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ELECTROMAGNETIC SHIELDING EFFECTIVENESS OF ALUMINIUM EPOXY COMPOSITE PLATES IN S AND X BAND

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ABSTRACT

In today's modern world, humans are more exposed to Electromagnetic (EM) waves from various sources. So an effective shielding from the harmful effects of EM waves is required. A shielding material is one which is conducts the EM waves and thereby not allowing it to interfere with humans and instruments which require high precision. As EM radiations are hazardous to environment, studies have been carried out to develop an effective electromagnetic shielding material. The present work concentrates on developing an EM shielding materials through aluminium epoxy particulate composites. The specimens are tested in the X band (8 GHz to 10 GHz) and S band (2 to 4 GHz) in EM spectrum. The results are compared for EM shielding effectiveness of aluminium particulates composites of various micro structures using Taguchi methods. The experimental results show that shielding effectiveness of plain polymer is improved by reinforcing it with aluminium particles.

Key words: *Electromagnetic Shielding, Aluminum Particulate Composites and Taguchi methods.*

1. Introduction

Portable electronic devices (PEDs) [1] are widespread in present market. They provide challenging performance combined with highly cosmetic housings. They are expected to be lightweight and cost effective. Miniaturization of these devices creates scores of shielding challenges, as high-frequency components become more closely spaced. As printed-circuit boards (PCB) shrink, new electromagnetic-interference (EMI) occurs. So shielding solutions must provide greater levels of interference suppression and at the same time, without significantly adding mass, weight, and cost to a device. Shields designed for portable devices must also meet demanding mechanical and electrical requirement.

Miuta Rau et al., have found that amorphous magnetic materials can be used to shield from EM field within the ultra-high frequency range. [2]. Conducting composites are used in present days for controlling electromagnetic interference (EMI) and electrostatic charge dissipation (ESD). They contain conductive fillers such as metal fibres and metal powders. Werner Graf and Edward F .Vance have done EM shielding measurements with the shield inserted between two antennas. They found that properties of the antennas and receivers, along with the insertion losses of the shield affect the shielding [3].

A shielding effectiveness (SE) of 4 to 58 dB was shown by conducting polyaniline composites in the frequency range of 101 GHz in experimental conditions [4]. Conducting polymers made from silicon rubber showed a SE of 16-20 dB in the frequency range of 3 to 1500 MHz [5]. Nickel-P-La alloy coating shows a SE in the range of 45 dB to 70 dB in the frequency range from 10 MHz to 350 MHz[6] Though electrically conducting polymers are becoming increasingly available, they are not common and tend to be poor in the process ability and mechanical properties.

Metals were typically been used as the material of choice for shielding applications. But they have heavy weight, corrosion, poor process ability and expensive. To overcome some of the limitations of conducting polymers and metals, composites made from thermosetting plastics are taken as shielding materials, in present work. Zuoyong Dou et al., found that by using the fly ash particles, the shielding effectiveness properties of the matrix aluminum could be improved in the frequency ranges 30.0 kHz–600.0 MHz and the increment varied with increasing frequency [7].In present study frequency range in X band and S band in radio frequency and micro oven range is selected which shows similar result of improvement in shielding with addition of conducting materials. From the detailed literature survey we found that an effective shielding material for protecting humans and precision instruments from electromagnetic waves is required and present study focuses on developing an effective shielding material.

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2. Materials & Process

Table 1 shows the properties of the matrix polymer and hardener supplied by ATUL India Ltd, which are used in present study. Lapox L12 resin, a thermosetting plastic used as matrix materials get hardened with the help of hardener K6 in room temperature. To make the composites conducting, aluminium particles of various sizes are used as reinforcement.

Table 1: Properties of Epoxy and Hardener

Constituent	Trade name	Chemical name	Density (gm/cm^3)
Resin	LAPOX L12	Diglycidyl Ether bisphenol (DGEBA)	1120
Hardener	K-6	Tryethylel tetramine (TETA)	954

2.1 Aluminium Particles

Aluminium powder used in the present study is taken in three different sizes viz 5, 20 and 36 microns .Their scanning electron microscope (SEM) are shown in Fig 1.1 (a), 1.1 (b) and 1.1(c).

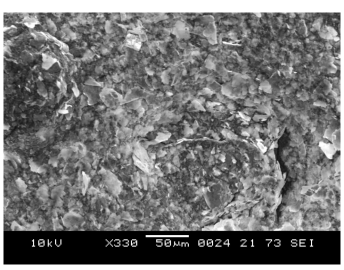

Fig 1.1(a) Fine Size Particle (5 micron)

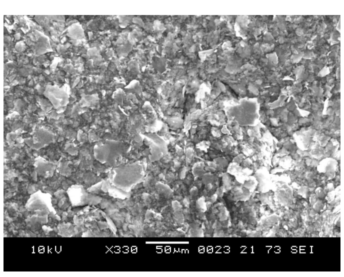

Fig 1.1(b) Medium Size Particle (20 micron)

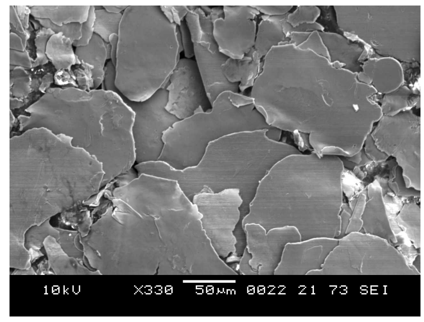

Fig 1.1(c) Coarse Size Particle (36 micron)

3. Processing of Composites

Mold for round specimen is made from polyvinylchloride stops. They are fixed to a base plate temporarily using wax. Specimens are made by mixing calculated amount of epoxy resin with 10 % of hardener. Then weighted quantity of aluminium powder of specified size is poured in to the mixture till it becomes jelly state. They are mixed properly for uniform distribution of aluminium particles and then poured in the mould. Silicon releasing agents are applied to mould before poring the composite mixture. The round specimen formed is kept in mould for 24 hours for proper solidification. Once it's solidified, it's taken out from the mould and kept in the oven for two hours at 80 degree centigrade to remove the vapors. Similarly specimens of various thicknesses (1mm, 2mm and 3mm) with different volume fractions (5%, 10% and 15 %) are made.

4. Experiment Plan

Main factors affecting the shielding effectiveness are taken as frequency of the EM source, distance of the shielding material from the source, thickness of the specimen and volume fraction of aluminium particles in the composites. These parameters are studied each in the three levels for S band and X band of microwaves. Minitab R14 is used to get analysis of variance (ANOVA) tables for drawing various graphs. Main effect graphs are plotted to optimize the process parameters.

Table 2 and 3 shows parameters used for testing in X and S band. The L9 orthogonal array obtained by Taguchi method, used for testing shielding effectiveness in X band and S band respectively [9]. Since distance is not affecting SE in S band, only three factors are taken in experiments.

Table 2: Parameters for X Band Testing

Sl No	Parameters	Levels		
1	Frequency (GHz)	2.78	2.85	2.94
2	Volume Fraction (%)	5	10	15
3	Thickness (mm)	1	2	3

In present study, 9 specimens each of fine, medium and coarse grain size are used, so that a total of 27 specimens are tested in S band and X band. Since L 9 series will give the trend of shielding effectiveness, orthogonal L9 series is selected for each specimen testing. For each specimen three readings, one at left end, second at right end and third at the centre of specimen are measured and average values in each case is calculated.

Table.3 Parameters for S band Testing

Sl No	Parameters	Levels		
1	Distance (mm)	220	440	660
2	Frequency (GHz)	9	9.3	9.5
3	Volume Fraction (%)	5	10	15
4	Thickness (mm)	1	2	3

5. Testing Methods

SE is calculated based on EM wave voltage levels as follows.

$SE = 20 \log_{10} (V_2/V_1)$ ……. (1) [8]

where:

V_1 and V_2 are voltage levels with and without shield respectively at the receiver output in volt.

5.1 Testing for X band

The test set up consists of an EM source and an EM sensor between which the composite plate under consideration is introduced as obstacle. The experimental setup is arranged in accordance with ASTMD4953 [10].The experiment is setup in a relatively reflection free surrounding. The gun diode is powered with a voltage of about 9V power supply. The modulation switch is set to produce square wave. Modulation BNC output is connected to the modulator in the setup. The detector is connected to the rotary joint and the Gunn oscillator is tuned up at 9.0 GHz to get a wave with maximum field intensity on the Digital Storage Oscilloscope (DSO) connected to the detector. Also the Gunn voltage is adjusted to around 9V to obtain wave of maximum amplitude in the DSO. Frequency meter if used can be detuned by at least 150 MHz. The horn antenna is placed on the rotary joint and the detector is connected to the horn antenna on the stand. The antenna on the rotary joint scale is aligned to read 90 degrees.

The parabolic antenna is placed on the stand at a distance of at least 880 millimeters from the horn antenna. The parabolic antenna is aligned on the stand in height and direction so that it indicates maximum field intensity on the DSO when the antennas are perfectly in line with the horn antenna. The attenuator is set at 12 dB which will be taken as reference for all the readings. The DSO is switched on. The readings are noted on the display in mV and are set as reference. Composites specimens of different thickness are placed at different distance from the horn antenna. Also attenuations for plain metal and epoxy are measured. The attenuation is the difference between the initial reading on the DSO and the final reading on the DSO after placing the material. Tests are conducted for three different frequencies (9.0 GHz, 9.3GHz, and 9.5GHZ) in the manner described above and attenuations corresponding to different levels of factors are tabulated.

5.2 Testing for S band

The experiment is conducted in accordance with ASTMD4935 [10].The helical antenna is mounted on one stand. This may be chosen as the transmitting antenna. The second helical antenna from the kit is mounted on another stand and this is chosen as the receiving antenna. Power is switched on. The frequency is set at 2.8GHz (2.75GHz and 2.95GHz) on the microwave signal source connected to the transmitting antenna. The receiving antenna is kept at a distance of about 200 millimeters from the transmitting antenna. The two antennas are aligned such that they face each other. When properly aligned, the DSO connected to the receiving antenna, will show maximum reading [Pk-Pk] (mV). This reading on the DSO is taken as the reference. Now polymers and the composites are placed in between the two antennas using the specimen holder at different frequencies. The reading on the DSO is noted. Using eq. (1) SE offered by that material is calculated. The experiment is repeated for one-side roughened polymers facing the transmitting antenna and both-side roughened polymers. Readings are tabulated. The results are plotted. The loss of energy in EM wave passing through the test material is measured as attenuation. The attenuation values are tabulated and used for analysis of EM shielding.

6. Results and Discussion

6.1 X-Band Testing (Main effect plots)

Testing of particulate composites at X band of microwave frequency range is done. The experimental data and its analysis are presented in modular fashion.

Data obtained from the experiments are analyzed using statistical technique Analysis of variance (ANOVA). In all cases the response of the experiment is related to the input changes namely frequency of the microwaves, thickness of the shield material, distance of the shield material from the transmitting antenna and volume fraction of composites.

Maximum SE of 0.55 dB is obtained at a distance of 440 mm, 9.5MHz, 5% volume fraction and 1 mm thickness in the case of fine aluminium composites as shown in fig 2.

Maximum SE of 0.45 dB is obtained at a distance of 220 mm, 9.5MHz, 5% voulme fraction and 3 mm thickness in the case of medium aluminium composites as shown in Fig 3.

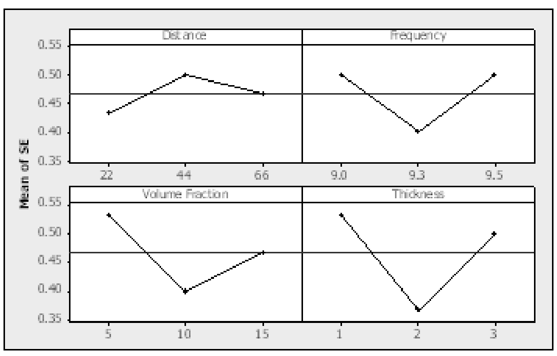

Fig. 2 Fine Aluminium Composites

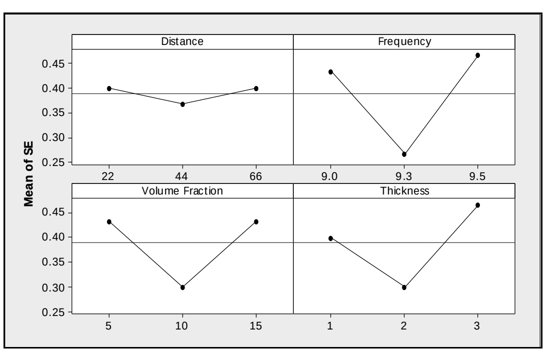

Fig. 3 Medium Aluminium Composites

Maximum SE of 0.45 dB is obtained at a distance of 440 mm, 9.5Hz, 5% volume fraction and 1 mm thickness in the case of coarse aluminium composites

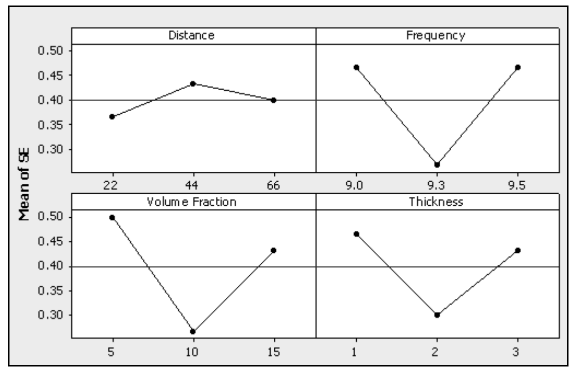

Fig. 4 Coarse Aluminium Composites

From the main effects plots, frequency seemed to be more influencing than other factors of as higher SE increases with respect to frequency. Graph shows that there is an increase in through-transmission of EM waves with respect to increase in thickness. This could be due to increased interaction of matter with EM wave for a thicker specimen.

6.2 S Band Testing Results (Main effect plots)

From the graph it can be observed that at S Band bears less significant effect on SE of the material. Maximum SE is obtained at frequency of 2.94 MHz, 5% volume fraction and 1 mm thickness in the case of fine aluminium composites as represented in Fig 5.

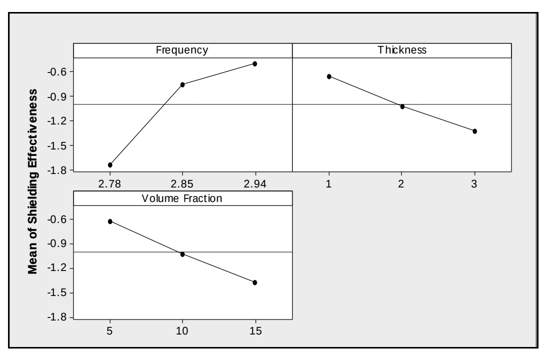

Fig. 5 Fine Aluminium Composites

Maximum SE is obtained at frequency of 2.94 MHz, 10% volume fraction and 1 mm thickness in the case of medium aluminium composites as represented in Fig 6.

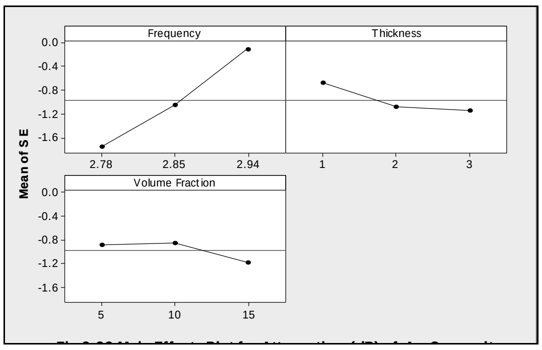

Fig. 6 Medium Aluminium Composites

Maximum SE is obtained at frequency of 2.94 MHz, 5% volume fraction and 1 mm thickness in the case of coarse aluminium composites as represented in Fig 7.

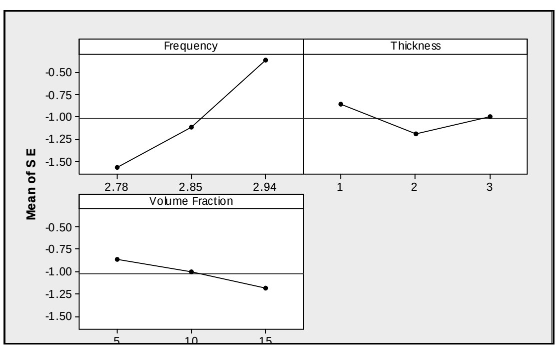

Fig. 7 Coarse Aluminium Composites

The SE in S band is negative in most of the cases. This is because the specimen behaves like a convex lens and increases the intensity of EM waves at the receiver side.

6.3 Comparison of S band and X band responses

Fig 8 shows that as the thickness of the composite materials varies SE is decreases with increase in thickness in S band. This may be contributed the presence of voids present in the composite materials.

Where

Af- fine aluminium particle
Am- medium aluminium particle
Ab- coarse aluminium particle

SE is improved in the case of X band which shows the thickness variation is not affecting SE in X band range as shown in Fig.9

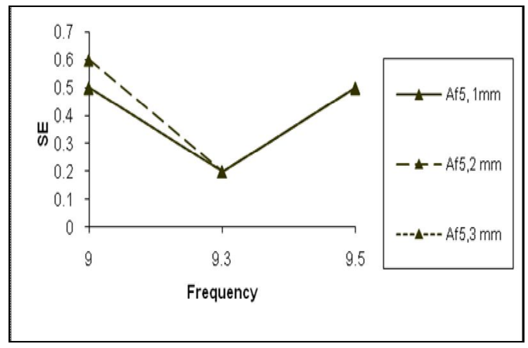

Fig. 9 SE in X Band with Thickness Variation

Fine particle composites of aluminium are showing better SE materials than coarse particulate composite in X band and S band as shown in Fig 10 and Fig 11. This may be due to the better conductivity, as low particle size aluminum particles get aligned uniformly to produce a network of conducting line.

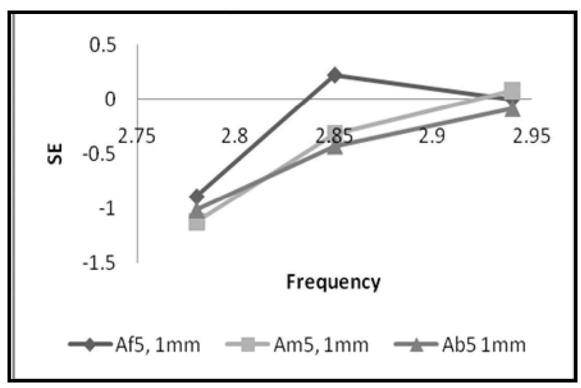

Fig. 10 SE with Particle Size Variation in S Band

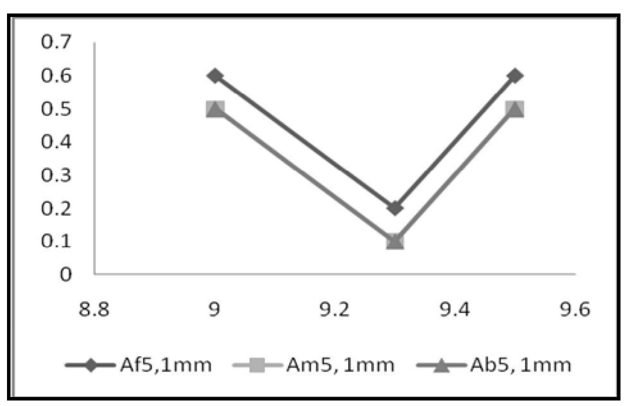

Fig. 11 SE with Particle Size Variation in X Band

7. Conclusions

In the present work, study of the electromagnetic performance of aluminium particulate composites at S band and X band of microwave frequency range is conducted. EM shielding effectiveness was evaluated in order to analyze the possibility of its usage in shielding elements. Experiments are carried out according to Taguchi's efficient experimental design methods and response data is analyzed with ANOVA technique with the help of commercial software MINITAB 14.The SE in S band is negative in most of the cases. This is because the specimen behaves like a convex lens and increases the intensity of EM waves at the receiver side. In X band a better shielding is shown by the composite materials as the conductivity of plain epoxy polymer is improved with the presence of aluminium particles as epoxy being insulator is a poor conductor of electricity

It is observed that fine particle composites of aluminium are showing better SE materials than medium and course particulate composite. SE of fine particle composites of aluminium having 5 % volume fraction and 1 mm thickness in S band at a frequency of 2.85 GHz is is found to be 83.3 % more than that of medium and coarse aluminium composites. Percentage of shielding of fine particle composites of aluminium in X band is 16.7 % more than that of medium and coarse aluminium composites. So from this it is concluded that at low particle size aluminum particles get aligned uniformly to produce a network of conducting line under manual mixing process , there by supporting SE as shown SEM photographs in Fig 1. At higher thicknesses, network formation is not promoted. As voids get increased from 2% for 1mm thickness , 8 % for 2 mm thickness and 14 % for 3 mm thickness, creating air gaps which is a manufacturing defect, which reduces the conductivity. Hence these composites have displayed no effectiveness but on contrary have encouraged more transmission of the EM energy. Volume fractions for these composites at larger particles sizes is found to be affecting SE to a larger extend in aluminium epoxy particulate composite in S band. As SE value is not much of significance, particulate composites are less preferred for S band range.

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