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Antimicrobial, selective antibiofilm, and antioxidant properties of plasticized PMMA/PVC and zinc oxide nano filler for biomedical applications

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Abstract: The PMMA/PVC/ZnO-nanocomposites with zinc oxide nanoparticle (particle size < 50nm) was synthesized by solution casting technique. Morphology of the synthesized nano composites have been investigated by FT-IR and XRD techniques. After characterization, synthesized composites were applied for antibacterial, selective antibiofilm and free radical scavenging screening. Antibacterial studies were measured against different bacterial strains. Antibiofilms activities were studied against those bacterial model pathogenic strains which showed highest and minimum sensitivity as a (~94 and ~88 at 160 µg/ml). Antioxidant activity of synthesized nanocomposites were measured by DPPH and showed scavenging capacity with IC_{50}, 110 to > 200 µg/mL. Thus PMMA/PVC/ZnO nanocomposite showed promising antimicrobial activity and antioxidant activity that can be used for biomedical applications.

Keywords: PMMA, PVC, nanocomposites, characterization.

INTRODUCTION

In recent years, the manufacturing of polymeric materials and nanocomposites has gained much attention as an emerging low-cost technology worldwide. Poly-(methyl methacrylate), (PMMA), is one of the most popular class of polymers which is used in composites industries. The PMMA is a long, soft chain and well-known brittle polymeric material that has been extensively used in different fields due to useful properties, such as low cost, good chemical stability, low density, non-toxicity and transparent optical properties (Wen *et al.,* 2019). Due to outstanding biocompatibility features of PMMA with oral tissues, it is extensively used in medical applications such as dentistry, however acrylic resin has very low impact, poor strength and fatigue resistance. Many attempts have been done to strength the thermal and mechanical properties of PMMA (Yaseen *et al.,* 2020). The most common method for increasing the toughness and thermal stability of Poly-(methyl methacrylate) is the blending of PMMA with polyvinylchloride (PVC) with high level of plasticizers and received much attention in polymeric electrolyte applications (Feng *et al.,* 2017; Ali *et al.*, 2015). Due to low-cost and hygienic properties, polyvinyl chloride (PVC) and oxygen-containing hydrophilic PMMA are extensively used thermoplastics. (Aziz *et al.,* 2019). PVC is used in microelectronic and plastics industries (for example, wires insulation and cables industries) because of its low combustibility, good abrasion resistance, corrosion as well as electrical insulation, and mechanical stability that arises as a result of interaction between H and Cl atoms (Suresh *et al.,* 2017; Joseph *et al.,* 2018; Arunkumar *et al.,* 2017).

In the insulating polymers the electrically conductive networks can be increased effectively by addition of nano-fillers. Nanofillers, metal oxide and chloride like ZnO-Nps, MnO_2, $CoCl_2$ were mixed with polymers to the improvement the optical and thermal properties (Alghunaim *et al.,* 2018; Shakir *et al.,* 2019), among them zinc oxide as an inorganic nano-filler has an outstanding feature such as high thermal conductivity and high refractive indices, (Abdelghany *et al.,* 2019), promising antibacterial and UV-protection properties (Hammani *et al.,* 2018; Choudhary *et al.,* 2018). The design of new materials, PMMA/ZnO nanocomposites, is of extra-ordinary potential which has a wide range of applications in photocatalysis, electrical switches, gas sensing, cancer treatment and tissue engineering fields (Mauro *et al.,* 2017). Zinc oxide nanoparticles have been used as an antibacterial agent for biofilm preventions and water purification (Abdallah *et al.,* 2020), sunscreen lotion (Osmond *et al.,* 2010; Rasmussen *et al.,* 2010), wound dressing (Sudheesh *et al.,* 2012), anticancer (Guo *et al.,* 2011), antibacterial and antioxidant activities (Premanathan *et al.,* 2011; Das *et al.,* 2013). The antimicrobial activity of zinc oxide nanoparticles was investigated against different bacterial strains. During bactericidal investigation, it has been found that the solubility surface area and particle size of ZnO-Nps were remained unchanged by changing the others (Li and Guo 2020). In biological systems, oxidative stress which is a major cause of cardiovascular disease, cancer, arthritis and diabetes is due to release of reactive free radical

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species or their precursors, so the antioxidants play a key role in the functioning of all biosystems (Nash *et al.,* 2015; Safawo *et al.,* 2018).

The aims of current study are to tune the physical properties of polymethyl methacrylate (PMMA), 80%, and thermoplastic polyvinyl chloride (PVC), 20%, blends loaded with different weight ratios of ZnO-Nps by sonication methods followed by solution casting technique. The ZnO-Nps contents and influences of films thickness on the structure, morphology, antibacterial, selective antibiofilm formation and antioxidant properties were investigated and discussed the effect of ZnO-Nps PMMA/PVC blends performance.

MATERIALS AND METHODS

Chemicals

Polymethylmethacrylate (PMMA) (m.w. ~100,000, Degussa, Germany) and moisture free Polyvinyl chloride, (PVC) (Mw.48000 D), Zinc acetate, Hydrogenperoxide (H_2O_2), 1,1-diphenyl-2-picrylhydrazyl (DPPH), tetrahydrofuran (THF) and DMSO (Aldrich) were of analytical grade.

Instrumentation

Different techniques were applied to characterize the synthesized nanocomposites. Infrared spectra were recorded by FT-IR spectrophotometer (Bruker) in range of 4000 to 400 cm^{-1}. Structural morphology was studied using X-ray diffraction by 3040/60 X'Pert PRO diffractometer. Microplate Reader (ELx808™ Absorbance, Biotek, USA) was used to check the antibiofilm activity.

Preparation of ZnO-Nps

ZnO nanoparticles with particle size <50 nm were prepared by the reaction of $Zn(CH_3COO)_2$. $2H_2O$ and H_2O_2, in alcoholic medium, typically, 5.0g of $Zn(CH_3COO)_2$. $2H_2O$ was dissolved in 150ml methanol diluted with 100 ml of deionized water and solution was stirred for 3 hrs. at 50ºC during stirring, 4 ml of hydrogen peroxide (H_2O_2, 47%) was added dropwise to make the solution clear. This solution was allowed to stand at ambient temperature for 24 hrs. and heated at 80ºC. The resulted white powder was washed with distilled water and dried at dried at 80ºC in oven and then calcinated at 600 ºC for one hour to get stable ZnO nanoparticles (Doddapaneni *et al.,* 2017).

Synthesis of plasticized PMMA/PVC/ZnO nanocomposites

Plasticized PMMA/PVC/ZnO nanocomposite was synthesized by solution casting technique followed by sonication (Mauro *et al.,* 2017). Typically, A solution of PMMA and PVC (80: 20 wt. %) was prepared in THF by string about 24 hrs at room temperature. ZnO-Nps with different concentration with respect to concentration of PMMA/PVC matrix, 2.5%, 5.0%, 7.5% and 10% was mixed with PMMA and PVC blend by sonication of mixture about 30 mint. and heated gently to get the homogeneous mixture, The PMMA/PVC/ZnO-Nps mixture was casted on glass plates and solvent was evaporated in air. The obtained solid was placed in vacuum desiccator for further characterization.

Antibacterial Investigation

The antibacterial activity of synthesized PMMA/PVC/ ZnO-nano composites was determine against *S. aureus* (ATCC 6538)*, B. subtilis* (ATCC 6633) and *S. pyogenes* (ATCC12344)*, P. aeruginosa* (ATCC 10145)*, E. coli* (ATCC 15224) and *S. Typhi* (ATCC 14028) by "disc-diffusion method" (Annie *et al.,* 2002; Jamil *et al.,* 2012; Khosa *et al.,* 2015). The bacterial strains were cultured in agar-agar nutrient broth at 37°C for 24 hrs. The broth cultures of test organisms of approximately 10^4-10^6 (CFU/mL) were added to nutrient broth at 45°C in sterilized petri dishes and solidify. Solution of PMMA/PVC/ZnO-nanocomposite in DMSO (Five µL) was tipped on sterilized paper disks. These disks were placed on agar-agar nutrient broth and incubated for 24 hours at 37°C. Experiments were performed in triplicate and zone of inhibition was measured in mm using Cefixime (1 mg/mL) as a standard antibiotic drug.

Antibiofilm assay

Staphylococcus aureus (ATCC 6538) and *Staphylococcus typhi* (ATCC 14028) were selected as a model bacterial strains which showed a highest to least bacterial activity for PMMA/PVC matrix and PMMA/PVC/ZnO-Nps according to reported method (Abdallah *et al.,* 2020). Biofilm forming bacteria were incubated at 37°C for 24 hrs. in 10 ml of trypticsoy broth (TSB) containing 1% glucose solution. Each bacteria strain (200µL) was inoculated into 96µLplates of PMMA/PVC/ZnO-nanocomposites. Bacterial strains were further incubated for 24 hours at 37°C. After that, each well was washed with saline phosphate buffer solution of pH 7.2 and crystal violet solution was added (200µL of 0.1% w/v) and 100µL of 96% ethanol to all well and left for a further 30 min to extract the stained bound biofilm. Microplate Reader was used to note the absorbance of crystal violet solution at 490 nm. Ciprofloxacin, a standard drug, was used as a standard (20µg ml^{-1}). Reduction in size of biofilm was measured and compared with the positive control. The % of biofilm inhibition was calculated as:

$$\%\ \text{inhibition} = 1 - \left(\frac{\text{optical density of composite}}{\text{optical density of negative control}}\right) \times 100 \quad (1)$$

Antioxidant activity

Free radicals scavenging activity of PMMA/PVC/ZnO-nanocomposites was investigated by 1,1-diphenyl-2-picrylhydrazyl (DPPH) according to standard method

(Khoushika *et al.,* 2017). Methanolic solution of DPPH was prepared. Stock solution of composites (5mg/mL) was prepared in DMSO and diluted to different concentrations (5, 10, 20, 40, 100, 200μg/mL). Each concentration was mixed with freshly prepared DPPH solution in glass vials. These vials were sealed and placed in dark at 37°C for 30 minutes. When the colour of DPPH was changed from deep violet to light-yellow, the absorbance was noted at 517 nm on a spectrophotometer. The % scavenging activity was calculated as:

$$\% \text{ scavenging activity} = \frac{\text{absorbance of control} - \text{absorbance of test sample}}{\text{absorbance of control}} \times 100 \quad (2)$$

Ascorbic acid as a positive control was used to measure the antioxidant activity.

STATISTICAL ANALYSIS

All the experiments were conducted in triplicates and data obtained was analyzed statistically by one-way ANOVA test using Minitab Software.

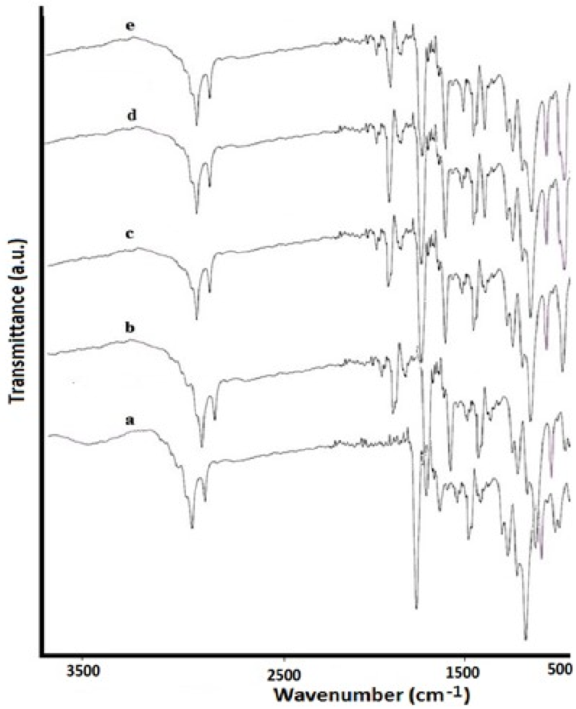

Fig. 1: Infrared spectra of ternary composites: (a; PMMA/PVC (80:20) blend, b; blend with: 2.5 %, c; 5%, d; 7.5% and e; 10% ZnO-Nps).

RESULTS

FT-IR investigation

Infrared spectra of PMMA/PVC with different contents of ZnO-Nano filler are shown in fig. 1. Characteristic absorption bands of PMMA (The bands at 1196, 1720, 1155 and 1050, 3455 cm^{-1} for –OCH_3, CO_{sym}, CO_{asym}, C-O-C and –OH groups respectively) and PVC (2985, 2950 and 2810 cm^{-1}) were ascribed to -CH, -CH_2 functional groups (fig. 1-a). new bands at 1725, 610 cm^{-1} appeared in PMMA/PVC with different contents of contents of ZnO-nanoparticles, while the –OH band at 3455 cm^{-1} vanished.

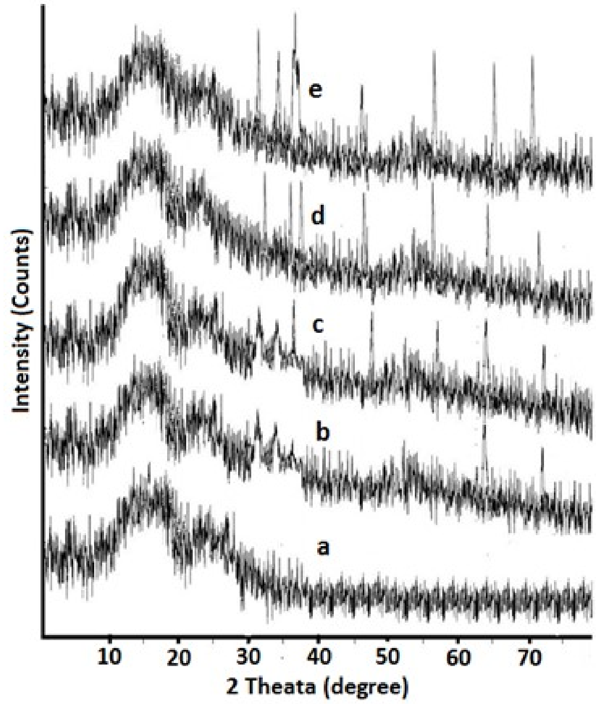

Fig. 2: XRD of PMMA / PVC / ZnO-Nps composites: (a; PMMA/PVC (80:20) blend, b-e blend with 2.5, 5, 7.5 and 10 % ZnO-Nps)

X-ray diffraction

The homogenous mixing and cross linkage between synthesized PMMA/PVC composites contained different contents of ZnO-Nps (2.5%, 5 %, 7.5 %, and 10 % w/w) was examined by wide-angle X-ray diffraction method. Fig. 2 showed the diffraction patterns for PMMA/PVC film and for PMMA/PVC/ZnO nanocomposites. two broad bands at 2θ = 16.6º and 24.5º related to amorphous PMMA/PVC matrix.

Biological Investigation

Antibacterial screening

The antibacterial activity of PMMA/PVC/ZnO-nanocomposites were determined and data is shown in table 1. The varying degree of antibacterial activity of PMMA/PVC blend and PMMA/PVC/ZnO-Nps was measured (mm) in term of zone of inhibition. Antibacterial activity of PMMA/PVC composite doped with ZnO-nanoparticles was compared with standard drug Cefixime.

Antibiofilm activity

Biofilm inhibition activity of PMMA/PVC blends loaded with different contents of ZnO-Nps which act as an inorganic filler was determined and results are shown in fig. 3 (A & B).

For this purpose, *S. aureus* (ATCC 6538) and *S. typhi* (ATCC 14028) were selected as model microorganisms because such strains shown highest and least antibacterial activity.

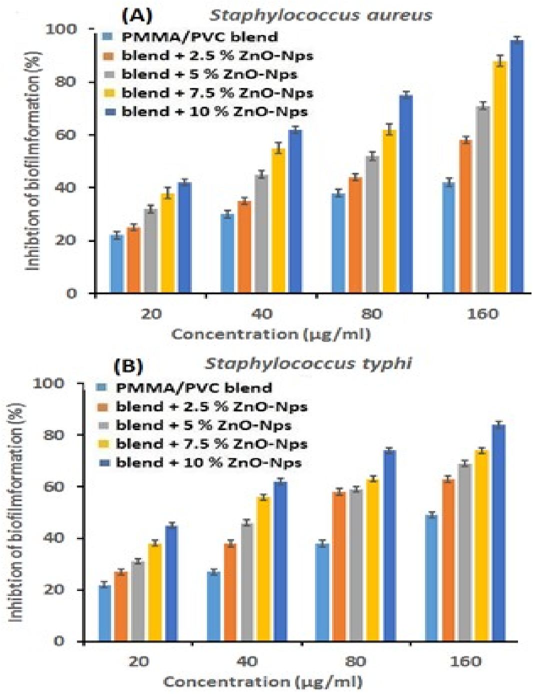

Fig. 3: (A &B) Antibiofilm activity of PMMA/PVC matrix and PMMA/PVC/ZnO nano-composites (P< 0.05 vs. control).

DISCUSSION

The structure identification of all prepared composites was confirmed from FT-IR spectrum. The characteristic absorption bands at respective wavelength as shown in fig.1 indicated the successful mixing between PMMA and PVC, whereas new band at 1725, 610 cm^{-1} appeared and decreased in intensity of band at 1720, 1155 cm^{-1} and band at 1480 cm^{-1} disappeared which confirmed the strong interaction between PMMA/PVC matrix with different contents of ZnO-Nps (fig. 1, b-e) (Adel *et al.,* 2020; Mauro *et al.,* 2017).

The XRD pattern of the PMMA/PVC matrix have two broad bands at 2θ = 16.6º and 24.5º related to the amorphous nature of the polymer matrix (fig. 2a). In PMMA/PVC/ZnO-nanocomposites has intense Bragg peaks corresponding to the planes (100), (002), (101), and (110), was increased with increasing ZnO-Nps contents inside the PMMA/PVC matrix (fig.2, b-e), while two broad bands are shifted to 2θ values of 17.7º and 24.8º. This means that the ZnO nano-particles were dispersed uniformly into PMMA/PVC and act as a reinforcement metal oxide, thus the new material is formed (Ilangovan *et al.,* 2017).

Such composites showed moderate to significant activity against all six tested bacterial strains. The results showed that *S. aureus* showed greater activity and *S. typhi* showed least sensitivity with 10% ZnO-nanoparticles which

Table 1: Antibacterial activity of PMMA /PVC blend and PMMA/PVC/ZnO-nanocomposites

Test compounds	*Zone of Inhibition of Sample (mm)					
	Gram (+Ve)			Gram (-Ve)		
	S. aureus	*S. pyogenes*	*B. subtilis*	*E. Coli*	*S. Typhi*	*P. aeruginosa*
PMMA/PVC (blend)	18 ± 1	15 ± 1	17 ± 1	14±1	18 ± 1	13 ± 1
ZnO-Nps	18 ± 1	22 ± 1	24 ± 1	21 ± 1	26 ± 1	23 ± 1
Blend + 2.5 percentage of ZnO-Nps	20 ± 1	19 ± 1	18 ± 1	19 ± 1	21 ± 1	16 ± 1
Blend + 5 percentage of ZnO-Nps	24 ± 1	23 ± 1	21 ± 1	23 ± 1	23 ± 1	21 ± 1
Blend + 7.5 percentage of ZnO-Nps	27 ± 1	24 ± 1	24 ± 1	25 ± 1	24 ± 1	23 ± 1
Blend + 10 percentage of ZnO-Nps	29 ± 1	27 ± 1	26± 1	26 ± 1	28 ± 1	27 ± 1
Cefixime	33 ± 1.5	31 ± 1	35 ± 1	29±0.5	36 ± 1	31 ± 2

± = SD, *Zone of inhibition: (5-10 mm = Activity present, 11-25 mm = Moderate activity, 26 - 40 mm = Strong activity)

Table 2: Antioxidant activity of PMMA / PVC blend and PMMA/PVC/ZnO-nanocomposites expressed as % of DPPH free radical scavenging.

Compound	% Scavenging ± sd Concentration µg / mL						IC_{50} (µg / mL)
	200	100	40	20	10	5	
PMMA/PVC (blend)	44 ± 1	39 ± 1	32 ± 1	26 ± 2	14 ± 1	8 ± 1	>200
ZnO-Nps	65± 15	51± 25	44 ± 1	33±15	21 ± 15	15 ± 25	125 ± 1
Blend + 2.5 percentage of ZnO-Nps	49 ± 1	43 ± 1	36 ± 1	29 ± 1	18 ±1	10 ± 1	180 ± 1
Blend + 5 percentage of ZnO-Nps	58 ± 1	51 ± 2	40 ± 2	31 ± 2	21 ± 1	13 ± 1	150 ± 1
Blend + 7.5 percentage of ZnO-Nps	66 ± 1	59 ± 2	43 ± 1	33 ± 1	24 ± 1	15 ± 1	130 ± 1
Blend + 10 percentage of ZnO-Nps	72 ± 2	64 ± 1	47 ± 1	39 ± 1	26 ± 2	17 ± 1	110 ± 1
Ascorbic acid	87 ± 1	84 ± 1	80 ± 1	70 ± 1	56 ± 1	35 ± 1	8.75±1

explained that with increased contents of ZnO-nanoparticles due to uniform mixing of nanoparticles in polymeric blend and have a greater effect on them *in vivo* bioactivity as reported in literature (Methew *et al.,* 2019). PMMA/PVC blends containing different contents of ZnO-Nps showed significant biofilm inhibition activity as compared to PMMA/PVC blend. As the biofilm inhibition effect is concentration dependent and showed significant effect as the concentration of PMMA/PVC/ZnO-Nps increased. The inhibition % of biofilm formation for *S. aureus* and *S. typhi* was found to ~ 96 and ~ 84, respectively at 160 µg/ml concentration (Thaya *et al.,* 2016).

Antioxidant activity data showed that as the concentration of ZnO-Nps contents increased in PMMA/PVC blend, the % scavenging activity also increased. On comparison of IC_{50} values of the PMMA/PVC blends and ZnO-Nps with IC_{50} >200µg/ml and 125µg/ ml respectively, it is found that synthesized nanocomposites are more active free radical scavenging activity than PMMA/PVC blend as well as ZnO-Nps (Joan *et al.,* 2017).

CONCLUSION

PMMA/PVC/ZnO-nanocomposite materials were successfully prepared by solution casting technique. Their structure was investigated by FT-IR and XRD. The interaction between the PMMA/PVC matrix with ZnO-Nps was confirmed by the shifting of absorption bands in IR spectra. The degree of crystallinity and area under peaks was determined by XRD which indicated that as the contents of zinc oxide nanoparticles increased in PMMA/PVC blend may affect the crystallinity and produce defects in polymeric matrix. Antibacterial, selective antibiofilm activity, and antioxidant screening showed the promising activity of the synthesized PMMA/PVC/ZnO nanocomposites. On the basis of biological screening, it is suggested that the synthesized PMMA/PVC/ZnO nanocomposites may have some excellent biomedical applications.

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REFERENCES

Abdallah OM, EL-Baghdady KZ, Khalil MMH, El Borhamy MI and Meligi GA (2020). Anti-bacterial, antibiofilm and cytotoxic activities of biogenic polyvinyl alcohol-silver and chitosan-silver nanocomposites. *J. Polym. Res.,* **27**: 74-82.

Abdelghany AM, Meikhail MS and Asker N (2019). Synthesis and structure-biological correlation of PVC/PVAc polymer blends. *J. Mater. Res. Technol*., **8**(5): 3908-3916.

Adel M (2020). Synthesis, optical, thermal, electric properties and impedance spectroscopy studies on P(VC-MMA) of optimized thickness and reinforced with MWCNTs, *Results in Phys*., **17**(2): 103025.

Ali U, Karim KJ and Buang NA (2015). A review of the properties and applications of poly (methyl methacrylate (PMMA). *Polym. Rev*., **55**(4): 678-705.

Alghunaim NS (2018). Structural, thermal, dielectric spectroscopic and AC impedance properties of SiC nanoparticles doped PVK/PVC blend. *Res. Phys.,* **9**: 1136-1140.

Annie F, Bernadette G, Philippe HL and Isabelle C (2002). Evaluation of three techniques for detection of low-level methicillin-resistant *Staphylococcus aureus* (MRSA): A disc diffusion method with Cefoxitin and Moxalactam, the Vitek 2-System, and the MRSA-screen latex agglutination test. *J. Clin. Microbial.,* **40**(8): 2766-2771.

Arunkumar R, Babu RS, Rani MU and Kalainathan S (2017). Effect of PBMA on PVC-based polymer blend electrolytes. *J. Appl. Polym. Sci*., **134**(27): 44939.

Aziz SB, Abdullah OG, Brza MA, Azawy AK and Tahir DA (2019). Effect of carbon nano-dots (CNDs) on structural and optical properties of PMMA polymer composite. *Res. Phys.*, **15**(4): 102776.

Bai B, Jin H, Zhu S, Wu P and Fan C (2019). Experimental investigation on in-situ hydrogenation induced gasification characteristics of acrylonitrile butadiene styrene (ABS) micro plastics in supercritical water. *Fuel Processing Technol*., **192**(10): 170-178.

Choudhary S and Sengwa RJ (2018). ZnO nanoparticles dispersed PVA-PVP blend matrix based high performance flexible nano dielectrics for multifunctional microelectronic devices. *Curr. Appl. Phys*., **18**(9): 1041-1058.

Das D, Chandra B, Phukon P and Kumar S (2013). Biointerface synthesis of ZnO nanoparticles and evaluation of antioxidant and cytotoxic activity. *Colloids Surf. Biointerface.,* **111**(7): 556-560.

Doddapaneni V, Saleemi M, Ye F, Gati R and Toprak MS (2017). Engineered PMMA/ZnO nanocomposites for improving the electric arc interruption capability in electrical switching applications: Unprecedented experimental insights, *Compos. Sci. Technol*., **141**(3): 113-119.

Feng A, Wu G, Wang Y and Pan C (2017). Synthesis, preparation and mechanical property of wood fiber-reinforced Poly (vinyl chloride) composites. *J. Nanosci. Nanotechnol*., **17**(6): 3859-63.

Guo J, Wang LD, Wang XH, Jiang H and Chen B (2010). The photodynamic effect of different size ZnO nanoparticles on cancer cell proliferation *in vitro*. *Nanoscale Res. Lett.,* **5**(6): 1063-1071.

Hammani S, Barhoum A and Bechelany M (2018). Fabrication of PMMA/ZnO nanocomposite: Effect of high nanoparticles loading on the optical and thermal properties. *J. Mater. Sci.,* **53**(3): 1911-1921.

Jamil M, Haq IU, Mirza B and Qayyum M (2012). Isolation of antibacterial compounds from *Quercus dilatata* through bioassay guided fractionation. *Ann. Clin. Microb. Anti.,* **11**(1): 11-11.

Joan A, Jaume G, Jose A, Adria L, Anna L, Alicia M, Josefina Q, Khosa MK, Carme C, Ramon M, Laura B and Josefa B (2017). Endo and exo cyclopalladated (E)-N-([1,1'-biphenyl]-2-yl)-1-mesitylmethanimines: Anticancer, antibacterial and antioxidant activities. *J. Organomet. Chem.*, **839**(6): 116-125.

Joseph J, Deshmukh K, Chidambaram K, Faisal M, Selvarajan E and Sadasivuni KK (2018). Dielectric and electromagnetic interference shielding properties of germanium dioxide nanoparticle reinforced poly(vinylchloride) and poly(methylmethacrylate) blend nanocomposites. J. Mater. Sci.: Mater. Electron., **29**(23): 20172-20188.

Khosa MK, Jamal MA, Farman M, Shoaib HM and Shahid M (2015). Synthesis, spectral investigation (^{1}H, ^{13}C) antibacterial and antifungal screening of benzophenone imines. *Pak. J. Pharm. Sci.,* **28**(6): 2167-2171.

Khoushika R and Brindha D (2017). Evaluation of the antityrosinase and antioxidant potential of zinc oxide nanoparticles synthesized from the brown seaweed-turbinaria conoides. *Int. J. Appl. Pharm.,* **9**(5): 116-120.

Li Y and Guo H (2020) Cross-linked poly (methyl methacrylate) with perfluorocyclobutyl aryl ether moiety as crosslinking unit: Thermally stable polymer with high glass transition temperature. *RSC Adv*., **10**(4): 1981-1988.

Mathew S, Mathew J and Radhakrishnan EK (2019). Polyvinyl alcohol/silver nanocomposites films fabricated under the influence of solar radiation as effective antimicrobial food packaging material. *J. Polym. Res*., **26**(9): 1-10.

Mauro D, Cantarella M, Nicotra G, Pellegrino G, Gulino A, Brundo MV, Privitera V and Impellizzeri G (2017). Novel synthesis of ZnO/PMMA nanocomposites for photocatalytic applications, *Sci. Rep*. **7**(1): 40895-40907.

Nash KM and Ahmed S (2015) Nanomedicine in the ROS-mediated pathophysiology: Appli-cations and clinical advances. *Nanomedicine.,* **11**(8): 2033-2040.

Osmond MJ and McCall MJ (2010). Zinc oxide nanoparticles in modern sunscreens: An analysis of potential exposure and hazard. *Nanotoxicology.*, **4**(1): 15-41.

Premanathan M, Karthikeyan K, Jeyasubramanian K and Manivannan G (2011). Selective toxicity of ZnO nanoparticles toward Gram-positive bacteria and cancer cells by apoptosis through lipid peroxidation, nanomedicine nanotechnology. *Biol. Med.,* **7**(2): 184-192.

Pugazhenthi I, Sakvai MS and Kottur AB (2017). Synergistic effect of functionally active methacrylate polymer and ZnO nanoparticles on optical and dielectric properties. *Mater. Chem. Phys.,* **193**(1): 203-211.

Rasmussen JW, Martinez E, Louka P and Wingett DG (2010). Zinc oxide nanoparticles for selective destruction of tumor cells and potential for drug delivery applications. *Expert Opin. Drug Deliv.,* **7**(9): 1063-1077.

Safawo T, Sandeepa B, Pola VS and Tadess A (2018). Synthesis and characterization of zinc oxide nanoparticles using tuber extract of anchote (*Coccinia abyssinica* (Lam.) Cong.) for antimicrobial and antioxidant activity assessment. *Open Nano.*, **3**(1): 56-63.

Sharma B, Malik P and Jain P (2018). Biopolymer reinforced nanocomposites: A comprehensive review. *Mater. Today Commun.*, **16**(1): 353-363.

Shakir MF, Khan AN, Khan R, Javed S, Tariq A, Azeem M (2019). EMI shielding properties of polymer blends with inclusion of graphene nano platelets. *Res. Phys*., **14**(1): 102365.

Sudheesh PT, Kumar VK, Lakshmanan and Anilkumar TV (2012). Flexible and microporous chitosan hydrogel/nano ZnO composite bandages for wound dressing: *in vitro* and *in vivo* evaluation. *ACS Appl. Mater. Interfaces.,* **4**(5): 2618-2629.

Suresh SS, Mohanty S and Nayak SK (2017). Preparation and characterization of recycled blends using poly(vinyl chloride) and poly (methyl methacrylate) recovered from waste electrical and electronic equipments. *J. Clean Prod.*, **149**(1): 863-73.

Tavakoli M, Bakhtiari SSE and Karbasi S (2020). Incorporation of chitosan / Graphene oxide nanocomposite in to the PMMA bone cement: Physical, mechanical and biological evaluation. *J. Biol. Macromol*., **149**(4): 783-793.

Thaya R, Malaikozhundan B, Vijayakumar S, Sivakamavalli J, Jeyasekar R, Shanthi S, Vaseeharan B, Ramasamy P and Sonawane A (2016). Chitosan coated Ag/ZnO nanocomposite and their antibiofilm, antifungal and cytotoxic effects on murine macrophages. *Microb Pathog.,* **100**(10): 124-132.

Wen L, Zunyuan X, Yaping L, Meixiang G, Weiqiang Z and Lingxiang G (2019). Fabrication and excellent electroresponsive properties of ideal PMMA@$BaTiO_3$ composite particles. *RSC Adv*., **9**(2): 12404.

Yaseen M and Taha (2020). An investigation of the mechanical properties of PMMA-based composites reinforced with PZT ternary nanoparticles. *Neuro Quantology,* **18**(2): 56-61.