International Journal of Applied Science and Engineering
Citation: *IJASE*: **10**(01): 23-29, June 2022
DOI: 10.30954/2322-0465.2.2021.2

IJASE
INTERNATIONAL JOURNAL OF APPLIED SCIENCE AND ENGINEERING

Research Paper

APPLIED PHYSICS

Enhanced Electrical and Mechanical Properties of Carbon Fiber Powder Polyvinyl Alcohol (PVA) Composite

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Received: 12 Mar., 2022 **Revised:** 23 May. 2022 **Accepted:** 02 Jun., 2022

ABSTRACT

Recently polymer composites embedded with conconductive carbon nano-filler (graphene or carbon nanofibers) have drawn considerable attention because of their multifunctional properties appropriate for electronic and biomedical applications. Cabon fibers (CFs) have extraordinary properties as filler material. As it is difficult to homogeniously mix CFs with polymer, in the present paper, insulating polyvinyal alcohol (PVA)/conducting carbon filament fiber powder (CFP) composite films were synthesized and characterized for the study of their electrical, dielectric and mechanical properties. Enhanced electrical conductivity, dielectric permittivity and mechanical properties were observed with the addition of conducting carbon filament powder in the composites. Such enhanced electrical, dielectric and mechanical properties represented multifunctional behavior of the biopolymer composite films and also indicated their compatibility for applications in fuel cell electrode material as well as for biomedical scaffold for tissue engineering.

Keywords: Carbon fiber poowder, polymeric composites, electrical properties, mechanical properties

Materials showing biocompatibility and biodegradability along with suitable mechanical and electrical properties are important for different electronic[1], clinical and biomedical application[2-4]. Pure organic conducting polymer films or fibers[5] are not, in general, mechanically stable and nflexible necessary for technological applications as in fuel cell and in biomedical application[1-2]. It is well known that cells grows and proliferate better in higher conducting polymer composite scaffolds[6]. Polymer composites films and fibers are important for applications as flexible capracitor and sensor materials[7]. Recently low cost and easily available bio-friendly polymers PVA and polyvinyl pyrilidine (PVP) have drawn special attention because of their potency for hydrogel formation and also for their uses as artificial cartilage[8,9], wound dressing[10], artificial skin, and cardiovascular devices[11,12]. Both PVA and PVP, forming interesting cross

How to cite this article: Bhadra, D. (2022). Enhanced Electrical and Mechanical Properties of Carbon Fiber Powder Polyvinyl Alcohol (PVA) Composite. *IJASE.,* **10**(01): 23-29.

Source of Support: None; **Conflict of Interest:** None

linking composites, are widely used polymers in medicine because of their water solubility and extremely low cytotoxicity[16]. Pure PVA and PVP based biocompatible polymers are suitable for biomedical (as scaffold materials) and electronic device applications due to their high solubility, low conductivity ($\sigma<10^{-8}$-10^{-9}S/m) and dielectric permittivity ($\varepsilon<10$). Enhanced dielectric properties provides fabourable cures, because of surface charge on the composite scaffolds, promoting better cellular interaction[13,14]. The PVP-PVA blend had already been reported to show enhanced conductivity and maximum conductivity for the blend 80wt%PVP-20wt%PVP[15,16] suitable for fuel cell and biomedical[2] applications. Low cost polymers like PVA, polyvinyl poly caprolidone (PVP) and their blend can be used to produce flexible composite films and fibers. But these films or fibers are also not mechanically stable for technological and biomedical applications. These polymers embedded with graphite[17], carbon nanofibers[18] or other fillers[19] were found to enhance mechanical and electrical properties[5-7]. The application of polymer electrolyte fuel cell, for example, is restricted due to high material cost and complicated manufacturing process. Optimum mechanical strength with a reasonable conductivity is the basic requirements for biomedical and other electronic applications.

Carbon fibers (CFs) might be an appropriate filler material for the making polymer composites because of their conducting[20] and antibacterial[21] properties. CFs have also several superior qualities like high mechanical strength, Young modulus and thermal conductivity[22]. Since it is difficult to make homogeneous carbon fiber polymer composite, carbon fiber powder might be an alternative use of carbon fiberfor making homogeniously mixed polymer compsites. In the present paper, our intention is to make use of carbon fiber powder for synthesis of composites with easily available low cost polyvinyal alcohol (PVA). Electrical, dielectric and mechanical properties of these composites films were investicated to elucidate probable technological applications[23]. Improved transport and mechanical properties of these flexible composite films indicated their multifunctional[10-15] behavior.

Experimental

Polyvinyl alcohol (PVA, MS: 2,40000), dimethyl sulfoxide (DMSO from Merck India) and commercially available carbon fiver filaments were used. As it is difficult to make carbon fiber powder, a simple technique was used to make powder from carbon fiber filaments. The fibers were first cut into small pieces (~0.5 mm size) which were grounded in mechanical grinder for about six hours to make powder (CFP) of size ~ 4- 10 μm. Equal amounts (2g each) of PVA were dissolved in a fixed volume of DMSO in three beaches and appropriate amounts (2, 8, 16 wt%) of carbon CFP were added separately. Each composite was well mixed by starring at 75^{o}C for three hr in order to obtain homogeneous composite mixture which was then poured into the Teflon mould and kept at room temperature (~300^{o}C) for several days so that the films could be peeled out from the Teflon mould. The films were further dried at 50^{o}C for 8-10 hrs to make free them DMSO. X-ray diffraction (XRD) and field emission scanning electron microscopic (FESEM) studies of the composite films were carried out using PHILIPS SHIFFERT 3710 diffractometer using Cu-K_{α} radiation source (λ=1.5418 A^{0}) at room temperature and SEM; JEOL Model JSM-6490). For tensile strength measurements (Model ASTM D 638), specimens were prepared in the form of thin sheet. AC Conductivity and dielectric permittivity were measured by impedance analyzer (HP Model 4192A) similarly to our previous work[24]. Furier transform infra red (FTIR) and Raman spectroscopic studies of the film were carried out using ALPHA II (MAKE: BRUKER UPTIK GBMH, GERMANY) and Laser Raman Spectrometer (HORIBA JOBIN Yuon: exciting wavelength 514 nm with argon ion laser).

Experimental Results and Discussion

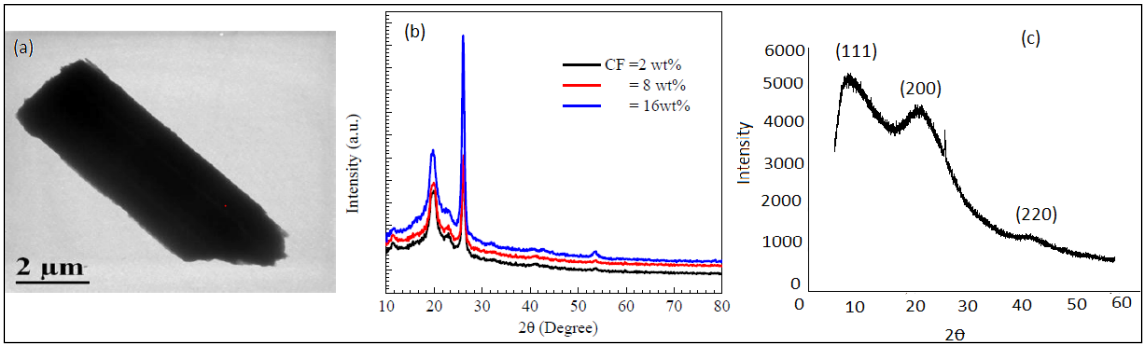

Fig. 1: (a) FESEM micrograph of a small piece of a carbon fiber grain, **(b)** X-Ray diffraction patterns of carbon fiber powder-PVA composites with different concentrations of CFP and **(c)** pure carbon fiber powder

Fig. 1 (a) showed FESEM micrograph of a few micron size carbon fiber grain used to make PVA-CFP composites. The corresponding XRD patterns of the composites with different CFP concentrations (2 to 16 wt %) were presented in Fig. 1b . The sharp crystalline peaks of the CFP−PVA composites indicated increase of crystallinity of the composite which might be related to the increase of conductivity discussed below. The well-dispersed low concentration-carborn particles acted as nucleating agents and thus the crystallinity of the composites was improved. The XRD patterns of pure CFP (Fig.1b) exhibit distinctive broad reflections at angles 2θ ~ 23 and 42° are associated with (111), (200) and (220) diffraction line, respectively. The peak broadening is an indicative of an amorphous structural aspect of the CFP sample. The FESEM micrographs of the CFP-PVA composites with 8 and 16 wt% CFP were shown in Figure -2. For higher concentration of the CPF connectivity is higher which increased conductivity as discussed in the subsequent paragraph.

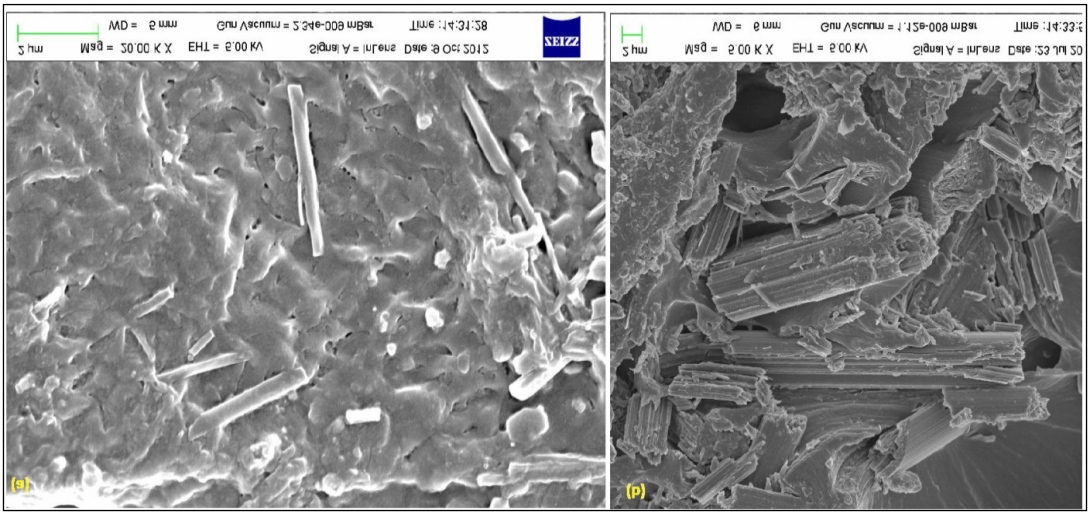

Fig. 2: The FESEM micrographs of CFP-PAVA composite films with (a) and (b) 8 wt% CFP.

The thermogravimetric analysis (TGA, in nitrogen atmosphere), FTIR and Raman spectra of the 16wt% CFP-PVA composite were shown, respectively, in Fig. 3(a-c) . The TGA of the 16wt% CNFP-PVA composite demonstrated (Fig.3a) one sharp weight loss started around 160 °C near to its softening temperature and then there is shape weight loss near the melting temperature 260°C at which it get decomposed sharply. In the FTIR curve (Fig. 3b), the very small absorption band at about 1539 cm^{-1} is assigned to the characteristic vibration of C = N (pyridine ring). The absorption band at 962 cm^{-1} is assigned to the out-of-plane rings C-H bending[23,25,26]. The wide absorption band at about 3385 cm^{-1} is attributed to O-H stretching vibration of hydroxyl group in PVA. The band corresponding to CH_2 asymmetric stretching vibration appeared around 2939 cm^{-1} in PVA. The band at about 1281 cm^{-1} corresponds to C-O stretching of acetyl groups present on the PVA backbone. The appearance of C-O stretching is due to semi-crystalline nature of PVA. The vibration band at about 1647 cm^{-1} corresponds to C-O symmetric bending of PVA. Raman spectra (Fig.3c) of the composite indicated the characteristic carbon peaks at frequencies around 1338 and 1600cm^{-1}, respectively, for the G and D band usually assigned to the E_{2g} phonon of Csp^2 atoms and a phonon breathing mode of symmetry A_{1g} [27,28].

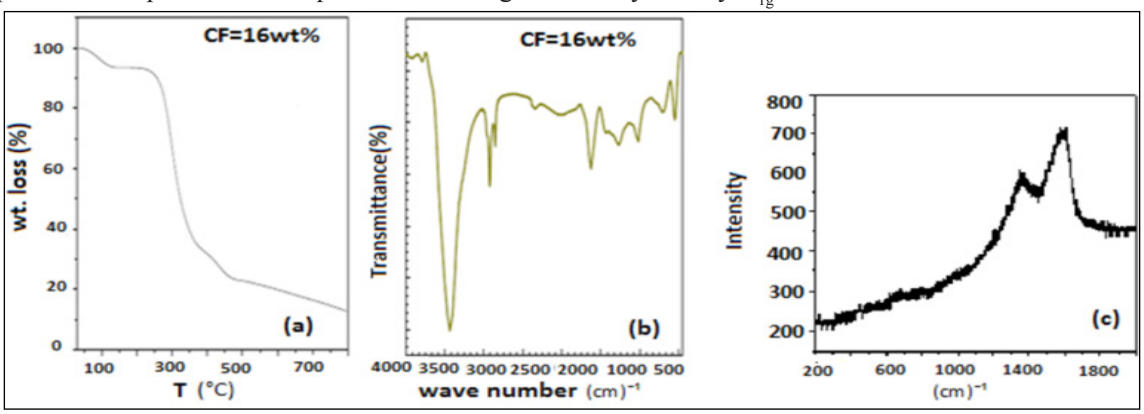

Fig. 3: (a) TGA, FTIR and Raman spectra of the 16wt%-PVA composite

The experimental stress-strain curves for different composite films with different CFP concentration are shown in Fig. (4a). Table (1) presents the average elastic modulus, the proportional limit, the ultimate tensile strength and the tensile fracture. Estimated from the stress –strain curves. The mechanical properties vary similarly in all the composites showing increase of elastic modulus with increase of CFP content. Increase of ultimate tensile strength and proportional limit stress with CFP indicated an important improvement. Frequency dependent dielectric permittivity curves of different composites with 0, 2, 4, 8 and 16 wt% CFP were shown in Fig. 4b. It is seen that compared to pure PVA film, dielectric constant increased (more than 2 orders of magnitude) with increase of CFP contents.

Table 1: Mechanical properties of CNPF-PVA composites

Wt % of CF	Elastic modulus	Proportional limit (Mpa)	Yield strength	Ultimate strength (MPa)	Tensile fracture (MPa)
0%	2.4 ± 0.4	10.0 ± 0.4	11.4 ± 0.4	13.8 ± 0.4	13.8
8%	1.1 ± 0.4	6.4 ± 0.4	12.04 ± 0.4	19.2 ± 0.4	19.2
16%	1.6 ± 0.4	8.0 ± 0.4	13.08 ± 0.4	19.5 ± 0.4	19.5

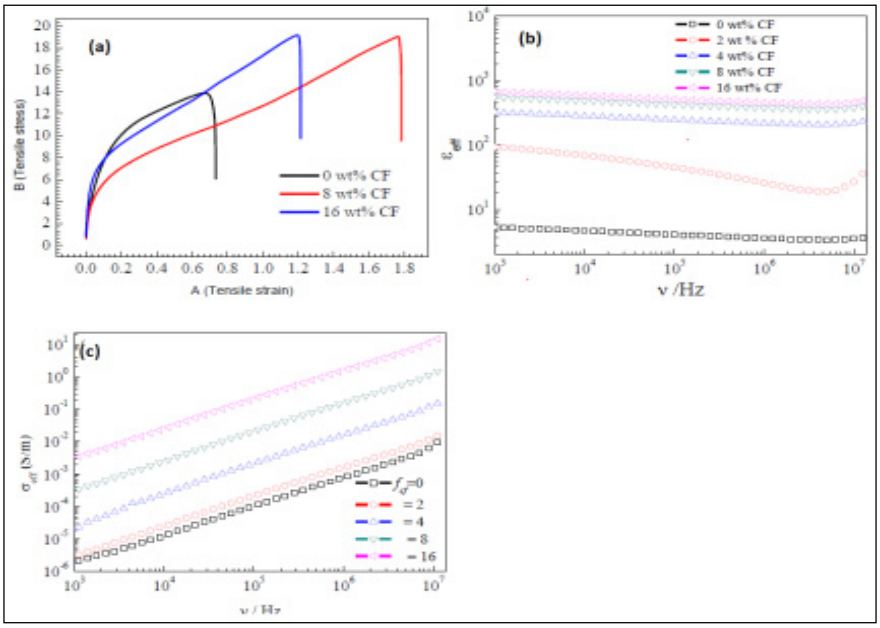

Fig. 4. (a) The stress-strain curves of different PVA-CFP composite films with 0, 8 and 16 wt % CFP concentrations, **(b)** frequency dependent dielectric permittivity and **(c)** electrical conductivity of different CFP-PVA composites measured at ambient temperature (~300K)

The frequency dependent electrical conductivity data presented in Fig. (4c) showed enhancement of conductivity with the increase of CFP contents. Conductivity enhancement (2- 3 orders of magnitude in units of S/m^2) is an important feature for the development of fuel cell. Such increase of conductivity of the biopolymer composite scaffold material is also important for a biomaterial scaffolds for tissue engineering. The CFP embedded PVA composites showed semiconducting behaviour. For a typical composite (16wt% and above) conductivity reached around 10^{-2} S/m which might be useful for bipolar cell application[29]. For such an application at last conductivity around 10^{-2} S/m^2 was needed[1]. So these composite films might be used for fuel cell battery electrodes.

CONCLUSION

Present study mainly demonstrated that the addition of reasonably small quantity of CFP can modify the mechanical, electrical and dielectric properties of the CFP -PVA composites which might be important for fuel cell material and biomedical applications. Further analysis of the conductiivy and dielectric dtata with different particle size of the carbon fiber and analysis of the data using different models would be important for elucidating the mechanism of enhanceen tof conductivity and dielectric permittivity of these composites. The mechanical strength and electrical conductivity of the composites increased with increase of CFP content. The 16wt% CFFP composition showed maximum conductivity suitable for fuel cell electrode material applications . On the other hand, for biomedical scaffold application lower concentration (<8wt% CFFP) with much smaller grain zize might be useful. Such multifunctional behaviour might also be exhibited with other biopolymers like PCL, PLGA and chitosan instead of PVA elucidating their compatibility for biomedical and electronic applications. Such studied are in progress.

ACKNOWLEDGEMENTS

Author is indebted to Central Research Unit of Bhairab ganguly College for Infrastructural support. Author also acknowledge the partial financial assistance West Bengal State Council of Science and Technology vide memo no: 28(Sanc.)/ST/P/S&T/1G-68/2017 dated on 12.06.18.

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