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Optimization of electromagnetic shielding tester process parameters for conductive textile composite materials through Taguchi design and ANOVA

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ABSTRACT

In this research, optimization of electromagnetic shielding tester process parameters for conducting textile composite materials through Taguchi design and ANOVA has been reported. The electromagnetic shielding tester process parameters were selected to optimize the EMSE. The effect of the size of the test Conductive Textile Material Composite sample on EMSE, effect of distance between Conductive Textile Material Composite sample and transmitting antenna on EMSE, effect of distance between the Conductive Textile Material Composite sample and receiving antenna on EMSE, and effect of RH% on EMSE were analyzed and optimized by Taguchi design and ANOVA. It was observed that the electromagnetic shielding effectiveness of conductive textile Composite materials were dominantly influenced by Conductive Textile Material Composite sample size and significantly influenced by distance between Conductive Textile Material Composite sample and transmitting antenna.

Introduction

Electromagnetic interference (EMI) shielding is critical to the proper functioning of device[1-2]. Any electrical and electronic equipment that has changing voltages and currents can be viewed as a source of EMI. It can be reach the victim equipment either by conduction or by electromagnetic radiation, or by both, and induce undesirable voltage and current in it. The EMI phenomena can be viewed as a kind of environmental pollution of electromagnetic spectrum. The spectrum is a natural resource being progressively used for a wide range of broadcasting and wireless communication purposes. The effect of EMI on products may lead to far reaching consequences depending upon their application and the working environment. EMC engineering is concerned with identifying, quantifying and controlling the unexpected transfer of electromagnetic energy from equipment to equipment such that they can perform the intended functions in the common electromagnetic environment without affecting each other. EMC is achieved by suppressing the interference at the source, by improving the immunity threshold of the victim and modifying the coupling paths. Shielding effectiveness is a key parameter which often determines the scope for application of a given material. The shielding effectiveness for metal shields can be determined by knowing the materials' electrical and magnetic parameters, whereas the materials containing inter-twined metallic or graphite threads, plastic materials having metallised surfaces or composite materials, the shielding effectiveness can be determined by actual measuring[3-8]. There are several methods available which allow the shielding effectiveness to be measured [9-20]. However, for flat shielding structures, there are currently no standards defining the evaluation of small samples.

The shielding effectiveness measurement results obtained using currently known methods depend not only on the properties/parameters of the shielding material but also on the size of the test sample, the geometry of the test setup, and the parameters of the source of electromagnetic radiation [21-28]. At the current state of research and development, it is not always possible to take all of these additional factors into account. It should also be noted that there is currently no effective method for comparing the results of shielding effectiveness measurement obtained based on MIL-STD 285 and IEEE-STD-299 for comparison with ASTM D4935.

There is also a lack of generally accepted standardized method for measuring shielding effectiveness of conductive Textile Composite materials[29-31]. One standard method for measuring the shielding Performance of a material is ASTM D4935[2]. According to this method, an approximately 5¼" (13.3 cm) disk is placed in a specially designed, enlarged coaxial transmission line, which is configured between a signal generator and receiver. The shielding effectiveness is calculated as the change in received power of the sample vs. the reference.

The ASTM D4935[2] method, however, has numerous disadvantages with regard to measuring EMI shielding performance for small device applications. First, the valid frequency range of the test typically does not exceed 1 GHz, whereas the range of interest for small devices is often, if not usually, higher.

In addition, the geometry of the specimen is dissimilar to that found in small devices. Furthermore, the test evaluates substrates with no regard for how they terminate. Finally, experience indicates that the test does not adequately discriminate shielding materials in term of their actual relative performance in small device applications. Shielding effectiveness can also be measured using a shielding chamber similar to that described in MIL STD 285 [32]. Transmitting and receiving antennae are placed on opposite sides of a wall of the chamber. The test sample is placed in a custom fixture which rests in a "window" in the wall. Shielding effectiveness is

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measured as the difference in attenuation with and without the sample in place [33-38].

The shielding chamber method is generally considered a better test in comparison to the ASTM. Unlike the ASTM method, this test can be used to measure at significantly higher frequencies, evaluate an entire shielding system including its termination, and test virtually any shaped sample part as long as one produces an appropriate fixture. On the other hand, the chamber technique has several disadvantages with respect to small device applications. The test is intended for and exhibits the most reliable data for large sized panels and high length gaskets. Data for small samples is difficult to measure accurately. This is deepened by the fact that the method is both highly labor intensive and highly capital intensive [29-31].

The objects with the greatest shielding effectiveness (SE), the measured attenuation of the interfering electromagnetic waves, were metallic plates. But today, after many advancements in the development of plating technology have occurred, metal scan now be plated onto thin cloths. The demand is increasing for electromagnetic shielding cloths which cover the electronic devices and which are light and strong [39-44].For attenuating an interfering wave, we have to attenuate 30 dB or more using shielding materials[45-52]. For attenuation we usually use thick materials, but for many applications the use of thick materials is unrealistics.

Based on the literature review, it is clear that at the current state of research development there is no measurement method which would singularly define the shielding effectiveness parameters of screening fabrics/textiles. The shielding effectiveness measurement results obtained using currently known methods depend not only on the properties/parameters of the shielding material, but also on the size of the test sample, the geometry of the test setup, and the parameters of the source of electromagnetic radiation. At the current state of research development, it is not always possible to take all of these additional factors into account. Considering this, in this research, the effect of the size of the test sample, the geometry of the test setup, and the parameters of the source of electromagnetic radiation were analyzed and optimized by Taguchi design and ANOVA

Experimental Procedure

In this investigation, in order to optimize the size of the test sample, distance between sample and transmitting antenna, distance between the sample and receiving antenna and RH%, the Taguchi design method and ANOVA were selected and applied for electromagnetic shielding effectiveness performance characteristic of conductive Textile Composite materials. Taguchi design method replicates each experiment with the aid of an outer array that deliberately include the sources of variation that a product would come across while in service. Such a design is called a minimum sensitivity design or a robust design and the Robust Design method is called Taguchi method. To achieve the optimum design factor setting, Taguchi advocated a combination of two stage process in which the first step is related to the selection of robustness seeking factors and the second step with the selection of adjustment factors to achieve the desired target performance. The various stages in the experimental design have been dealt by many authors in the past. In other experimental designs, noise factors are kept under observation during experimentation, whereas Taguchi methods include those factors in the experimentation to make the design a robust one in the form of S/ N ratios. In robust design, one minimizes sensitivity to noise by seeking combinations of DP settings. The most appropriate S/N ratio can be selected depending upon the properties of interest (Table 1), for both scaling factors and adjusting factors. The experiments using the listed variables at different levels (Table 2 and 3) were carried out randomly to avoid the systematic errors. The selection of appropriate orthogonal array (OA) is a critical step in Taguchi's experimental design. Four design parameters at three different levels were selected for optimization purpose in this study. The control factors are sample size (m), distance between sample and transmitting antenna (cm), distance between sample and receiving antenna (cm) and RH .Temperature and frequency were considered as the two different noise factors because they influence the electro magnetic shielding effectiveness individually to significant extent. which are shown in Table 2 and 3 The OA selected should satisfy the following criterion: Degrees of freedom (DOF) of OA $\geq$ Total DOF required .Therefore, L_9 Taguchi orthogonal array and 3 levels were selected to assign various columns. The experiments were conducted according to the trial conditions specified in L_9 OA. A total of 36 experiments (three repetitions at each trial condition) were conducted. Using Taguchi's analysis and analysis of variance (ANOVA), the optimal performance parameters were determined and the optimal values were predicted. The average values of performance characteristics at each level and against each parameter were calculated and are given in Table 3.

Results and Discussion

The electromagnetic shielding effectiveness of Conductive Textile Composite material is influenced by various important factors of shielding tester. Effect of Conductive Textile Composite material sample size, effect of distance between Conductive Textile Composite material sample and transmitting antenna, effect of distance between Conductive Textile Composite material sample and receiving antenna, effect of RH%, antenna mismatch, antenna calibration uncertainty, antenna cables and antenna polarization are various parameters to influence the electromagnetic shielding effectiveness. but the effect of Conductive Textile Composite material sample size, effect of distance between Conductive Textile Composite material sample and transmitting antenna , effect of distance between Conductive Textile Composite material sample and receiving antenna, and effect of RH% are most important factors to directly influence the electromagnetic shielding effectiveness

Effect of Conductive Textile Composite material Sample Size on EMSE

The Shielding effectiveness measurement results obtained using this methods depend not only on the properties / parameters of the shielding materials but also on the size of the test samples, the geometry of the test set-up and the parameters of the source of electro magnetic radiation. In order to analyse the effect of sample size on electro magnetic shielding effectiveness during the measurement, the three Conductive Textile Composite material samples size (0.3 x 0.3, 0.5 x 0.5 and 1.0 x 1.0m) are considered. The Figure 1 shows the effect of various control factors on signal to noise of Conductive Textile Composite material sample size, distance between the transmitted antenna to Conductive Textile Composite material sample size, distance between the Conductive Textile Composite material sample to receiving antenna and RH%. Design factors used in the experiments appeared to exercise strong influence over electromagnetic Shielding effectiveness of conductive

Textile Composite materials in all the measurements. Signal to noise ratio, larger-the-better, showed the highest value for the sample measured with the highest Conductive Textile Composite material sample size and distance between Conductive Textile Composite material sample and transmitting antenna It can be also observed that the Conductive Textile Composite material sample size 1.0 x 1.0m have good electro magnetic shielding result than 0.3 x 0.3 and 0.5 x 0.5m Conductive Textile Composite material sample sizes. Similarly the ANOVA carried out for electro magnetic shielding effectiveness of fabric showed the dominant effect of Conductive Textile Composite material sample size and distance between Conductive Textile Composite material sample to transmitted antenna compared to distance between the Conductive Textile Composite material sample and receiving antenna and RH% in determining the electro magnetic shielding effectiveness of the fabric samples during measurements. However, all the design parameters appeared to influence the Electromagnetic shielding effectiveness shown by analysis of variance in terms of factor effects and F-values (Table 4).

Effect of Distance between Conductive Textile Composite Sample and Transmitting Antenna on EMSE

The distance between the Conductive Textile Composite samples and transmitting antenna, also influences the electromagnetic shielding effectiveness of conductive materials. In order to study the effect of distance between the Conductive Textile Composite sample and transmitting antenna, three distances (100 cm, 150cm and 200cm) are considered for optimization of distance between transmitted antenna and Conductive Textile Composite samples at same frequency with same antenna diameters. The Figure1 shows that the distance between transmitting antenna and Conductive Textile Composite Conductive Textile Composite sample has significant effects on electromagnetic shielding effectiveness of conductive material. It can be observed that maximum electromagnetic shielding effectiveness can be obtained in the distance of 150 cm between transmitting antenna and Conductive Textile Composite samples than other two distances. The ANOVA carried out for electromagnetic shielding effectiveness of fabric showed the significant effect on distance between Conductive Textile Composite samples to transmitted antenna (Table 4). It is also observed that as the diameter of the antenna and frequency increases, the distance between Conductive Textile Composite samples and transmitting antenna also increase.

Effect of Distance between the Conductive Textile Composite Sample and Receiving Antenna on EMSE

Distance between Conductive Textile Composite sample and receiving antenna also influences the electromagnetic shielding effectiveness of the conducting materials. in order to study effect of the distance between Conductive Textile Composite sample and receiving antenna, three distances (10cm, 50cm and 20cm) are considered for optimization of distance between the Conductive Textile Composite sample and receiving antenna, measured at same frequency with same antenna diameters. The Figure1 shows that the distance between the Conductive Textile Composite sample and receiving antenna has little effects on electro magnetic shielding effectiveness of conducting materials. It can be observed that the maximum electromagnetic shielding effectiveness can be obtained in the distance of 20 cm between the Conductive Textile Composite sample and receiving antenna than the other two distances. The ANOVA carried out for electromagnetic shielding effectiveness of fabric showed the neutral/ negligible effect on distance between Conductive Textile Composite samples to receiving antenna (Table 4).

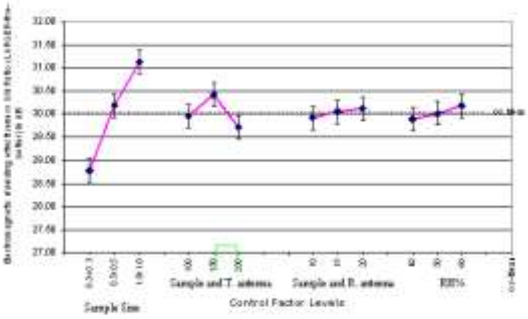

Figure 1 Effect of process parameters on EMSE of the fabric

Effect of RH% on EMSE

To study the effect of RH % on Electro Magnetic shielding Effectiveness, copper core yarn fabrics are considered. It was observed that RH% has a little influence on Electro Magnetic shielding Effectiveness of Conductive Textile Composite Materials. Figure 1 shows the Effect of RH% of Conductive Textile Composite Materials with an increase in RH%, a general increase in shielding effectiveness of Conductive Textile Composite Materials sample. It may be due to the water vapour and oxygen in the atmosphere. The specific attenuation is strongly dependent on frequency and temperature of the atmosphere.

The RH% attenuation increases with frequency and becomes a major contributor in the frequency band. The rayleigh scattering occurs when particles are very small compared to the wave length. Electro Magnetic waves are absorbed in the atmosphere according to wave length. The two compound of oxygen (O_2) and water vapor are responsible for the majority of signal absorption. These could be particle such as small specks of dust (or) nitrogen and oxygen molecules. Mie scattering occurs when the particle are just about the same size as the wave length of the radiations. The water vapour is common cause of mie scattering which tend to affect longer wave length than those affected by rayleigh scattering. Absorption is the other main mechanism at work due to which electro magnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomena causes molecules in the atmosphere to absorb energy at various wave lengths. Water vapour in the atmosphere absorbs much of the incoming long wave infrared and short wave variations (between 22mm and 1mm). Water vapour has a permanent dipole moment, and so a strong pure rotations spectrum beginning at about 25µm and extending with greater and greater absorptions to long wavelengths. The ANOVA carried out for electromagnetic shielding effectiveness of fabric showed the neutral/ negligible effect on RH% (Table 4)

Confirmation Test

Methodology advocated by Taguchi for optimization problems involve typically four stages namely, problem formulation, Data collection / simulation, factor effects analysis and confirmation test. The confirmation test in the Taguchi methods supplements, assures validity of the results obtained in the experimental design and orthogonal array selected in the study and various levels of the design parameters and the introductions. Confirmation test carried out with every set of optimum parameters for all the response variable showed the closer result to that of original results and did not show any significant difference at 95% confidential level. Table 5 shows the values obtained in confirmation tests along with the original values for all response variables, considered in the study.

Conclusions

All the design factors selected in the experiments demonstrated pronounced effects on various parameters used in the assessment of electromagnetic shielding effectiveness of conductive Textile Composite materials. The electromagnetic shielding effectiveness of conductive Textile Composite materials were found to be influenced by Conductive Textile Composite Materials sample size, distance between Conductive Textile Composite Materials sample and transmitting antenna, distance between Conductive Textile Composite Materials sample to receiving antenna and RH% selected in the experiments. The electromagnetic shielding effectiveness of conductive Textile Composite materials were dominantly influenced by Conductive Textile Composite Materials sample size and significantly influenced by distance between Conductive Textile Composite Materials sample and transmitting antenna.

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Table 1 Signal-to-Noise ratio for EMSE of EMS tester and its significance

S.No.	Case	S/N ratio
1	Target is the best	S/N $(\theta) = 10 \log_{10} (\tau^2 / s^2)$
2	Small-the-better	S/N $(\theta) = -10 \log_{10} (y_i^2 / n)$
3	Larger-the-better-EMSE of EMS tester	S/N $(\theta) = 10 \log_{10} [(1/yi^2) / n]$
4	Binary scale (GO/NO-GO)	S/N $(\theta) = 10 \log_{10} (p/1-p)$ p= proportion of good products

Table 2 Controlled factor and Noise factor

S.No.		Control factor Levels			Noise factor level	
		1	2	3	1	2
1	Conductive Textile Composite material Sample Size (m)	0.3x0.3	0.5x0.5	1.0x1.0	--	--
2	Distance between Conductive Textile Composite sample and transmitting antenna (cm)	100	150	200	--	--
3	Distance between Conductive Textile Composite sample to Receiving Antenna(cm)	10	15	20	--	--
4	RH%	40	50	60	--	--
5	Temperature	--	--	--	N1(HIGH)-27^{0}C	N2 (LOW)-21^{0}C
6	Frequency	--	--	--	N3 (HIGH)-9 GHz	N4 (LOW)-3GHz

Table 3 Effect of process parameters on signal-to-noise ratio of maximization of EMSE

Expt. No.	Conductive Textile Composite Sample Size (m)	Distance between Conductive Textile Composite sample and transmitting antenna (cm)	Distance between Conductive Textile Composite sample and from Receiving Antenna (cm)	RH%	N1 N3	N2 N3	N1 N4	N2 N4	SN Ratio (Larger-the Better)
1	0.3x0.3	100	10	40	20	24	35	39	28.45
2	0.3x0.3	150	15	50	23	25	37	40	29.17
3	0.3x0.3	200	20	60	21	24	36	40	28.70
4	0.5x0.5	100	15	60	27	29	40	42	30.28
5	0.5x0.5	150	20	40	29	29	40	43	30.53
6	0.5x0.5	200	10	50	25	27	38	41	29.73
7	1.0x1.0	100	20	50	31	31	33	36	31.11
8	1.0x1.0	150	10	60	33	31	48	50	31.56
9	1.0x1.0	200	15	40	29	30	41	44	30.69

Table 4 Factor effects and F-Value of response Variables

Design factor	Degree of freedom	Factor effect (%)	F – Value (Before pooling)	Empty or pooled F=<1.5	F after pooling	Dominant or significant or neutral/ negligible	*Optimum level*
Conductive Textile Composite Sample size (m)	2	90	45	No	88	Dominant	*1.0 x 1.0*
Distance between Conductive Textile Composite sample and Transmitting antenna (cm)	2	8	4	No	8	significant	*150*
Distance between Conductive Textile Composite sample and Receiving antenna (cm)	2	1	0	Pooled	---	neutral/ negligible	---
RH%	*2*	*1*	*1*	*Pooled*	---	*neutral/ negligible*	---

Table 5 Confirmation Test with scaling and adjustments factors

Parameter	Original results	Conformation results	Significance at 95% confidential level (Yes/No)	Scaling factor	*Adjustment factors*
550 MHz	30	31	No	A3,B2	*C3,D3*
750 MHz	43	43	No	A3,B2	*C3,D3*
1GHz	59	58	No	A3,B2	*C3,D3*
3GHz	33	33	No	A3,B2	*C3,D3*
6GHz	34	34	No	A3,B2	*C3,D3*
9.22 GHz	19	18	No	A3,B2	*C3,D3*
10 GHz	19	19	No	A3,B2	*C3,D3*
12 GHz	*17*	*17*	*No*	*A3,B2*	*C3,D3*