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RESEARCH ARTICLE

PREPARATION AND FACILITATION OF ANTIBACTERIAL ACTIVITY, HYDROPHILICITY OF PIEZO-PVDF/n-MgO FILM BY ELECTRO-SPINNING AND SPIN COATED FOR WOUND DRESSING: A COMPARATIVE STUDY

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ARTICLE DETAILS

ABSTRACT

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Antimicrobial resistance of bacteria is one of the serious problems that appears in wound healing and may result in difficulties such as reduction in healing time or inflammations. Piezoelectric materials might be utilized in producing bioactive electrically charged surface. This paper focuses on producing two groups of bio-composite from polyvinylidene fluoride with addition of Nano-magnesium oxide (3, 5 and 7 %) wt. by two methods: electro-spinning and spin coating under special condition, with the aim of producing bio film as sensor for wound healing. The Antibacterial test was illustrated by Agar well dispersion strategy for three groups of the prepared film, reflecting the ability of n-MgO/PVDF biofilm to prevent the bacterial growth. The best sample that showed the greatest inhabitation zone was 7 wt.% n-MgO for both types of bacteria, in contrast with spin coated samples, which did not give any results for both type of bacteria. The AFM revealed topography of nanofiber (PVDF /n-MgO), which appeared like hills as compared to the same sample prepared by spin coating. DSC test showed that the increment of n-MgO to PVDF brought about a diminishing in the enthalpy for fusion (ΔH_m), suggesting a reduction in the crystallinity in PVDF. From contact angle test, it can be seen that the pure PVDF nanofiber showed water contact angle (WCA) of $\sim 108^\circ$, which showed the hydrophobic nature. The WCA is enhanced by presenting MgO and increasing MgO content. The WCA showed enhancement in increasing hydrophilic action where nanofiber (PVDF /n-MgO) showed WCA of 120° diminishes to 41° and the sliding angle diminishes displaying super-hydrophilicity. Consequently, the antibacterial action of the arranged nanofiber tests was improved, when contrasted with the counterpart spin coated membrane. Morphological analysis of first group demonstrated the presentation of random Nano fiber with some agglomeration of nano-MgO, where these agglomerates diffuse through agar plate and cause inhabitation of bacterial growth, while the second group shows smoother and flattened surface topography where the morphology appeared as a ringed-spherulitic matrix. FTIR studies reveal the presence of piezoelectric β -phase at 840cm^{-1} wave. As a result, the piezoelectric properties are found in the electrospun PVDF/n-MgO nanofiber which is necessary for advancement of biosensors used in sensing wound healing.

KEYWORDS

antibacterial activity, Piezoelectric-PVDF, Wound healing, biosensors, Inorganic Martials, Wound dressing, Electrospinning, Spin coating, hydrophilic

1. INTRODUCTION

The advancement of antifouling or antimicrobial polymers points transcendently at the counteractive action of microbial grip and biofilm arrangement. Such materials either repulse organisms (antifouling) or eliminate microbes (antimicrobial) present near the surface. The skin, the biggest organ of the body, has as an essential capacity of being a defensive boundary against nature. Loss of vast segments of the skin, as after effect of damage or disease, may prompt real incapacity or on the other hand even passing [1].

Recently, the utilization of biopolymers as replacement for tissue or diseased organ has become more common. Despite, the fact that there are some biomaterials displaying reasonable mechanical properties and low cytotoxicity, they are regularly inclined to form bacterial colony [2]. This bacterial colonization is related to Staphylococcus epidermidis and E. coli, which is the most well-known microorganism available in wound dressing and orthopedics prosthesis etc. Moreover, these microbial organisms may cause failure for implants after surgery. Consequently, the advancement of

new coatings with enhanced antimicrobial properties has become more pressing [3].

Polymeric nanofibres have increased considerable consideration in the recent past due to those specifically interest in tissue engineering applications [4]. In spite of that, antibiotic discharge from these hydrophilic, materials were fairly quick, bringing about a short antibacterial impact [5]. To alleviate this problem, two unique systems have been utilized: (i) sedate stacking improvement by arrangement of covalent bonds or ionic communications among medication and polymer framework; (ii) hydrophilic medication consolidation in hydrophobic manufactured polymers. With respect to this last system, numerous works have detailed the advancement of biodegradable fiber-based injury dressings for anti-microbial discharge. Wound-dressing electrospun nanofibrous grids can without a doubt have high gas pervasion and assurance of twisted from contamination and drying out [6].

Inorganic antibacterial agent such as MgO, ZnO and TiO₂ used to enhance the performance of bacterial polymeric materials for wound dressing

application is by elevating antimicrobial activity to PVDF utilizing nano-MgO [7].

The antibacterial mechanism of inorganic antimicrobial agent is the biocides, which is based on the micro-organism's cells through Van der Waals forces or electrostatic reaction, causing the disturbance of cell layer structure, as shown in Fig.1. Aside from that, the produced nanotoxicity is nearly related with nanoparticles and metal particles, creating free radicals that trigger oxidative pressure (receptive oxygen species, ROS) towards the microorganisms and causing irreversible cell harm [8]. Accordingly, the nanoscale antibacterial operators show a higher productivity of bacterial inactivation contrasted with bulkier partners owing to their expansive surface zone, which guarantees private contact with microbes and arrival of the responsive radicals [9].

Newly MgO nanoparticles have been utilized to incorporate various biopolymers. Zhao et al. fabricate MgO nanowhiskers reinforced PLA nanocomposites samples for bone replacement and repair [10]. In another investigation, chitosan was incorporated with spherical nano -MgO for superior bundling applications [11]. In this present paper, nano- MgO incorporated PVDF were produced by electrospinning and spin coating techniques for wound healing and their antibacterial, hydrophobicity, and morphological were characterized. Furthermore, the effect of Nano-MgO on the antibacterial, hydrophilicity and thermal properties of PVDF scaffolds was examined. Moreover, antibacterial, hydrophilicity, and morphological properties of MgO strengthened PVDF scaffolds were compared to those of the spin coated nano MgO/PVDF biofilm. The fabricated MgO strengthened PVDF nanofiber scaffolds showed an extraordinary potential to be utilized as synthetic scaffolds for regeneration and healing of wounded tissue.

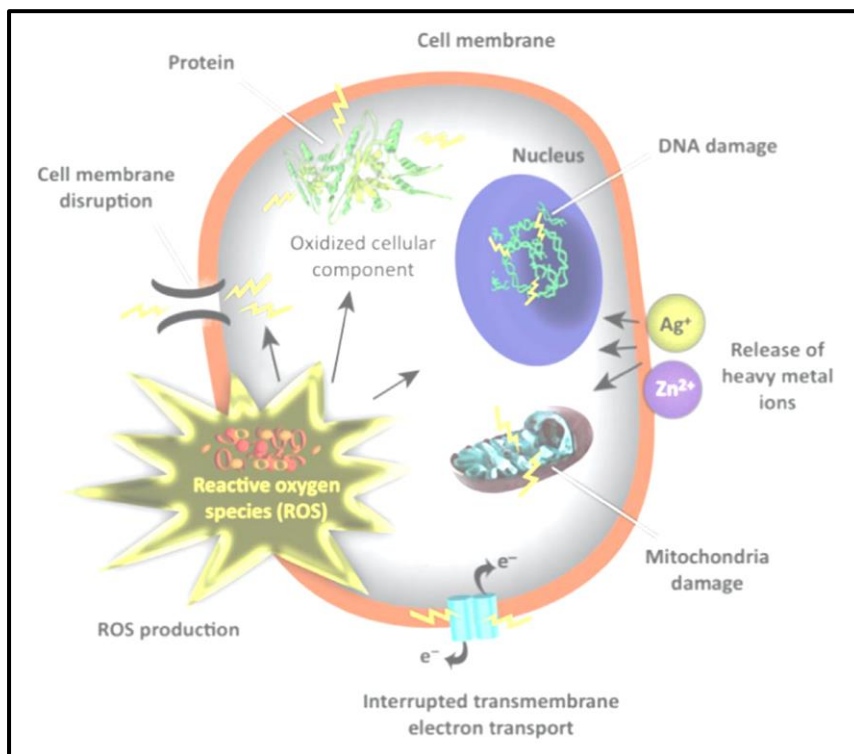


Figure 1: Mechanisms of toxicity of nanoparticles (NPs) against bacteria [9].

2. MATERIALS AND EXPERIMENTAL PROCEDURE

Polyvinylidene fluoride, (PVDF) with density (1.78 g/cm³), particle size (16 μ m) was supplied by China Guangzhou Li Chang Floro plastics Co., Ltd. This polymer was characterized by DSC, FTIR tests. n-MgO Powder average diameter of MgO particles (76.96 nm). Size: 30-40 nm, Purity: 99.9 % supplied by Nanjing Nano technology. A common solvent for chemical reactions, Dimethylformamide and acetone DMF, was supplied by the Central Drug House CDH (P) Ltd. India.

2.1 Sample preparation

Two groups of samples were fabricated; each group with four samples, as revealed by Table.1. The preparation method included preparing the solution pure polymer of PVDF and polymer Nano composite with selected weight percentage ratios of MgO (0.3, 0.5 and 1%). The samples were fabricated by two techniques: electrospinning and spin coating.

Table 1: Weight Percentage of the sample

Type of composite	Weight fraction of the polymer (%)PVDF	Weight fraction of nano particles(%) MgO
Pure polymer	100 %	0 %
Nano composites	97 %	3 %
	95 %	5 %
	93 %	7 %

For first group, the procedure was dissolving PVDF in (20ml) of (DMF+ Acetone) on the stirrer at temperature 70°C for 4hr. The prepared polymer Nano composite PVDF was dissolved in (10ml) (DMF + Acetone) on the stirrer at temperature 70°C for 4hr and then Nano MgO was mixed with (10ml) (DMF + Acetone) in the ultrasonic mixer with different concentration for dispersion for 10 min. The solution was prepared by using glass cylinder consisting of (2g) of pure polymer. After that nano -MgO was added to the polymer solution on the stirrer without heat for 2hr. Thereafter, the samples were fabricated by electrospinning device to

prepare the nanofibers with the specification Pumping Rate (0.55ml), Volts (13) KVolt, Syringe Diameter 0.48mm, Distance 15cm (Between The Bandol And Collector), Volt Type DC, Collector Length 30cm.

For the second group, the same prepared sample was spin coated on aluminum substrate after cleaning with acetone with condition mentioned in table 2. It is then dried in an oven at 80°C for 24hr in order to remove solvent from the samples.

Table 2: Condition of spin coating samples

Name of sample	Time (min.)	Speed (RPM)
Pure PVDF	5	100000
PVDF+3%MgO	5	100000
PVDF+5%MgO	5	100000
PVDF+7%MgO	5	100000

3. CHARACTERIZATION

3.1 Antibacterial

Antibacterial activity was determined by using Agar well Diffusion Method with test organisms (*E. coli* and *S. aureus*) by dispersion of the inoculums on the surface of the media using sterile swab. Plates (6mm in diameter) were punched in the agar by using sterile borer. Samples were put in the plates (100 microliter). The plates were preserved at 37 C for 18-24 hours. The antibacterial activity was evaluated by measuring the diameter of the inhibition zone in mm.

The thermal analysis was evaluated by DSC test. The procedure includes heating the sample from room temperature to 200°C; with heating rate 45°C/min., thereafter, cooled from 200°C to room temperature with a rate of 10°C/m.

The topography of samples under study was revealed by non-contact mode AFM type BY-3000, and surface roughness for each group of samples was determined. The wettability of two groups has been studied utilizing SL 200C - Optical Dynamic I Static Interfacial Tensiometer & Contact Angle Meter which is manufactured by KINO Industry Co., Ltd., USA with contact angle range from 0° to 180° to show the effect of nano MgO on hydrophobicity of prepared membrane. An FT-IR analyzer (IRAFFINITY-1) (Shimatzu) has been utilized. Samples were examined in a range of

(500-4000) of wavelength. Morphological analysis of two groups has been studies utilizing at 20Kv.

4. RESULTS AND DISCUSSION

4.1 Antibacterial Studies

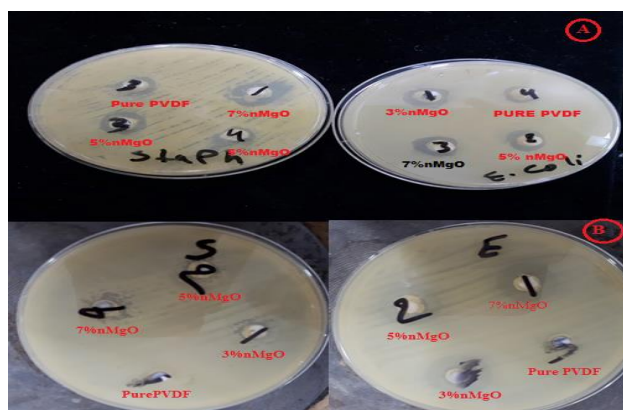
Figure 2A represents the antimicrobial efficacy of first group PVD/nMgO nanofibers. The pure PVDF nanofiber is not bactericidal. On the other hand, adding various amounts of n-MgO (3, 5, 7wt %) resulted in large inhibitory zones against *S. aureus* and *E. coli* and figure 1A. shows that the created diameter of the inhibition zone by PVDF/nMgO nanofiber is proportionate to the weight fraction of nMgO, as shown in Table 3. The measurements of the inhibition zone of PVDF/MgO nanofiber with the various concentration of magnesium oxide are 18mm and 14mm (3 wt. %), 20 and 18 mm (5 wt. %), 27 and 22 mm (7 wt. %), for both *S. aureus* (Gram positive) and *E. coli* (Gram negative), respectively. The inhibition efficacy caused by 3wt. % nMgO has been increased by 1.11 and 1.2 times (5wt %), 1.5, 1.57 times (7 wt. %). The addition of 3 wt. % nMgO has a valuable antimicrobial activity; and adding 7 wt. % nMgO gives the maximum inhibition zone of 27 and 22 mm for both *S. aureus* (Gram positive) and *E. coli* (Gram negative), respectively, which has an extraordinary increase by 7 and 4mm, as compared to the inhibition area produced by 3 wt. % n-MgO. This significant increase in measuring the diameter of inhibition area also suggests that 7 wt. % nMgO is the optimal parameter [12].

Table 3: Antibacterial assessment by Agar diffusion method

	Zone inhibition diameter (mm)	
	<i>S. aureus</i> (Gram positive)	<i>E. coli</i> (Gram negative)
Pure PVDF	0	0
PVDF+3%n-MgO	18	14
PVDF+5%n-MgO	20	18
PVDF+7%n-MgO	27	22
DMF	5	3

Magnesium oxide has antibacterial efficacy due to the creation of hydrogen peroxide, H₂O₂ on the surface of n-MgO species. This will lead to the damage of bacterial cell wall, which has a significant effect on the inhabitation of antibacterial zone, where n-MgO has great antibacterial

resistance against *S. aureus* (Gram positive) and *E. coli* (Gram negative), respectively [13]. Figure 2B represents the antibacterial activity of the spin coated PVDF/MgO, which does not show any inhabitation area.

**Figure 2:** Antibacterial efficacy Test of A. PVDF /nMgO nanofibers B. spin coated PVDF /nMgO.

4.2 FTIR studies

The FTIR spectra of pure PVDF and PVDF/MgO Nano fiber film, with variety of weight percentage range (3, 5, 7wt. %) is shown in Figure 3. The electro spun PVDF/MgO samples revealed an absorption band at 1403cm^{-1} , which illustrated an in-plane bending of $-\text{CH}_2$. During annealing, broader absorption peak at 1403cm^{-1} was noticed. Shift in the absorptivity of bands from 1220cm^{-1} to 1180cm^{-1} was revealed for PVDF/MgO Nano composites thin film. The band demonstrated a change from wagging to rocking of $-\text{CH}_2$ bond, which also referred to the β -phase of PVDF.

PVDF/MgO Nano composites thin films also showed a sharp peak at absorbance of 840cm^{-1} , indicating a significant presence of β -phase of PVDF. This was in agreement with [14,15]. The absorbance at 1282cm^{-1} shows the bonding of $-\text{CN}$ group, belonging to the DMF, which was used as a solvent for dissolving PVDF and dispersing MgO Nano-filler. However, the absorption band shifted from 1180cm^{-1} to 1220cm^{-1} , indicating transformation from polar β -phase crystals to polar γ -phase crystals. The reduction in transmittance for absorption band at 880cm^{-1} and 841cm^{-1} , as well as the availability of α -phase PVDF at absorbance band 796cm^{-1} were also observed.

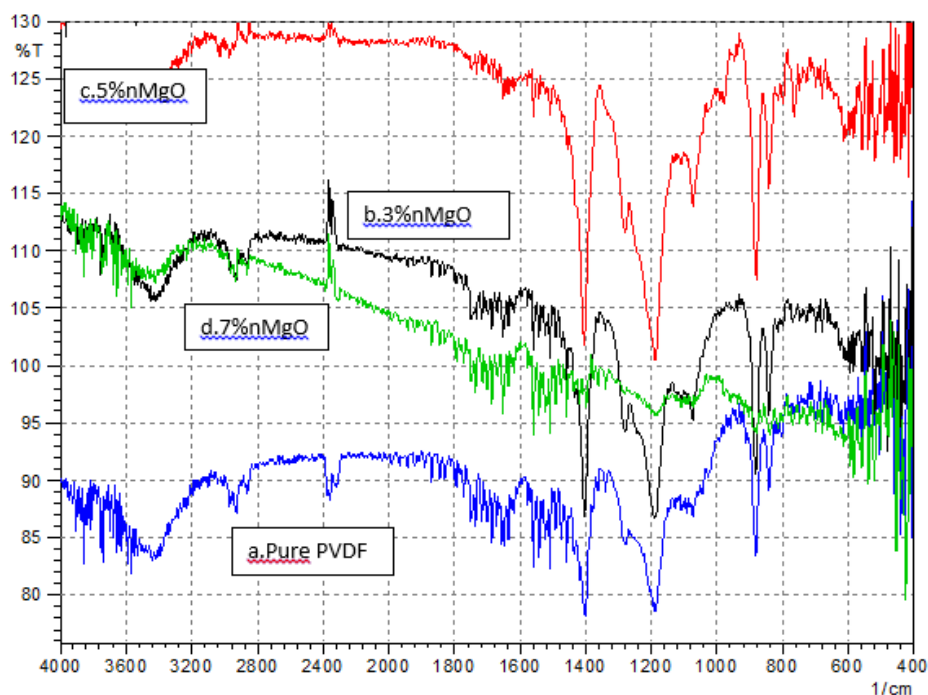


Figure 3: FTIR Spectrum of PVDF nanocomposites a. Pure b. 3% n-MgO c. 5% n-MgO d. 7% n-MgO

4.3 AFM Studies

Figure 4 shows the AFM image of PVDF reinforced with different n-MgO concentrations: (a) 0 wt. %, (b) 3 wt. %, (c) 5 wt. %, and (d) 7 wt. %. The film shows the topography of electro spun PVDF reinforced with different n-MgO. The film shows the topography of PVDF /nMgO nanofiber which

appears like hills, which is a characteristic of nanofiber, as compared to the same sample prepared by spin coating, as shown in Fig.5. Moreover, the mediate homogeneity of dispersion of nMgO with electro-spun fiber as compared to spin coated film can be observed, as shown in Fig. 4 and 5.

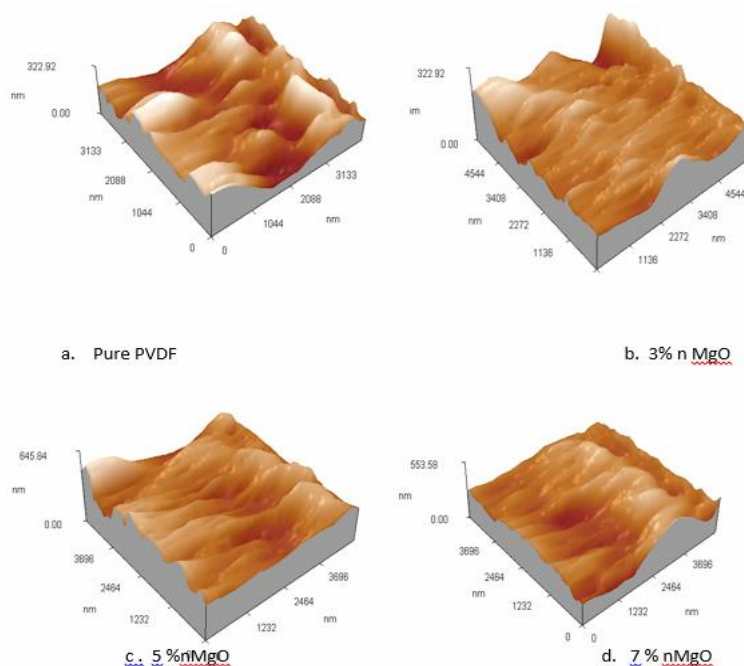


Figure 4: AFM images of electrospun (a) PVDF, (b) PVDF/MgO (3%), (c) PVDF/MgO (5%), (d) PVDF/MgO (7%).

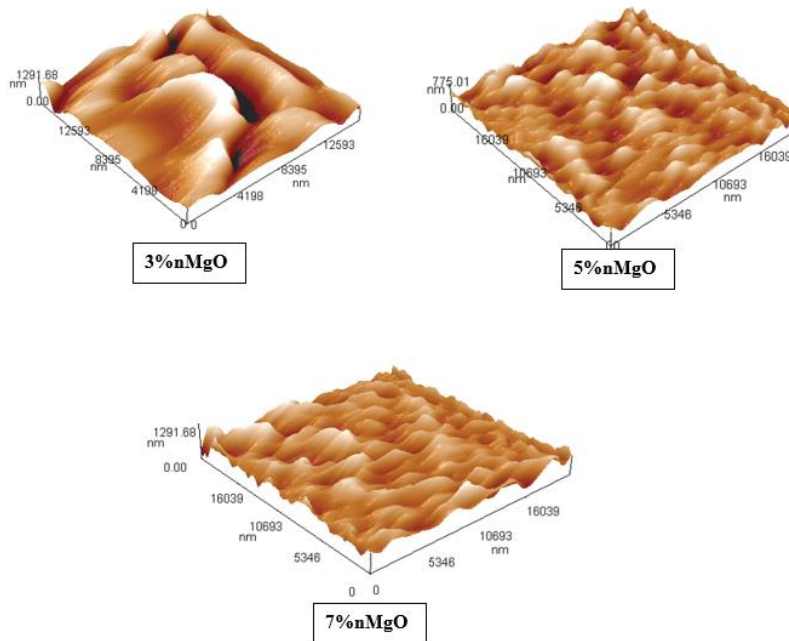


Figure 5: AFM images of spin coated (A) PVDF/nMgO (3%), (B) PVDF/nMgO (5%), (C) PVDF/nMgO (7%)

From Table 4 it is clear that the surface roughness of electro spun PVDF reinforced with different nMgO is less than the counterpart group. This may be attributed to the homogenous dispersion of nanoparticles and the

efficiency of preparation method for nanofiber rather than spin coating method.

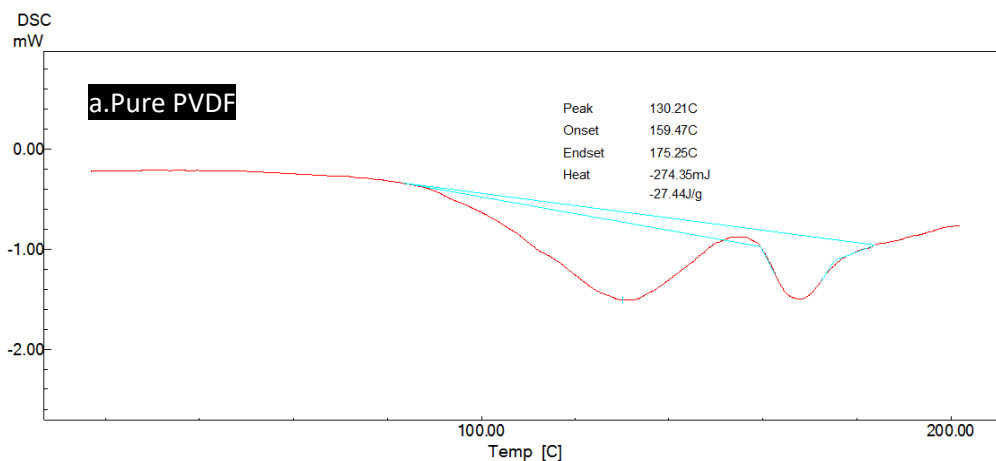
Table 4: AFM data for surface roughness of Nano composite

Percentage	Root mean square Sq (Nano fiber)	Root mean square Sq (Coating layer)
Pure PVDF	56.7 nm	111 nm
3 % MgO + PVDF	31 nm	272 nm
5 % MgO + PVDF	65.7 nm	153 nm
7 % MgO + PVDF	55.2 nm	

4.4 DSC Studies

From Figure 6, the melting temperature (T_m) of PVDF is 159.47°C. The temperature obtained was utilized as the temperature range for the annealing process of prepared Nano composite thin films. The thin films were annealed in an oven for an hour at temperature of 70°C and were rapidly removed from the oven upon completion of annealing process. However, data from the literature clarified that the double heating peaks for melting shown in the DSC analysis on PVDF due to the polymorphic change taking place in this polymer [16]. Specifically, this reference demonstrated that the low melting temperature, at 130 °C, was because of

the dissolving of α -shape precious crystal, while the high melting temperature, situated at around 175 °C, was related with the β -frame [17]. In addition, it is obvious from ordinary DSC heating test plotted in Figure 5 in which the enthalpy has been standardized by the net weight of PVDF in the Nano composites. From the information, it tends to be seen that the increments of MgO in PVDF brought about an abatement in the enthalpy got for melting (ΔH_m), suggesting a lessening in the crystallinity in PVDF. The abatement in crystallinity might be due to the interaction between the MgO and PVDF, which gave an impression of being very solid, as proved by the formation of the new phase PVDF (γ -stage). The melting temperature (T_m) was raised essentially upon adding 5wt. % MgO.



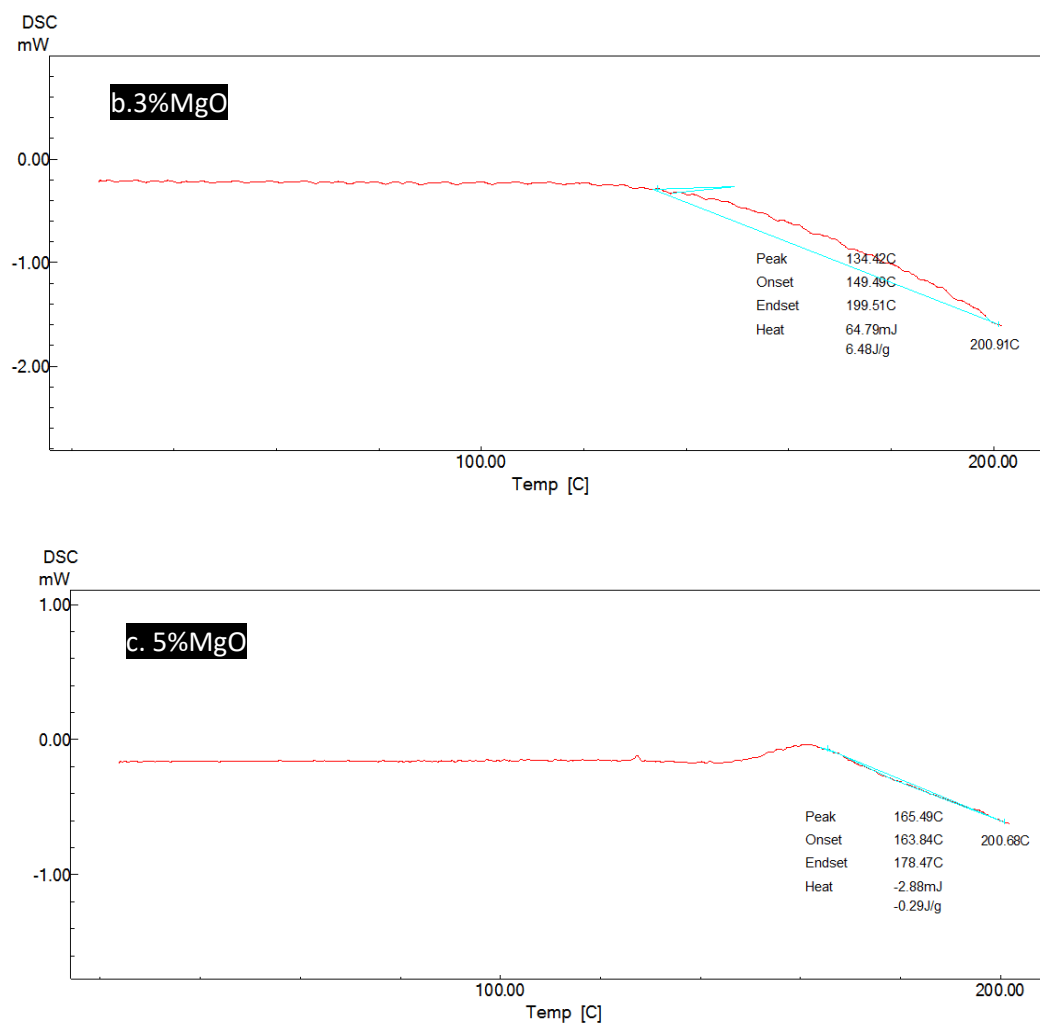


Figure 6: DSC thermogram of heating cycle for a. Pure PVDF, b. 3%MgO, c. 5%MgO

4.5 Contact Angle Studies

To monitor the effect of Nano MgO on the susceptibility of polymer nanofiber membranes to the serum that is normally accompanying wounds, the contact angle was examined after 60sec and 300 sec. The test is carried out for two groups of prepared film; the first group is electro spun PVDF-MgO, and the second group spin coatings with n-MgO ratio of (a) 0 wt.%, (b) 3 wt.%, (c) 5wt.%, (d) 7 wt.%, have been studied and are listed in Fig. 7. and 8. From Fig.7, it can be seen that the pure PVDF Nanofiber shows water contact angle (WCA) of $\sim 120.364^\circ$, which shows the hydrophobic nature. The WCA is decreased by presenting n-MgO and by increasing MgO content. The WCA reduction from 120.364° to 111.816° and the sliding angle diminishes displaying super hydrophilicity, which improved antibacterial action of the arranged nanofiber tests when compared with counterpart spin coated membrane. Furthermore, it was

Morphology of electrospun pure PVDF and the optimized sample PVDF / 7% MgO have been characterized with SEM analysis as illustrated by Fig.9 . To avoid electrostatic charging, the samples have been sputter-coated with gold . Generally, as shown in (figure 9.a), morphology of electrospun pure PVDF appeared as a smooth fiber surface with a random distribution. For the best nanocomposites sample PVDF / 7% MgO, as revealed in (figure 9. b, c). Some agglomerates have been observed

Figure 10 a, b & c represents the morphology of spin coated PVDF / 7% MgO nanocomposite. From figure it is clear that the annealing treatment of prepared spin coated PVDF / 7% MgO thin film has affected the morphology and surface smoothness whereas the expected morphology is

noted that the viability of membranes is a function of time and adding nano MgO makes it a Hydrophilic more at long times. For example, in time 300 seconds change the value of the Contact angle of 111.612° nano-MgO-free membrane to 41.576° of the membrane containing 7% of the nano-MgO. This supports the idea that increased nano MgO will absorb the high moisture that is available in wound and dry it which increases the chances of healing and increases the surface area of the wound exposed to antibacterial nanofiber effect.

Figure 8 for spin coating PVDF WCA shows slight change at long time for neat PVDF which was 126.630° and decreased at 7% to 65.028° which mean that the surface is moderately hydrophilic and this is preferred for antibacterial properties because a modest hydrophilic surface improved the antimicrobial activity, while too much hydrophilic surface reduced it [18].

between the electrospun nanofibers which may be attributed to the higher concentration of the nanofiller MgO [19]. Those agglomerates are significant cause of higher nano-MgO contents leading non-uniform fiber size distribution [20]. Moreover, the addition of nanoceramics to polymers solution leads to higher viscosity of polymer nanocomposites and higher size of electrospun Nano fiber [21].

porous structure but the annealing of samples at 80°C has influenced the morphology and surface roughness . Heat treatment for the deposited film at 80°C improved the solvent evaporation and prevented the formation of large pores which resulted in flattened and smooth topography [22,23].

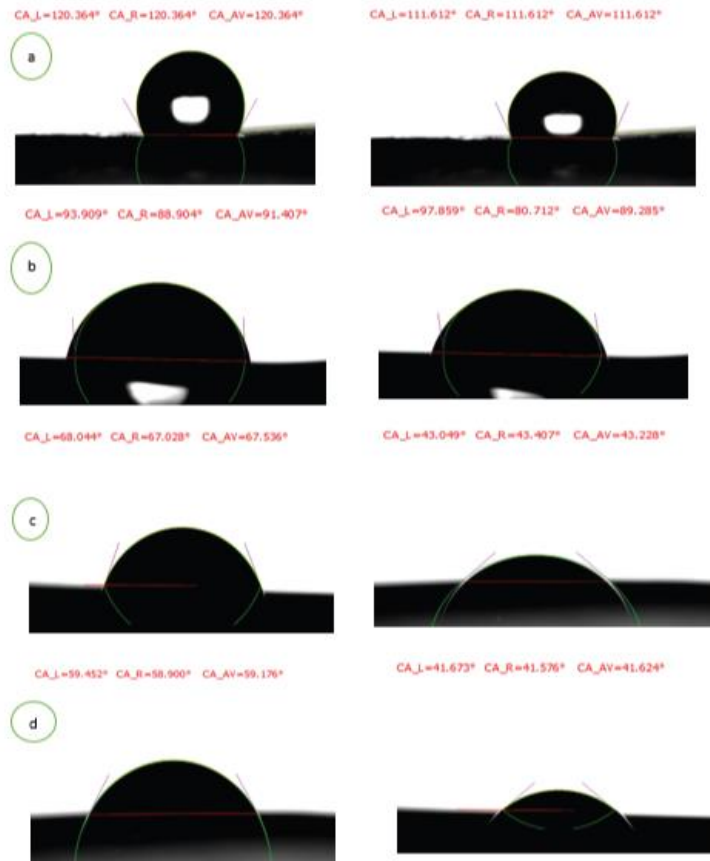


Figure 7: Contact angle measurement of electrospun nano PVDF-MgO at 60sec. (Left) and 300sec. (Right). for a. Pure b. 3%MgO c. 5%MgO d. 7% MgO.

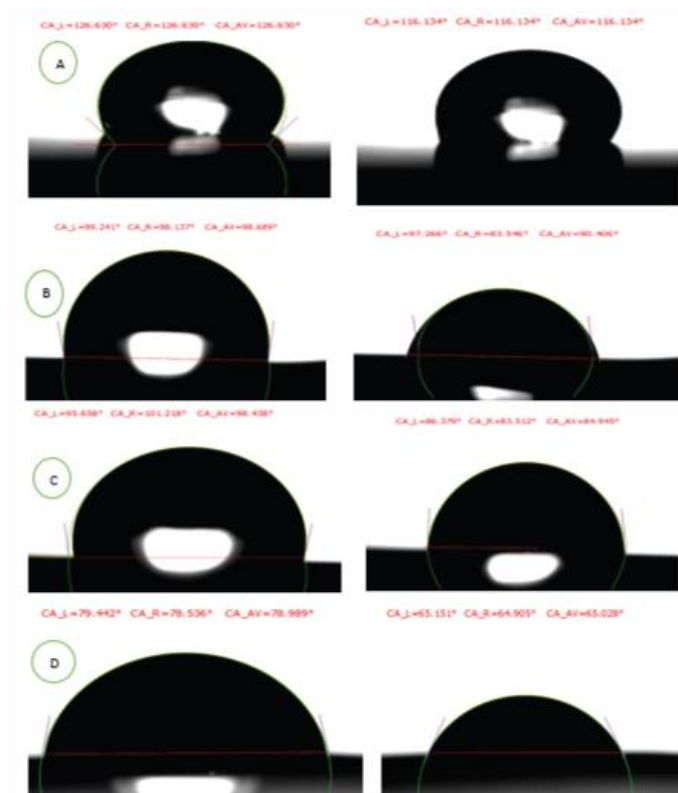


Figure 8: Contact angle measurement of spin coated PVDF-MgO at 60(Left) and 300sec (Right). for A. Pure B. 3%MgO C. 5%MgO D. 7% MgO.

4.6 Morphological Studies

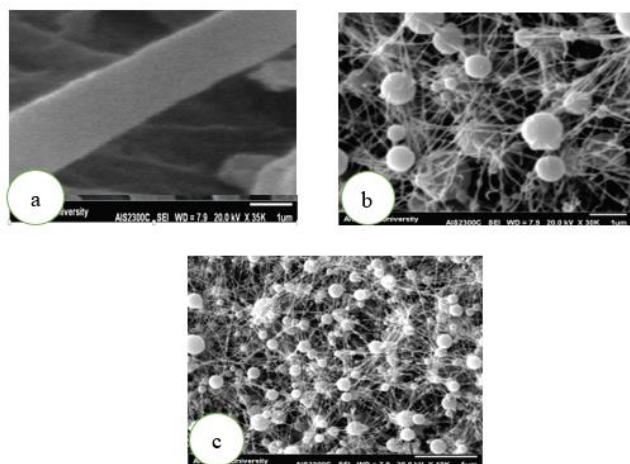


Figure 9: Morphology of electrospun fiber a. Pure PVDF b and c. 7%Nano MgO/PVDF nanocomposites with various magnification 1000×and 5000× respectively.

However, annealing of spin coated samples at 80 °C promoted the formation of α phase where the morphology appeared as a ringed-spherulitic matrix as illustrated by (figure 10(c)) and proved by FTIR (figure 1 (c)).

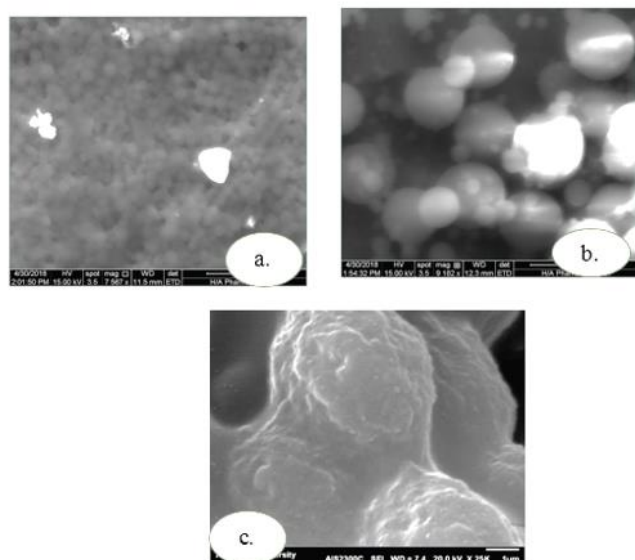


Figure 10: Morphology of Spin coated 7% n-MgO /PVDF nano composites samples a., b. and c. With different magnification 10000× 5000 ×and 1000×respectively

5. CONCLUSION

The target of this research was the assessment of the antibacterial properties of the electrospun PVDF/n-MgO and spin coated PVDF/n-MgO with various concentration of nano MgO (3, 5, 7) wt. %. In both groups, it was noticed that β -PVDF phase diffraction peak was appeared, which showed that the test conditions did not have reversible effect on the polymeric structure, being conceivable to infer that piezoelectric properties were kept. This is helpful for the advancement of sensors for biomedical application. It has been concluded that only electrospun PVDF/n-MgO showed antibacterial inhabitation where the n-MgO particles presented on the surface of the nanofiber and dispersed on agar plate, exhibiting reduction in the zone of bacteria growth. Thermal analysis demonstrated that the increment of n-MgO to PVDF brought about a diminishing in the enthalpy got for fusion (ΔH_m), suggesting a reduction in the crystallinity in PVDF. The hydrophobicity pure PVDF nanofiber showed water contact angle (WCA) of $\sim 120^\circ$ which decreased by presenting nano-MgO; the WCA decreased from 111° to 41° at long time 300sec; and the sliding angle diminishes displaying super-hydrophilic surfaces, which improved the antibacterial action of the arranged nanofiber tests when contrasted with the counterpart spin coated

membrane. Morphological electrospun samples were random nanofiber with some agglomeration of nano-MgO, while spin coated group showed smoother and flattened surface topography where the morphology appeared as a ringed-spherulitic matrix.

CONFLICT OF INTEREST

No conflict of Interest.

REFERENCES

- [1] Francolini, I., Crisante, G.D.F., Taresco, V., Piozzi, A. Antimicrobial Polymers for Anti-biofilm Medical Devices: State-of- Art and Perspectives, *Advances in Experimental Medicine and Biology*, 831, 93-117. DOI: 10.1007/978-3-319-09782-4_7.
- [2] Oliveira, C., Gonçalves, L., Almeida, B.G., Tavares, C.J., Carvalho, S., Vaz, F., et al. 2018. XRD and FTIR analysis of Ti-Si-C-ON coatings for biomedical applications, *Surf.Coatings Technol*, 203, 490-494. DOI: 10.1016/j.surfcoat.2008.06.121.
- [3] Marques, S.M., Carvalho, I., Henriques, M., Polcar, T., Carvalho, S. 2015. PVD-grown antibacterial Ag-TiN films on piezoelectric PVDF substrates for sensor applications, *Surface & Coatings Technology*, DOI: 10.1016/j.surfcoat.2015.09.05.
- [4] Ratnayake, G., Amaratunga, A.J., Nalin de Silva, K.M. 2017. Magnesium Oxide Nanoparticles Reinforced Electrospun Alginate-Based Nanofibrous Scaffolds with Improved Physical Properties, *Hindawi, International Journal of Biomaterials*, Article ID 1391298, 9, DOI: <https://doi.org/10.1155/2017/1391298>.
- [5] Ruzszzak, Z., Friess, W. 2003. Collagen as a carrier for onsite delivery of antibacterial drugs. *Adv Drug Deliv Rev*, 55, 1679-1698.
- [6] SriPriya, R., Kumar, M.S., Sehgal, P.K. 2004. Improved collagen bilayer dressing for the controlled release of drugs. *J Biomed Mater Res B Appl Biomater*, 70B, 389-396.
- [7] Zhen, X.T., Bin, F.L. 2014. MgO Nanoparticles as Antibacterial Agent: Preparation and Activity", *Brazilian Journal of Chemical Engineering*, 31(3), 591 - 601.
- [8] Soenen, S.J., Rivera-Gil, P., Montenegro, J.M., Parak, W.J., Smedt, S.C.D., Braeckmans, K. 2011. Cellular toxicity of inorganic nanoparticles: common aspects and guidelines for improved nanotoxicity evaluation, *Nano Today*, 6, 446-465.
- [9] Zhua, J.Y., Hou, J.W., Zhang, Y.T., Tian, M.M., Hee, T., Liu, J.D., Chen, V. 2018. Polymeric antimicrobial membranes enabled by nanomaterials for water Treatment, *Journal of Membrane Science*, 550, 173-197.
- [10] Zhao, Y., Liu, B., You, C., Chen, M. 2016. Effects of MgO whiskers on mechanical properties and crystallization behavior of PLLA/MgO composites, *Materials and Design*, 89, 573-581.
- [11] De Silva, R.T., Mantilaka, M.M.M.G.P.G., Ratnayake, S.P., Amaratunga, G.A.J., Nalin de Silva, K.M. 2017. Nano-MgO reinforced chitosan nanocomposites for high performance packaging applications with improved mechanical, thermal and barrier properties, *Carbohydrate Polymers*, 157, 739-747.
- [12] Yi, J.P., Jia, H.L., Kun, C.C. 2016. Biomedical Applications of Antibacterial Nanofiber Mats Made of Electrospinning with Wire Electrodes, *Appl. Sci.*, 6, 46. DOI: 10.3390/app6020046.
- [13] Krishnamoorthy, K., Manivannan, G., Kim, S.J., Jeyasubramanian, K., Premanathan, M. 2012. Antibacterial activity of MgO nanoparticles based on lipid peroxidation by oxygen vacancy, *J Nanopart Res*, 14, 1063. DOI: 10.1007/s11051-012-1063-6
- [14] Arshad, A.N., Dahan, R.M., Wahid M.H.M., Sarip, M.N., Mahmood, M.R. 2015. Enhancement on the Electrical Properties of PVDF/MgO Nanocomposite Thin Films, *Advanced Materials Research Submitted*, 1134, 16-22.

- [15] Arshad, A.N., Dahan, R.M., Wahid, M.H., Zulkefle, H., Ismail, L., Sarip, M.N., Mahmood, M.R. 2013. The Study of the Surface Morphology of PVDF/MgO Nanocomposites Thin Films, *Advanced Materials Research*, 626, 311-316.
- [16] Arranz-Andrés, N., Pulido-González, C., Fonseca, E., Pérez, M.L., Cerrada. 2013. Lightweight nanocomposites based on poly (vinylidene fluoride) and Al nanoparticles: Structural, thermal and mechanical characterization and EMI shielding capability, *Materials Chemistry and Physics*, 142, 469-478.
- [17] Tang, X.G. 2012. Poly (vinylidene fluoride) based nanocomposites: the preparation, structures, and properties, A thesis submitted for the degree of Doctor of Philosophy at The University of Queensland
- [18] oz-Bonilla, A.M., Mari', L., Cerrada, M.L., Marta Ferná'ndez-Garci'. 2013. Polymeric Materials with Antimicrobial Activity from Synthesis to Applications, *RSC Polymer Chemistry Series*, 10.
- [19] Cossich, E., Bergamasco, R., Pessoa de Amorim, M.T., Martins, P.M., Marques, J., Tavares, C.J., Lanceros-Mendez, S., Sencadas, V. 2015. Development of electrospun photocatalytic TiO₂-polyamide-12nanocomposites, *Materials Chemistry and Physics*, 1-7.
- [20] Lopes, A.C., Ribeiro, C., Sencadas, V., Botelho, G., Lanceros Me'ndez, S. 2014. Effect of filler content on morphology and physical-chemical characteristics of poly (vinylidene fluoride)/NaY zeolite-filled membranes, *J Mater Sci*, 49, 3361-3370. DOI:10.1007/s10853-014-8043-4.
- [21] Abbasipour, M., Khajavi, R., Yousefi, A.A., Yazdanshenas, M.E., Razaghian, F. 2017. The piezoelectric response of electrospun PVDF nanofibers with graphene oxide, graphene, and halloysite nanofillers: a comparative study, *J Mater Sci: Mater Electron* DOI 10.1007/s10854-017-7491-4.
- [22] Cardoso, V.F., Minas, G., Costa, C.M., Tavares, C.J., Lanceros-Mendez, S. 2011. Micro and nanofilms of poly (vinylidene fluoride) with controlled thickness, morphology and electroactive crystalline phase for sensor and actuator applications, *Smart Mater. Struct*, 20, 087002, 4.
- [23] Magalhães, R., Durães, N., Silva, M., Silva, J., Sencadas, V., Botelho, G., Gómez Ribelles, J.L., Lanceros-Méndez, S. 2011. The Role of Solvent Evaporation in the Microstructure of Electroactive β - Poly (Vinylidene Fluoride) Membranes Obtained by Isothermal Crystallization, *Soft Materials*, Taylor & Francis Group, LLC, 9(1), 1-14, DOI: 10.1080/1539445X.2010.525442

