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Electric and magnetic field simulation of polymer nano-composites for electromagnetic shielding effectiveness

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This paper discusses correlation between results of electric and magnetic field simulation using Finite Element Method (FEM) and laboratory measurements of electromagnetic shielding effectiveness. The study shows that the addition of the MWCNT filler to HDPE base matrix tends to increase the electrical conductivity and helps in reduction of the Electromagnetic field in terms of radiated emission. With the increase in the weight percentage of MWCNT filler, improvements in terms of reduction in electromagnetic field is achieved. Addition of nano nickel to the HDPE improves the shielding efficiency. The results of this study has helped in achieving the optimum filler concentration in HDPE nano composite for improved EMI Shielding effectiveness

Keywords: *Finite element method, electromagnetic interference, electrical conductivity, nano composites, EMI shielding effectiveness.*

1.0 INTRODUCTION

Electromagnetic Interference (EMI) is a serious problem faced by many electrical and electronic systems. The level of interference determines whether the system is electromagnetically compatible or disturbed or interfered. With increased usage of electronic equipment and gadgets, eco-system is pervaded by man-made electromagnetic radiation whose levels are increasing significantly [1-3]. The EM radiation cause many physiological and psychological effects in humans [4] in addition to affecting the performance of electronic devices in close proximity. This also results in breakdown or malfunctioning of electronic devices and systems thereby reducing their efficiency and reliability [5]. Hence there is a need for protecting electronic devices from incoming electromagnetic radiation to maintain their functionality and to avoid failures, by incorporating filters in electrical circuits or by employing shielded enclosures. In recent years, strict compliance to the electromagnetic compatibility standards has now become mandatory.

Electromagnetic interference is a complex phenomenon and its shielding depends on electric field strength, the type of material used for shielding and its topology. There are many EMI shielding options such as metallic cabinets, conductive coating, foil laminates, polymer composites etc. Conductive coatings and metal coated polymers have their own limitations and disadvantages like difficulty in recycling, delamination etc., while metallic cabinets have limitations due to their weight and corrosion of metals. The foil laminates have limitation in application where strength of material is

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important. To overcome these disadvantages, polymer composites are being widely used all over the world [6]. The increasing demand for handy and portable communication devices like cell phones, laptops, tablets and few applications for aerospace where the weight constraint is given prominence, the polymer composites are observed to be very useful material for application in EMI Shielding.

Worldwide, many research studies involving polymer composites are in progress [7]. Composites are designed by addition of the filler particles in the base polymer matrix. The electrical properties such as conductivity and EMI shielding of these composites depend on the type of filler materials used. The fillers used are typically carbon black, carbon fiber, carbon nanotube etc,. Worldwide research has mainly focused on characterization of carbon based composites as promising EMI Shielding material in which the basic electromagnetic principles and strategies are employed to design efficient EMI shielding materials [8]. It is reported that the electrical properties of the conducting polymer nano composites are closely related to structural property and filler network structure including filler characteristics, shape, size, orientation and dispersion with in the polymer matrix [9-11].

In this study, High Density Polyethylene (HDPE) is considered as the base polymer and Multi Walled Carbon Nano Tube (MWCNT) and Nano nickel are used as filler materials. Using different weight consideration, the fillers were blended with HDPE and sheets were moulded for laboratory measurements.

This paper attempts to correlate the electrical and magnetic properties of polymer composite with and without filler materials using FEM model. With laboratory results for different combinations of composite material, the electrical and magnetic fields was simulated using FEM. A correlation has been established between electric and magnetic field simulations and the laboratory results of electromagnetic shielding effectiveness.

2. 0 FEM MODEL

2.1 FEM modelling for Electric Field

Simulations in this study was performed using a three dimensional (3D) model in which the effect of electric field in polymer composites is determined. The simulation is carried out on a simple parallel plate capacitor model which is shown in Figure 1. The model consists of two copper conductors, each of size 7 cm (width), 0.6cm (thickness) and 7 cm (length). The polymer composite which is to be evaluated for electric and magnetic property is placed between two parallel plates of the capacitor. The simulations were carried out for pure HDPE and HDPE with different weight percentage of MWCNT filler and nano nickel.

2.2 FEM Modelling of Magnetic field

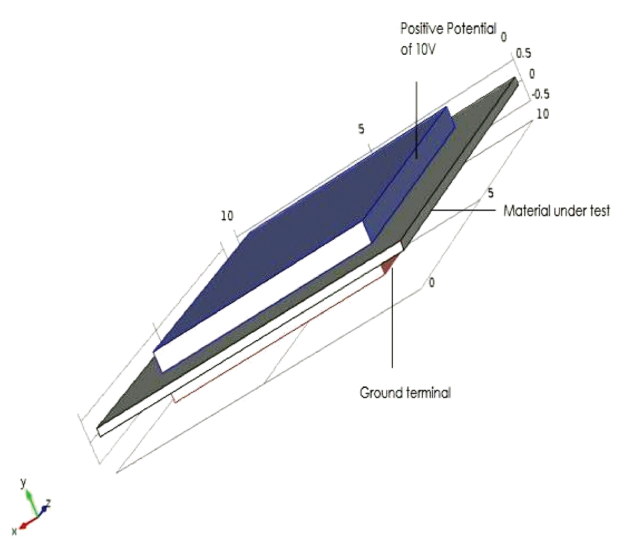

FIG. 1 GEOMETRY USED FOR ELECTRIC FIELD COMPUTATION

In this three dimensional (3D) magnetic field simulation model, simple permanent magnet is used. With the help of Permanent magnet, the magnetic field is generated. The composite is placed below a permanent magnet kept inside an empty box which is placed in air medium.

Length of the limbs of permanent magnet are 2 cm, thickness is 0.5 cm and width is 0.5 cm. The simulations were carried out on pure HDPE and HDPE composite with different filler weight percentages of MWCNT and nano ni

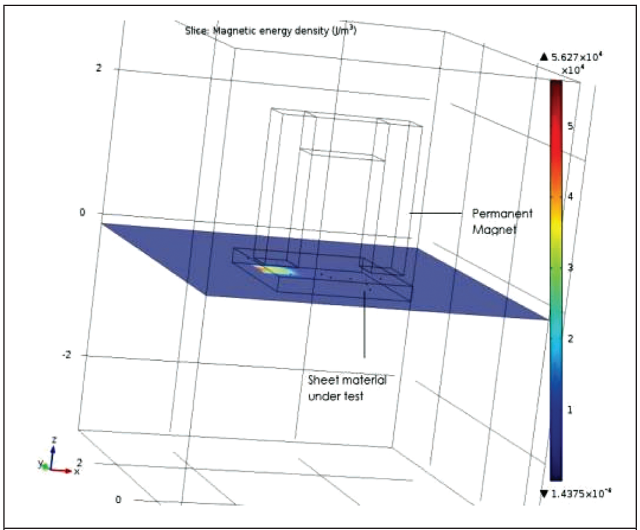

FIG. 2 GEOMETRY USED FOR ELECTRIC FIELD COMPUTATION

2.3 Computation of Electric and Magnetic Field

Electric and Magnetic Field Simulations are based on basic Maxwell's equations. In this 3D Modelling, HDPE samples with different weight percentage of fillers as indicated in Table 1 have been considered.

TABLE 1

DESCRIPTION OF DIFFERENT CASES SELECTED FOR SIMULATION

Sl. No.	Description of material
Case 1	HDPE
Case 2	HDPE + 5wt% MWCNT
Case 3	HDPE + 25wt% MWCNT
Case 4	HDPE + 25 wt% MWCNT + Nano Nickel

The Electric field generated is a function of the electrical conductivity, permittivity and permeability of materials used. In all cases of FEM modelling, boundary conditions used in simulation are V=10 V at the top electrode and V= 0 V at the bottom electrode. Schematic diagram of the model used is shown in Figure 2. For Magnetic field, a magnetization of 750 kA/m was assigned.

3.0 RESULTS AND DISCUSSION

3.1 Electric Field Displacement

Electric field displacement is generally related to the net electric field inside the material. Figure 3 and 4 show the comparison of electric field displacement in pure HDPE and HDPE with 25 Wt% MWCNT. Figure 3 shows the 3D block of a slice taken from zx-plane of the model in the sample material, which is used for computing the electric field displacement. The Electric field displacement in pure HDPE and HDPE with MWCNT filler differ to a large extent. In case of pure HDPE it is 70×10-9 C/m^2 and in HDPE with 25% MWCNT it varies from 10×10-8 C/m^2 to 14×10-8 C/m^2. At a point, away from the electrode, the electric field effect is negligible in both cases. This shows that the filler particles help in reducing the resistivity of the material.

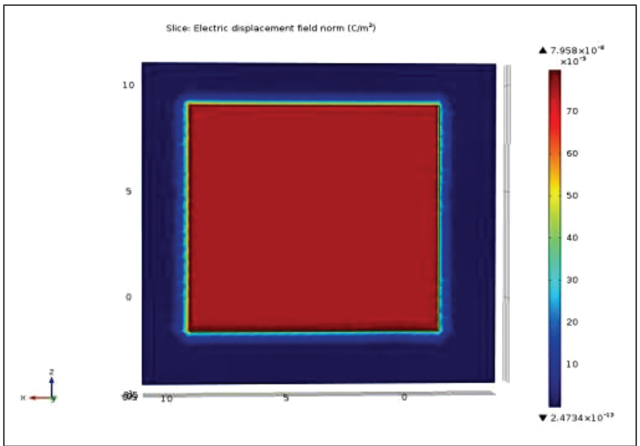

FIG. 3 ELECTRIC FIELD DISPLACEMENT OF PURE HDPE

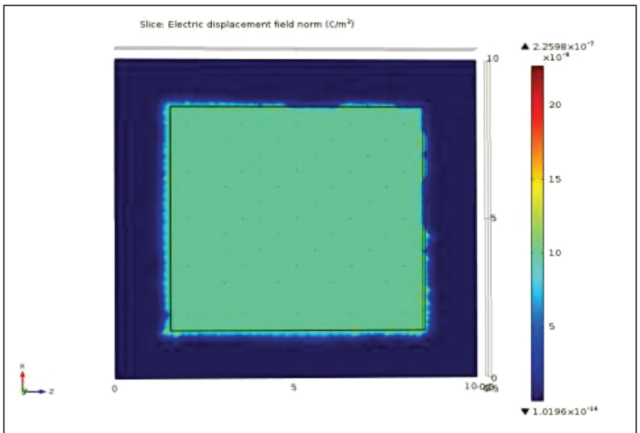

FIG. 4 ELECTRIC FIELD DISPLACEMENT OF 25 WT% MWCNT FILLER

3.2 Electric Field

Electric field values of pure HDPE is observed to be lower than the corresponding value in case of HDPE with 25 wt% MWCNT. The maximum electric field in pure HDPE is observed to be 3200 V/m and it remains constant across the sheet. For HDPE with 25 Wt% of MWCNT, though the highest electric field is 5000 V/m as in pure HDPE, it shows a tendency to drop to around 4000 V/m across the material at the location of filler. Thus the effect of MWCNT is mainly seen in terms of drop in electric field across the material.

In case of HDPE with 25 wt% MWCNT, due to the presence free electrons as compared to pure HDPE flow of charges is possible and this makes the nano composite more conducting.

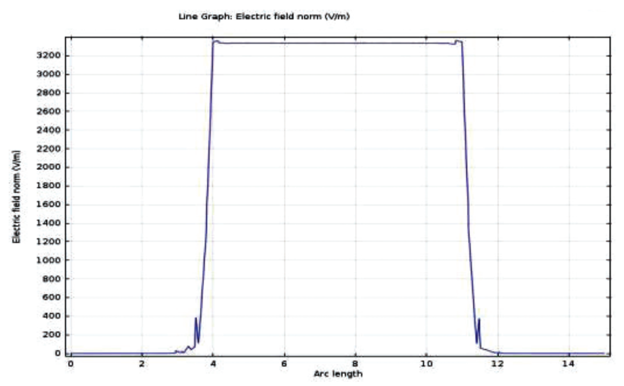

FIG. 5 ELECTRIC FIELD VARIATIONS IN PURE HDPE

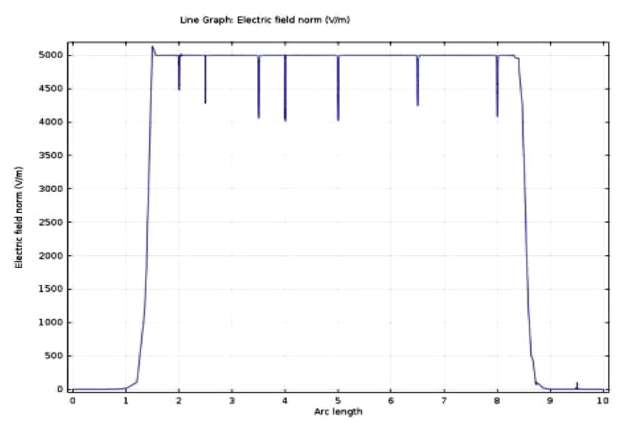

FIG. 6 ELECTRIC FIELD FOR 25WT % OF MWCNT

3.3 Polarization

For a potential of 10 V, the resulting values of polarization in the material are shown in Table 2. The effective polarization in HDPE with MWCNT reduces since dipoles created by displacement are less as compared to that of pure HDPE which is a dielectric. Depending upon the relative permittivity values of the filler material, the value of polarization vary proportionally following the equation

$$P = N\,\alpha_e E \qquad ....(1)$$

Here N = number of molecules per unit

volume, α_e = Electronic polarizability and E = electric field. Here α_e can be related to permittivity by

$$\varepsilon_r = 1 + (N\alpha_e/\varepsilon_o) \qquad ....(2)$$

It is observed that effective polarization decreases with addition of 5wt% of MWCNT to HDPE. However there is relative increase in the polarization due to addition of 25 wt% of MWCNT as compared to the value with 5 Wt% of MWCNT. This is offset to a certain extent by the addition of wt% of nano nickel.

TABLE 2

VALUES OF POLARIZATION

No	Material	Polarization C/m^2
1	Pure HDPE	45×10^{-9}
2	HDPE + 5wt% MWCNT	05×10^{-9}
3	HDPE + 25wt% MWCNT	10×10^{-8}
4	HDPE + 25 wt% MWCNT + 2 wt% Nano Nickel	6×10^{-8}

3.4 Magnetic Field

In Figure 7, 8 and 9, the magnetic field variations in pure HDPE, HDPE +25 wt% MWCNT and HDPE +25 wt% MWCNT + Nano nickel are shown. In pure HDPE, the magnetic field is 1.3×105 A/m and in HDPE composite with 25 wt% MWCNT itis 23000 A/m. Thus the magnetic field across the sheet is reduced very much due to addition of MWCNT. With addition of wt.% of nano nickel to 25 wt% of MWCNT, the magnetic field further reduces to 1500 A/m and varies up to 2000 A/m across the sheet. This signifies the effect of nano nickel filler on the magnetic field property of the composite. Reduction in the magnetic field intensity is a clear indication of the possibilities of better electromagnetic shielding behaviour of the composite.

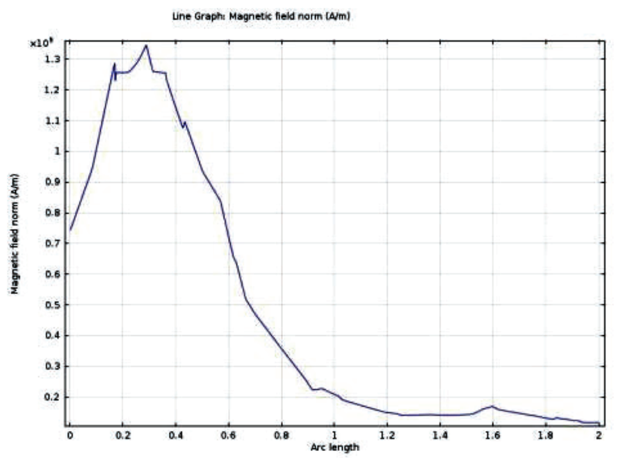

FIG. 7 MAGNETIC FIELD OF PURE HDPE

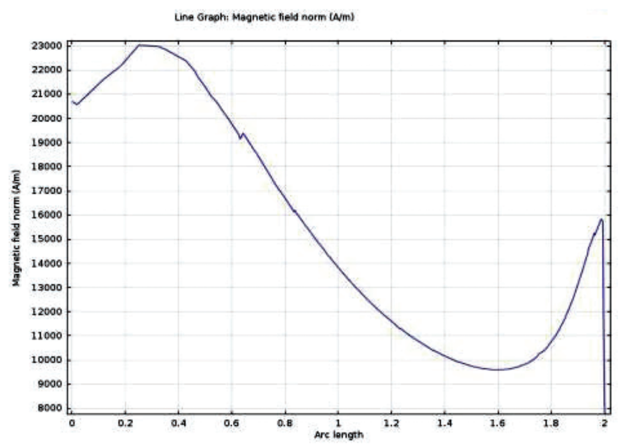

FIG. 8 MAGNETIC FIELD OF 25 WT% OF MWCNT

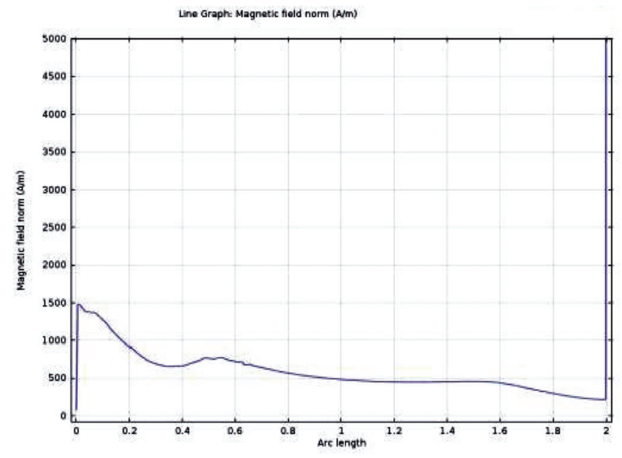

FIG. 9 MAGNETIC FIELD OF 25 WT% OF MWCNT AND 2 WT% NANO NICKEL

3.5 Magnetic Flux density

In Figure 10 and 11, the magnetic flux density variations in case of pure HDPE and HDPE 25 wt% MWCNT + 2 wt% of Nano Nickel are shown. The magnetic flux density of HDPE is observed to be 0.028 T, which shows that the effect of magnet field is low as compared to magnetic flux density. In case of HDPE + wt% of MWCNT, flux density varies from 0.22 T to 0.25 T and with addition of 2Wt% of nano nickel, the magnetic flux density increases to 0.75 T.

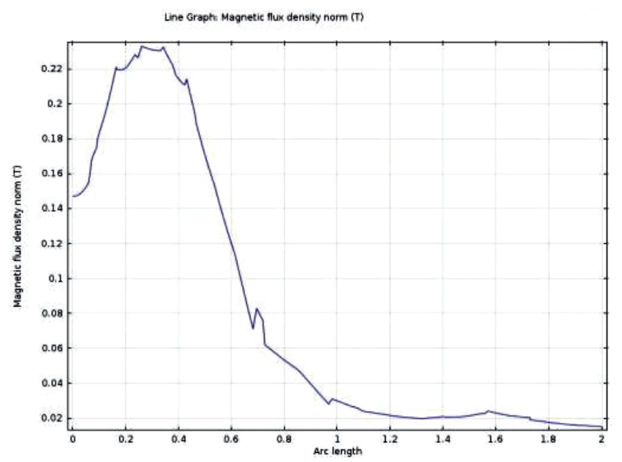

FIG. 10 MAGNETIC FLUXDENSITY OF PURE HDPE

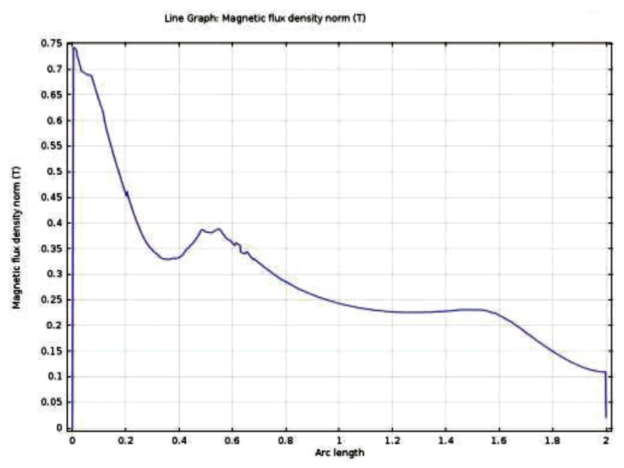

FIG. 11 MAGNETIC FLUX DENSITY OF 25 WT% MWCNT AND 2 WT% OF NANO NICKEL

3.6 EMI Shielding Effectiveness

The results of electromagnetic shielding effectiveness of the HDPE composite are shown in Table 3. It is very clear that HDPE with 25 wt% of MWCNT and 2 wt% of nano nickel gives the best electromagnetic shielding efficiency of 31 dB at 1 GHz and the results of simulation of electric and magnetic field support this experimental result.

TABLE 3

LABORATORY RESULTS OF EMI SHIELDING EFFECTIVENESS AT FREQUENCY OF 1GHZ

Material	EMI Shielding Effectiveness (dB)
Pure HDPE	0.2301
HDPE + 25 Wt% MWCNT	28.42
HDPE + 25 wt% MWCNT+ nano nickel	31.25

4.0 CONCLUSION

Electric and magnetic field simulation of pure HDPE and HDPE – MWCNT and HDPE-MWCNT-nano nickel polymer nano-composites has been carried out and the results are compared with the experimental results of EMI shielding efficiency. From this investigations, the following important conclusions are drawn:

1. The electric field and conductivity increase with the addition of MWCNT to HDPE.
2. Electrical polarization of material is reduced with the increase in the MWCNT filler loading and this implies that permittivity of the composite is influenced by fillers.
3. Magnetic property does not show significant improvement with MWCNT alone and hence nano nickel is added to improve magnetic properties.
4. A correlation between results of simulation of electric and magnetic fields and the laboratory results of EMI Shielding effectiveness has been established.
5. The good correlation between electric/ magnetic simulation and experimental results of EMI effectiveness would help in avoiding large processing of materials during development of nano composite for this application.
6. Addition of MWCNT improves electrostatic shielding while addition of nickel improves electromagnetic shielding. Hence, depending on requirements of end application, suitable filler or filler combination can help in improving the requirements of the shielding effectiveness.
7. Based on the simulation and laboratory measurements, HDPE + 25 wt% MWCNT + wt.% of nano nickel is observed to be the optimum combination for EMI Shielding effectiveness of 31.25 dB at 1 GHz.

Though the mechanical properties are not discussed in this paper, the suggested nano composite material is observed to possess good mechanical properties as well.

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