Fly Ash Filled Polyaniline Composites for Enhanced Electromagnetic Interference Shielding Effectiveness

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Abstract:

Developing electromagnetic interference (EMI) shielding material is significantly imperative due to the ever increasing silent and invisible electromagnetic (EM) radiation pollution. This paper reports synthesized polyaniline/fly ash (PANI/FA) composites as a material to control the ever increasing radiation pollution. For effective EMI shielding, impedance matching and absorption of EM wave are two most important key parameters. An amorphous and porous coal byproduct from coal fired thermal power stations; the fly ash and one of the most versatile conducting polymers; polyaniline establish an interconnected semiconducting network which strengthen the mechanism of shielding by absorbing incoming EM wave. Fly ash beneficiation for technological application is another important aspect as enormously increasing amount of fly ash is a growing environmental problem. The EMI shielding measurements were carried out in the frequency range of 12-18 GHz (Ku-band), relevant for practical applications. Shielding analysis demonstrates that the synergic coupling of morphological and dielectric characteristics of the composites result in high shielding effectiveness (SE) in the range of –37 to –34 dB (> 99.9 % attenuation of EM energy) dominated by absorption. The results reveal that the composites can be optimized for potential broadband EMI shielding applications.

Keywords: Polyaniline composites, Fly ash, EMI, Shielding, Dielectric properties

1. Introduction

Electronic devices are getting smarter, being made smaller and growing in number every day. Anywhere from smart watches to satellites, radios to rockets, we use the electronic devices. These electronic device that transmits, distributes, or uses electrical energy creates electromagnetic interference (EMI) has detrimental impacts on the surrounding environment and device performance too. As electronics and their components operate at faster speeds and smaller size, there is a substantial increase in EMI which can lead to malfunctioning and degradation of electronics [1–5].This increase in electromagnetic pollution can also affect human health, as well as the surrounding environment, if no shielding is provided [6].

Hence, EMI has been addressed under electromagnetic compatibility (EMC) regulations by governments and organizations around the world (IECTC77, IEC-CISPR, FCC-20780, MIL-STD-461/462, etc.) [7,8-10] to focus on the key issues related to EMI shielding. One of the important parameters in characterizing EMI shielding materials is the electromagnetic interference shielding effectiveness (EMI SE) values in the frequency range of interest [7,11-12].

In the past, metals and their composites which exhibit high conductivity and enhanced dielectric constant were the most common materials for EMI shielding [7,13,14]. But their disadvantages are heavy weight, physical rigidity and susceptibility to corrosion. Metals have limitations as EM wave absorbers since their shallow skin depth make them shield EMI mainly through surface reflection [7,8]. In recent times EMI shielding materials based on polymers with conductive fillers have been widely used as they induce high efficiency,

light weight and excellent electrical and mechanical properties [7,15-19].

Later conducting polymers have emerged as an important class of electronic materials because of their potential applications in EMI shielding as well as numerous other applications [7,20-25]. Among the various conducting polymers, polyaniline and its composites have been widely investigated due to their ease of protonic acid doping in the emeraldine form and their environmental stability in both doped and undoped forms. In addition, they are relatively light-weight and corrosion-resistant and can be easily produced in large scale at low cost. Fly ash is an environmental pollutant, a solid waste product from thermal power generation plants and there is increasing demand for the safe disposal of fly ash. It exhibits properties such as light weight, low density, high porosity, nontoxic with unique morphological features. The present article highlights the suitability of fly ash incorporated polyaniline composite as a broad band EMI shielding material. There are number of studies on the EMI shielding and microwave properties of polyaniline and its composites reported elsewhere [7,20,23,24,26,27], but the studies on EMI shielding along with polyaniline/fly ash (PANI/FA) composites in the frequency range of 12-18 GHz (Ku-band) are very limited.

2. Experimental

2.1 Materials

Aniline, ammonium peroxy disulphate (APS), and hydrochloric acid (HCl) were all of analytical reagent grade and purchased from S.D. Fine Chem. Ltd., Mumbai, India. Aniline monomer was distilled under reduced pressure and stored below 0°C. Fly ash received from Raichur Thermal Power Station, Raichur, Karnataka, India was sintered at 600°C for 5 h and ground well into fine fly ash powder.

2.2 Preparation of PAni/FA composites

Synthesis of PAni/FA composites were carried out by single step in-situ chemical oxidative polymerization technique with ammonium persulphate (APS) as the oxidant [28,29]. Fly ash powder in the weight percentage of (wt%) 10, 20, and 30 was added to freshly prepared reaction mixture (0.2M aniline and 0.25M APS in 1M HCl) at 5°C. The mixture was stirred during the polymerization of aniline for 14 h. The resultant solution was filtered and washed with deionized water and acetone. The recovered composite was dried at 60°C in a hot air oven for 12 h to achieve constant weight. These synthesized PAni composites with various concentration (wt%) of fly ash (PFA10 - PAni with 10 wt% FA; PFA20 - PAni with 20 wt% FA and PFA30 - PAni with 30 wt% FA) were compressed into rectangular pellets under a pressure of 9 tons in a table top hydraulic pellet press. These rectangular pellets of standard Ku- band (WR-62) dimensions of thickness up to 2 mm fit exactly between the Ku-band wave guide adapters of vector network analyzer.

2.3 Characterization

The X-ray diffraction (XRD) patterns were collected using a Bruker (model - AXS D8 Advance, Germany) diffractometer with Cu-Ká radiation (ë = 1.5418AÚ) in the 2 scanning range from 10° to 80° at a step of 0.02°. Scanning electron microscopy JOEL SEM (model 6390LV, Japan) and high resolution transmission electron microscopy (JOEL JEM 2100, Japan) were employed to study the morphological features of the composite samples. The EMI shielding measurements were carried out on pressed rectangular pellets by the waveguide transmission line technique [30,31] in a vector network analyzer (Hewlett Packard-model 8510C; 45 MHz to 26.56 GHz, USA). The vector network analyzer was calibrated for errors due to source matching and load matching before the experiment. The transverse electromagnetic waves in the frequency range from 12 to 18 GHz were made to incident on to the loaded samples. The scattering parameters (S-parameters) correspond to the transmission (S12/S21) and reflection (S11/S22) of the incident electromagnetic waves were measured. These S-parameters were used to analyze the shielding properties in Ku-band microwave spectrum.

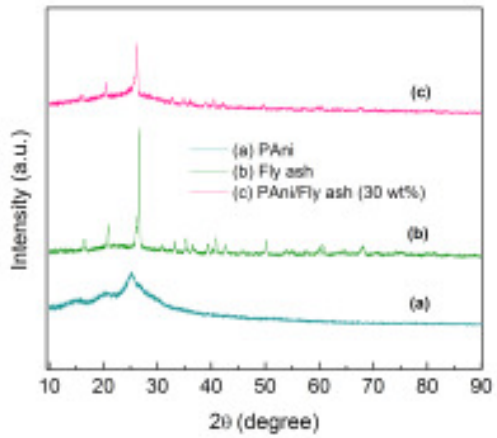
3. Results and discussion

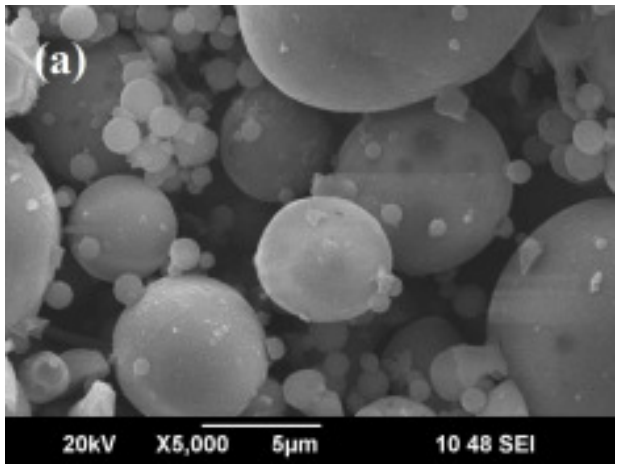
3.1. XRD analysis

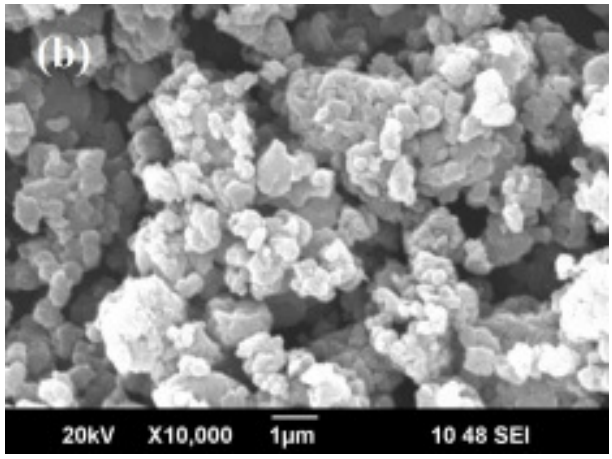
The XRD pattern of PAni, FA and PAni/FA (30 wt%) composite were shown in Fig. 1(a,b and c). In the XRD pattern of pure PAni (shown in Fig. 1(a)), the broad peaks in the region of 2q = 20-30° shows amorphous nature ascribed to the parallel and perpendicular periodicity of the PAni chains. As shown in Fig. 1(b), the XRD pattern of FA exhibited traces of SiO_2, Al_2O_3 and Fe_2O_3 phases [32]. The diffraction peaks for the composite in Fig. 1(c) exhibit the characteristic peaks of FA with reduced intensities of the crystalline peaks. Also, in the composite, the broad amorphous peak intensity of PAni is decreased. These intensity variations of all the peaks for the composite reveal the interaction between PAni backbone chain and FA particles.

3.2 Morphology

As shown in Fig. 2a, the pure FA particles exhibited random population of fly ash particles [33] and were consistent with XRD data. The majority of the particles consisted of solid and irregular spheres, aggregates and agglomerates of particles. From the SEM image of PAni/FA composite shown in Fig. 2(b), it can be seen that the FA particles are enwrapped by PAni coating. Meanwhile, the HRTEM image (Fig. 2(c)) indicates the modified phase boundary of the composite.







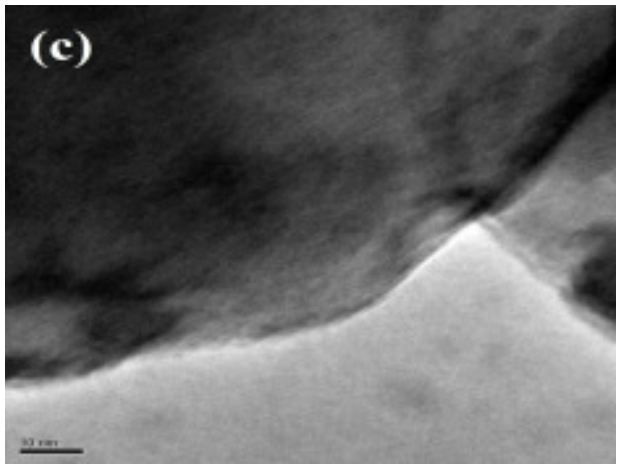


Fig. 2. SEM images of: (a) pure fly ashes, (b) PAni/FA composite (20 wt%); HRTEM image of: (c) PAni/FA composite (20 wt%).

3.3 EMI shielding effectiveness

The EMI shielding effectiveness (SE) of PAni and PAni/FA composites in the Ku-band is shown in Fig. 3. It is observed that the composites had higher shielding effectiveness compared to pure PAni in the entire 12-18 GHz range. Increasing the concentration (wt%) of FA in PAni enhanced the SE and the observed higher value of SE is significant in terms of practical applications in the broad microwave region. For most of the EMI shielding applications a shielding effectiveness of the order of -20 dB (indicates that 99 % of the electromagnetic energy is attenuated by the material) is required [28]. The PAni/FA composites prepared in the present investigation exhibited SE in the range of – 37 to – 34 dB. Here the higher shielding efficiency observed for the composites may be attributed to the higher interfacial area and the porous network provided by the fly ash particles in PAni molecular chains. The action between the magnetic and electric dipoles present in the composites can also contribute the electromagnetic wave attenuation.

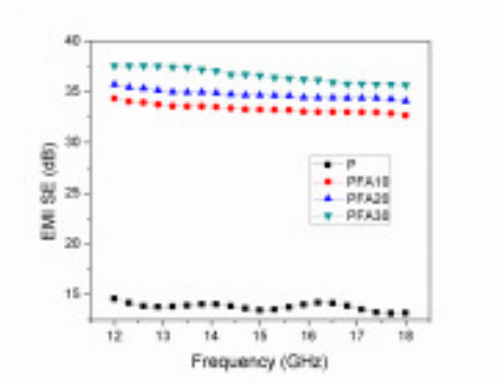


Fig. 3. EMI shielding effectiveness of PAni/FA composites as a function of Ku-band frequency.

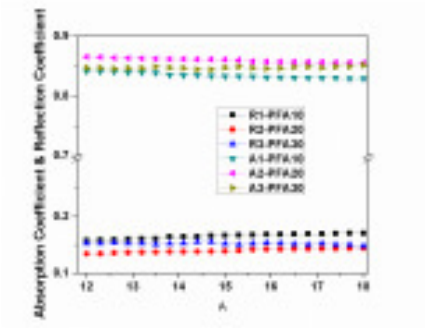


Fig. 4. Shielding contribution in terms of reflection and absorption coefficients.

4. Conclusions

In this paper, EMI shielding properties of synthesized PAni/FA composites in the Ku-band frequency range have been presented. Our results clearly demonstrate that conducting PAni/FA composite show excellent shielding properties. Intrinsically conducting three dimensional inter connected network of conducting PAni acted as an effective matrix for the dispersed phase of fly ash particles. The composite formation resulted in modified phase boundaries through effective morphological change enabled to act as better electromagnetic wave attenuators. The results reveal that the composites have potential applications in broadband EMI shielding and microwave attenuation applications and give light to the scope on fly ash beneficiation for technological application.

Acknowledgements

The authors would like to thank the management of PES University-Electronic City Campus for their support and encouragement towards carrying out this work.

References

1. Faisal Shahzad, Mohamed Alhabeb, Christine B. Hatter, Babak Anasori, Soon Man Hong, Chong Min Koo,Yury Gogotsi. Electromagnetic interference shielding with 2D transition metal carbides. 1,1137-1138(2019)

2. Z. Chen, C. Xu, C. Ma, W. Ren, H. M. Cheng, Adv. Mater. 25, 1296–1300 (2013).

3. D. X. Yan et al., Adv. Funct. Mater. 25, 559–566 (2015).

4. N. Yousefi et al., Adv. Mater. 26, 5480–5487 (2014).

5. Y. Zhang et al., Adv. Mater. 27, 2049–2053 (2015)

6. A. H. Frey, Environ. Health Perspect. 106, 101–103(1998).

7. Muhammad Faisal ,Syed Khasim. Broadband electromagnetic shielding and dielectric propertiesof polyaniline-stannous oxide composites.1,(2013)

8. M.S. Kim, H.K. Kim, S.W. Byun, S.H. Jeong, Y.K. Hong, J.S. Joo, K.T. Song, J.K. Kim, C.J. Lee, J.Y. Lee, Synth. Met. 126, 233 (2002)

9. M.H. Al-Saleh, U. Sundararaj, Carbon 47, 2 (2009)

10. B. Fugetsu, E. Sano, M. Sunada, Y. Sambongi, T. Shibuya, X.Wang, T. Hiraki, Carbon 46, 1256 (2008)

11. S. Celozzi, R. Araneo, G. Lova, Electromagnetic Shielding (John Wiley & Sons, Inc., Hoboken, 2008)

12. K.L. Kaiser, Electromagnetic Shielding (CRC Press, Boca Raton,FL, 2006)

13. C.Y. Huang, J.F. Pai, J. Appl. Polym. Sci. 63, 115 (1997)

14. E.G. Han, E.A. Kim, K.W. Oh, Synth. Met. 123, 469 (2001)

15. A. Das, H.T. Hayvac, M.K. Tiwari, I.S. Bayer, D. Erricolo, M. Constantine, J. Colloid Interface Sci. 353, 311 (2011)

16. Y.L. Yang, M.C. Gupta, K.L. Dudley, R.W. Lawrence, Nano Lett. 5, 2131 (2005)

17. N. Li, Y. Huang, F. Du, X. He, X. Lin, H. Gao, Y. Ma, F. Li, Y. Chen, P.C. Eklund, Nano Lett. 6, 1141 (2006)

18. J.J. Liang, Y. Wang, Y. Huang, Y.F. Ma, Z.F. Liu, F.M. Cai, C. Zhang, H. Gao, Y. Chen, Carbon 47, 922 (2009)

19. Z.F. Liu, G. Bai, Y. Huang, Y.F. Ma, F. Du, F.F. Li, T.Y. Guo, Y. Chen, Carbon 45, 821 (2007)

20. P. Chandrasekhar, K. Naishadham, Synth. Met. 105, 115 (1999)

21. S.K. Dhawan, N. Singh, S. Venkatachalam, Synth. Met. 129, 261 (2002)

22. S.K. Dhawan, K. Singh, A.K. Bakhshi, A. Ohlan, Synth. Met. 159, 2259 (2009)

23. B.R. Kim, H.K. Lee, S.H. Park, H.K. Kim, Thin Solid Films 519, 3492 (2011)

24. S.K. Dhawan, D.C. Trivedi, D. Rodrigues, Sci. Tech. Adv. Mater. 4, 105 (2003)

25. A. Barnes, A. Despotakis, P.V. Wright, T.C.P. Wong, B. Chambers, A.P. Anderson, Electron. Lett. 32, 358 (1996)

26. T. Makela, S. Pienimaa, T. Taka, S. Jussila, H. Isotalo, Synth. Met. 85, 1335 (1997)

27. S. Fauveaux, J.L. Miane, Electromagnetics 23, 617 (2003)

28. M. Faisal, S. Khasim, J.Mater.Sci.: Mater.Electron., 24, 2202-2210 (2013).

29. M. Faisal, S.Khasim, Iranian Polym. J., 22, 473-480 (2013).

30. Sowmya Sankaran, Kalim Deshmukh, M. Basheer Ahamed, Kishor Kumar Sadasivuni, Muhammad Faisal & S. K. Khadheer Pasha, Electrical and Electromagnetic Interference (EMI) shielding properties of hexagonal boron nitride nanoparticles reinforced polyvinylidene fluoride nanocomposite films, Polymer-Plastics Technology and Engineering, (2018) DOI: 10.1080/03602559.2018.1542725

31. Ranjini R. Mohan, Sreekanth J. Varma, Muhammad Faisal, S. Jayalekshmi, "Polyaniline/graphene hybrid film as an effective broadband electromagnetic shield", RSC Advances, 5 (2015), 5917-5923.

32. Prinya Chindaprasirt, Chai Jaturapitakkul, Wichian Chalee, Ubolluk Rattanasak, Characteristics of fly ash, Waste management, (2009), 29, 539-543.

33. Barbara G. Kutchko, Ann G. Kim, Fly ash characterization, Fuel 85,(2006), 2537-2544