polymeric material, Phenol-Formaldehyde resin typically yields well-defined XRD peaks due to its amorphous nature. However, a broad hump centred on $2\theta = 20^\circ$ is commonly observed in XRD analysis of Bakelite, indicative of its amorphous nature.

The XRD pattern shows distinct peaks corresponding to Carbon, with a sharp peak at approximately 20.7° 2θ and theta values (002 and 100) at 40° (Fig. 2a) [9, 37]. Achieving good dispersion of Carbon within the polymeric matrix is essential for the desired improvement in most properties of polymer nanocomposites. In this case, Phenol-Formaldehyde resin has penetrated between the Carbon particles, resulting in intercalated/exfoliated nanocomposites [38, 45]. Specifically, all the polymer nanocomposites exhibit peaks at 15, 30, 44, 45, and 62 degrees. However, upon the addition of Carbon, the diffraction peaks become significantly broader. With 10% Carbon (Fig. 2b), only two peaks at around 15 and 44 degrees are observed. At 20% Carbon (Fig. 2c), one more peak at 30 degrees

becomes visible, which is again absent with 30% Carbon in Fig. 2d.

It has been reported that when no peaks are observed in the XRD profiles and the spacing between platelets is large, the platelets are singular and may be exfoliated. The absence of XRD peaks in all Phenol-Formaldehyde resin / carbon nanocomposite specimens suggests that most of the Carbon used in this study was well dispersed within the Phenol-Formaldehyde resin matrix.

FESEM Studies

FESEM micrographs of (a) pure Phenol-Formaldehyde resin and (b), (c), and (d) the Carbon nanocomposites containing 10, 20, and 30 wt% are presented in Fig. 3 at various magnifications. In Fig. 3(a), pure Phenol-Formaldehyde resin displays spherical structures that cluster together, incorporating active carbon. As depicted in Fig. 3(b, b, c), the size of these spheres progressively increases with the rising concentration of Carbon

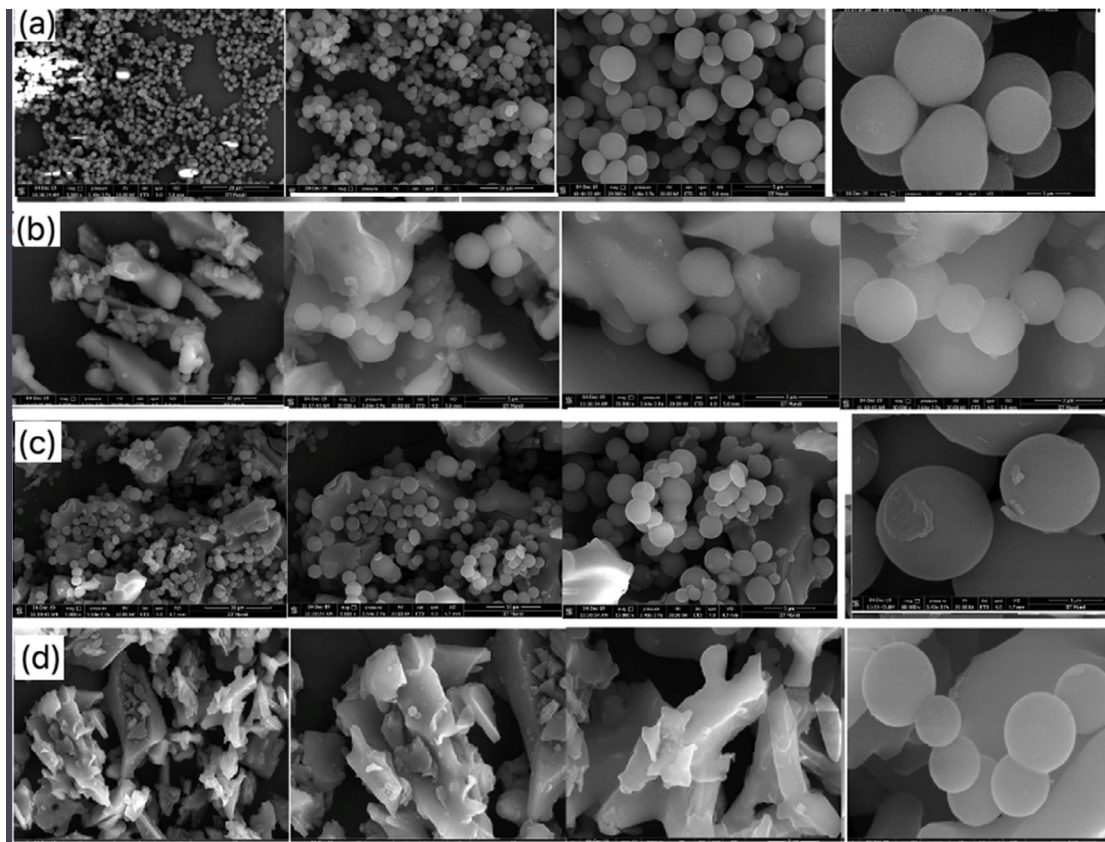


Fig. 3. FESEM pure Phenol-Formaldehyde resin micrographs for (a) and (b), (c) and (d) the Carbon nanocomposites containing 10, 20, and 30 wt%.

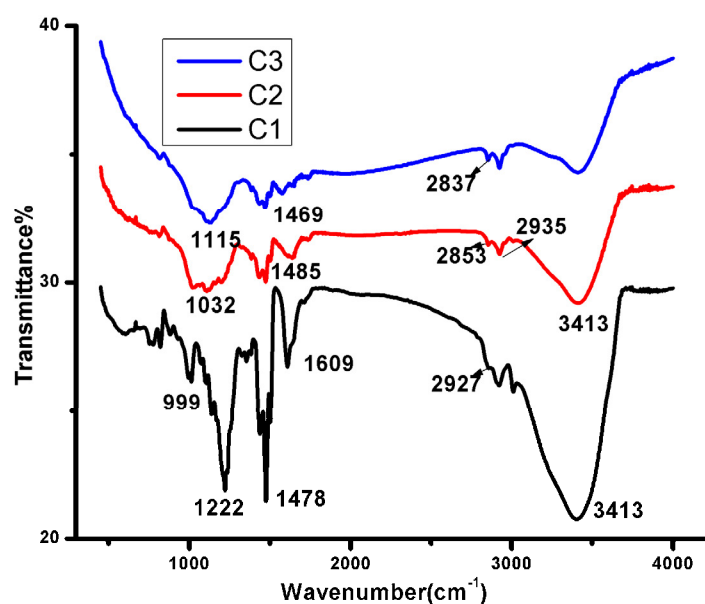


Fig. 4. FTIR spectra for (C1), (C2), and (C3) the Carbon nanocomposites containing 10, 20, and 30 wt%.

Table 1. Functional groups for (C2), (C3), and (C4) the Carbon nanocomposites containing 10, 20, and 30 wt%.

Bond Vibration	Wavenumber (cm ⁻¹)		
	a	b	c
-OH hydroxyl stretching [17]	3413	3413	3413
-C=C stretching [16,18]	1478	1485	1469
-C-O and -C-O-C stretching [18]	1222	1032	1115
-CH, -C=O stretching[19]	999	999	915

FTIR studies

FT-IR studies of Phenolic Formaldehyde and its Carbon composites are depicted in Fig. 4 (a-d). A broad peak is consistently observed at 3450 cm⁻¹, falling within the range (3000-3600 cm⁻¹) as reported by previous researchers [46-47]. The intensity of this peak, attributed to OH stretching, decreases with the addition of Carbon to Phenol formaldehyde. Notably, in Fig. 4(C3) with 30% Carbon doping, this peak becomes almost negligible. This observation suggests the removal of OH groups and the incorporation of Carbon into the Phenol formaldehyde matrix.

Methyl hydroxyl phenolic ring is also discernible at 1315-1400 cm⁻¹, and phenolic ring substitutions at ortho and para positions are evident in the range of 1500-820 cm⁻¹ [48-54]. It is worth noting that all these peaks exhibit a decreasing trend as the Carbon ratio increases, consistent with the XRD findings. The FTIR peaks for the Carbon nanocomposites in Fig. 4 (C1), (C2), and (C3),

containing 10, 20, and 30 wt%, respectively, are summarized in Table 1.

CONCLUSIONS

The paper presents the successful synthesis and detailed characterization of nanocomposites composed of Activated Carbon and Phenol-Formaldehyde. These materials are chosen for their exceptional thermal properties, chemical stability, and strong affinity for various forms of carbon. XRD analysis of the nanocomposites reveals the presence of a distinct carbon peak, indicating the incorporation of activated carbon within the composite structure. This peak suggests a strong interaction between the activated carbon and the Phenol-Formaldehyde matrix. FTIR spectroscopy results show the presence of functional group peaks in their respective regions, further confirming the successful synthesis of the nanocomposites. These functional groups likely contribute to the chemical stability and enhanced

properties of the materials. The combined results from XRD and FTIR analysis support the conclusion that these nanocomposites possess the necessary structural and chemical characteristics to excel in various Engineering applications.

ACKNOWLEDGEMENTS

The authors are also thankful to the PC Ray Centre, ITM University Gwalior for providing the FTIR facility, IIT Mandi FESEM studies and UGC DAE Consortium for Scientific Research Indore for XRD studies.

CONFLICT OF INTEREST

The authors confirm that there is no conflict of interest in this article content.

REFERENCES

- Liu L., Ruan R., Yang W. W., (2017), Clay/polymer nanocomposites for biomedical applications: A review. *Mater. Sci. Eng. C*. 75: 1324-1327.
- Amini Nia A., Pourshamsian Kh., Sadeghi B., (2020), Nano-ZnO impregnated on starch highly efficient heterogeneous bio-based catalyst for one-pot synthesis of pyranopyrimidinone and xanthene derivatives as potential. *J. Org. Chem.* 56: 1279-1288. <https://doi.org/10.1134/S1070428020070234>
- Osayemwenre G. O., Meyer E. L., (2014), Thermal decomposition of EVA composite encapsulant of single junction amorphous silicon photovoltaic (PV) module. *J. Ovonic Res.* 10: 221-225.
- Rezaei R., Darzi S. J., Yazdani M., (2020), Synthesis and Evaluation of 198Au/PAMAM-MPEG-FA against Cancer Cells. *Anticancer Agents in Medic. Chem.* 20: 1250-1265. doi: 10.2174/1871520620666200220113452. PMID: 32077832. <https://doi.org/10.2174/1871520620666200220113452>
- Park S., Lee K. H., (2015), Polymer-metal nanocomposites: A review. *J. Ind. Eng. Chem.* 31: 1-6.
- Lin Y., Li D., Li X., Li G., Huang Z., (2014), Study on the mechanical properties of phenolic resin composites filled with carbon nanotubes. *Polym. Compos.* 35: 343-346. <https://doi.org/10.1002/pc.22778>
- Zhang M., Lai X., Xu Y., Cao J., (2017), Surface modification of alumina nanoparticles for improving the scratch resistance of phenolic resin-based composites. *Compos. Part B: Eng.* 125: 114-117.
- Fong H., Lau K. T., (2009), Effect of filler loading on phenolic resin composites. *Electronic J. Mater. Sci.* 44: 4659-4663.
- Fang X., Zhai T., Gautam U. K., Li L., Wu L., Bando Y., Goldberg D., (2011), ZnS nanostructures: From synthesis to application. *Prog. Mater. Sci.* 56: 175-179. <https://doi.org/10.1016/j.pmatsci.2010.10.001>
- Thottoli A., Achuthanunni A., (2013), Effect of trisodium citrate concentration on the particle growth of ZnS nanoparticles. *J. Nanostruc. Chem.* 3: 56-60. <https://doi.org/10.1186/2193-8865-3-56>
- Kalu O., M., Amah A. N., Echi I., (2019), Physicochemical properties of mixed twin clay deposits in Awgbu used for pottery and possible structural applications. *Niger. J. Technol.* 38: 355-363. <https://doi.org/10.4314/njt.v38i2.12>
- Tiwary C. S., Kumbhakar P., Mitra A. K., Chattopadhyay K., (2009), Synthesis of wurtzite-phase ZnS nanocrystal and its optical properties. *J. Lumines.* 129: 1366-1369. <https://doi.org/10.1016/j.jlumin.2009.07.004>
- Kole A. K., Kumbhakar P., (2012), Cubic-to-hexagonal phase transition and optical properties of chemically synthesized ZnS nanocrystals. *Res. Phys.* 2: 150-155. <https://doi.org/10.1016/j.rinp.2012.09.010>
- Ummartyotin S., Bunnak N., Juntaro J., Sain M., Manuspiya H., (2012), Synthesis and luminescence properties of ZnS and metal (Mn, Cu)-doped-ZnS ceramic powder. *Solid State Sci.* 14: 299-303. <https://doi.org/10.1016/j.solidstatesciences.2011.12.005>
- Horoz S., Dai Q., Maloney F. S., Yakami B., Pikal J. M., Zhang X., Wang J., Wang W., Tang J., (2015), Absorption induced by Mn doping of ZnS for improved sensitized quantum-dot solar cells. *Phys. Rev. Appl.* 3: 1-7. <https://doi.org/10.1103/PhysRevApplied.3.024011>
- Sahare S., Dhoble S. J., Singh P., Ramrakhiani M., (2013), Fabrication of ZnS : Cu/PVA nanocomposite electroluminescence devices for flat panel displays. *Adv. Mater. Lett.* 4: 169-173. <https://doi.org/10.5185/amlett.2012.6374>
- Jayaseelan C., Ramkumar R., Rahuman A. A., Perumal P., (2013), Green synthesis of gold nanoparticles using seed aqueous extract of *Abelmoschus esculentus* and its antifungal activity. *Indus. Crops and Products.* 45: 423-429. <https://doi.org/10.1016/j.indcrop.2012.12.019>
- Vidya C., Hiremath S., Chandraprabha M. N., Antonyraj M. A. L., Gopala I. V., Jain A., Bansal K., (2013), Green synthesis of ZnO nanoparticles by *calotropis gigantea*. *Int. J. Curr. Eng. Technol.* 1: 118-120.
- Hudlikar M., Joglekar S., Dhaygude M., Kodama K., (2012), Latex-mediated synthesis of ZnS nanoparticles: green synthesis approach. *J. Nanoparticle Res.* 14: 865-870. <https://doi.org/10.1007/s11051-012-0865-x>
- Senapati U. S., Sarkar D., (2014), Characterization of bio-synthesized zinc sulphide nanoparticles using edible mushroom *Pleurotus ostreatus*. *Indian J. Phys.* 88: 557-562. <https://doi.org/10.1007/s12648-014-0456-z>
- Senapati U. S., Jha D. K., Sarkar D., (2013), Green synthesis and characterization of ZnS nanoparticles. *Res. J. Phys. Sci.* 1: 1-6.
- Tiwari A., Khan S. A., Kher R. S., Dhoble S. J., (2014), Synthesis, characterization and optical studies of highly luminescent ZnS nanoparticles associated with hypromellose matrix as a green and novel stabilizer. *Lumines.* 29: 637-641. <https://doi.org/10.1002/bio.2597>
- Zhang, M., Rong, M. Z., (2019), Nanocomposites based on carbon nanotubes and polymer matrices. *Polym. Rev.* 59: 1-5.
- Patton R. D., Pittman Jr. C. U., Wang L., Hill J. R., (1999), Vapor-grown carbon fiber composites with epoxy and poly(phenylene sulfide) matrices. *Composites A.* 30: 1081-1091. [https://doi.org/10.1016/S1359-835X\(99\)00018-4](https://doi.org/10.1016/S1359-835X(99)00018-4)
- Yu Q.-C., Wan H., (2012), Ablation capability of flake graphite reinforced barium-phenolic resin composite under long pulse laser irradiation. *Wuji Cailiao Xuebao/J. Inorg. Mater.* 27: 157-161. <https://doi.org/10.3724/SP.J.1077.2012.00157>
- Liu Y., Lu Z., Chen X., Wang D., Liu J., Hu L., (2009), Study on phenolic-resin/carbon-fibre ablation composites modified

- with polyhedral oligomeric silsesquioxanes. *Proceed. 4th IEEE Int. Conf. Nano/Micro Eng. Molec. Sys.* (pp. 605-608). Shenzhen, China.
27. Bahramian A. R., Kokabi M., (2009), Ablation mechanism of polymer layered silicate nanocomposite heat shield. *J. Hazard. Mater.* 166: 445-454. <https://doi.org/10.1016/j.jhazmat.2008.11.061>
 28. Srikanth I., Daniel A., Kumar S., (2010), Nano silica-modified carbon-phenolic composites for enhanced ablation resistance. *Scripta Mater.* 63: 200-203. <https://doi.org/10.1016/j.scriptamat.2010.03.052>
 29. Koo J. H., Natali M., Tate J. S., Allcorn E., (2013), Polymer nanocomposites as ablative materials: A comprehensive review. *Int. J. Energetic Mater. Chem. Propulsion.* 12: 199-162. <https://doi.org/10.1615/IntJEnergeticMaterialsChemProp.2013005383>
 30. Natali M., Monti M., Kenny J., Torre L., (2011), Synthesis and thermal characterization of phenolic resin/silica nanocomposites prepared with high shear rate-mixing technique. *J. Appl. Polym. Sci.* 120: 2632-2640. <https://doi.org/10.1002/app.33494>
 31. Natali M., Monti M., Kenny J. M., Torre L., (2011), A nanostructured ablative bulk moulding compound: Development and characterisation. *Composites A.* 42: 1197-1204. <https://doi.org/10.1016/j.compositesa.2011.04.022>
 32. Natali M., Monti M., Puglia D., Kenny J. M., Torre L., (2012), Ablative properties of carbon black and MWNT/phenolic composites: A comparative study. *Composites A.* 43: 174-182. <https://doi.org/10.1016/j.compositesa.2011.10.006>
 33. Wang C., Cheng H., Hong C., Zhang X., Zeng T., (2018), Lightweight chopped carbon fibre reinforced silica-phenolic resin aerogel nanocomposite: Facile preparation, properties, and application to thermal protection. *Compos. Part A: Appl. Sci. Manuf.* 112: 81-90. <https://doi.org/10.1016/j.compositesa.2018.05.026>
 34. Zhang M., Rong M. Z., (2019), Nanoparticle-reinforced polymer nanocomposites. *Polym. Rev.* 59: 44-48.
 35. Taghiyari H. R., (2014), Effect of metal nanoparticles on hardness in particleboard. *Int. J. Nano Dimens.* 5: 379-386.
 36. Beiranvand M., Farhadi S., Mohammadi A., (2019), Graphene Oxide/Hydroxyapatite/Silver (rGO/HAP/Ag) nanocomposite: Synthesis, characterization, catalytic and antibacterial activity. *Int. J. Nano Dimens.* 10: 180-194.
 37. Sadeghi B., (2018), Controlled growth and characterisation of Ag/ZnO nano tetrapods for humidity sensing. *Chem. High Throughput Screen.* 21: 462-467. <https://doi.org/10.2174/1386207321666180717120417>
 38. Ghane M., Sadeghi B., Jafari A. R., Paknejhad A., (2010), Synthesis and characterization of a bi-Oxide nanoparticle ZnO/CuO by thermal decomposition. *Int. J. Nano Dimens.* 1: 33-40.
 39. Huang Y., Li D., Wang X., Yan L., Xiao Z., (2012), Carbon-nanotube-modified phenol-formaldehyde resins for use as high-performance adhesives. *J. Mater. Sci.* 47: 5416-5423.
 40. Cheng Y., Zhang Y., Yang L., Wang H., (2019), Quantum dot-based polymer nanocomposites for optoelectronic applications. *Nanos. Res. Lett.* 14: 28-33.
 41. Yang X., Zeng X., Han G., Sui D., Song X., Zhang Y., (2020), Preparation and performance of porous Carbon nanocomposite from renewable phenolic resin and halloysite nanotube. *Nanomater.* 10: 1703-1705. <https://doi.org/10.3390/nano10091703>
 42. Zhang M., Rong M. Z., (2019), Nanocomposites based on carbon nanotubes and polymer matrices. *Polym. Rev.* 59: 1-5.
 43. Maria A., (2019), Nanoparticle-reinforced polymer. *Polymers.* 11: 625-629. <https://doi.org/10.3390/polym11040625>
 44. Vella Durai S. C., Kumar E., Indira R., Muthuraj D., (2020), Preparation and investigation of structural, optical, and conductivity properties of polyaniline dioxide nanocomposites. *J. Ovonic Res.* 16: 345-348. <https://doi.org/10.15251/JOR.2020.166.345>
 45. Sadeghi B., (2018), Synthesis and characterisation of ultra-fine Ag/ZnO nanotetrapods (AZNTP) for environment humidity sensing. *J. Env. Health Eng.* 5: 115-119. <https://doi.org/10.15171/ajehe.2018.15>
 46. Bankar A., Joshi B., Ravi Kumar A., Zinjarde S., (2010), Banana peel extract mediated synthesis of gold nanoparticles. *Colloids Surf. B. Biointerfaces.* 80: 45-49. <https://doi.org/10.1016/j.colsurfb.2010.05.029>
 47. Bankar A., Joshi B., Ravi Kumar A., Zinjarde S., (2010), Banana peel extract mediated novel route for the synthesis of silver nanoparticles. *Colloids Surf. A Physicochem. Eng. Asp.*, 368: 58-63. <https://doi.org/10.1016/j.colsurfa.2010.07.024>
 48. Zhou G. J., Li S. H., Zhang Y. C., Fu Y. Z., (2014), Biosynthesis of CdS nanoparticles in banana peel extract. *J. Nanosci. Nanotechnol.* 14: 4437-4442. <https://doi.org/10.1166/jnn.2014.8259>
 49. Happe Emaga T., Robert C., Ronkart S. N., Wathélet B., Paquot M., (2008), Dietary fibre components and pectin chemical features of peels during ripening in banana and plantain varieties. *Biores. Technol.* 99: 4346-4354. <https://doi.org/10.1016/j.biortech.2007.08.030>
 50. Verma D., Kole A. K., Kumbhakar P., (2015), Red shift of the band-edge photoluminescence emission and effects of annealing and capping agent on structural and optical properties of ZnO nanoparticles. *J. Alloys and Comp.* 625: 122-130. <https://doi.org/10.1016/j.jallcom.2014.11.102>
 51. Singh B., Chauhan N., (2009), Modification of psyllium polysaccharides for use in oral insulin delivery. *Food Hydrocolloids.* 23, 928-935. <https://doi.org/10.1016/j.foodhyd.2008.06.004>
 52. Basak P., Adhikari B., (2009), Poly (vinyl alcohol) hydrogels for pH dependent colon targeted drug delivery. *J. Mater. Sci: Mater. Medic.* 20: 137-146. <https://doi.org/10.1007/s10856-008-3496-0>
 53. Kumar K., Kaith B. S., Mittal H., (2010), Utilization of acrylamide and natural polysaccharide based polymeric networks in PH controlled released of 5-Amino salicylic acid. *J. Chil. Chem. Soc.* 55: 522-526. <https://doi.org/10.4067/S0717-97072010000400025>
 54. Xiong J., Xiong S., Guo Z., Yang M., Chen J., Fan H., (2012), Ultrasonic dispersion of nano TiC powders aided by tween 80 addition. *Ceram. Int.* 38: 1815-1821. <https://doi.org/10.1016/j.ceramint.2011.10.004>