Electromagnetic Shielding Effectiveness and Mechanical Characteristics of Polypropylene Based CFRP

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Abstract— Electromagnetic interference is one of the most undesirable by-products of rapid proliferation of electronic products and telecommunications. Mutual interference among devices such as televisions, computers, mobile phones and radios degrade device performance. Electromagnetic interference (EMI) occurs when electronic devices are subject to electromagnetic radiation from unwanted sources at the same frequency ranges that these devices operate.

Metals typically serve as excellent EMI shielding agents, but their heavy weight, high cost and susceptibility to forms of environmental degradation make them an undesired choice for many current electronic devices. The present study investigates the effect of the carbon fiber reinforced Plastics on the electromagnetic transparency. To improve electromagnetic shielding in high frequencies, carbon fiber mixed polypropylene was studied. It is found that 10% carbon fiber added specimen improve total shielding effectiveness of carbon fiber reinforced plastics in the considered 8–12 GHz ranging band

Key words— Electromagnetic shielding, Carbon fiber, Polypropylene

I. INTRODUCTION

Mankind has been aware composite materials since several hundred years before Christ and applied innovation to improve the quality of life. Although it is not clear has to how Man understood the fact that mud bricks made sturdier houses if lined with straw, he used them to make buildings that lasted. Ancient Pharaohs made their slaves use bricks with to straw to enhance the structural integrity of their buildings, some of which testify to wisdom of the dead civilization even today.

Contemporary composites results from research and innovation from past few decades have progressed from fiber for automobile bodies to particulate composites for aerospace and a range other applications.

Fibers or particles embedded in matrix of another material would be the best example of modern-day composite materials, which are mostly structural. Laminates are composite material where different layers of materials give them the specific character of a composite material having a specific function to perform. Fabrics have no matrix to fall back on, but in them, fibers of different compositions combine to give them a specific character. Reinforcing materials generally withstand maximum load and serve the desirable properties.

1.1 Polymer Matrix Materials:

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are thermosets and thermoplastics. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the chopped fiber composites form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins. Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of conventional compress techniques to mould the compounds.

Resins reinforced with thermoplastics now comprised an emerging group of composites. The theme of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the morphology to a considerable extent, prompting the reinforcement to empower nucleation. Whenever crystalline or amorphous, these resins possess the facility to alter their creep over an extensive range of temperature. But this range includes the point at which the usage of resins is constrained, and the reinforcement in such systems can increase the failure load as well as creep resistance.

1.2 Electromagnetic shielding

In recent years, the usage of electrical and electronic devices has grown rapidly. Many devices such as AC motors, digital computers, calculators, printers, modems, electronic typewriters, digital circuitry and cellular phones are capable of emitting radio-frequency energies. There is an ongoing controversy worldwide about the potential health hazards associated with the exposure to electromagnetic fields. There is a growing need for suitable materials that will act as a shield against electromagnetic energies. Traditionally, metals and alloys are used for this purpose.

The primary mechanism of electromagnetic shielding is usually reflection. For reflection of the radiation by the shield, the shield must have mobile charge carriers which interact with the electromagnetic fields in the radiation. As a result, the shield tends to be electrically conducting, although a high conductivity is not required. However, electrical conductivity is not the scientific criterion for shielding, as conduction requires connectivity in the conduction path, whereas shielding does not. Although shielding does not require connectivity, it is enhanced by connectivity. A secondary mechanism of electromagnetic shielding is usually absorption. For significant absorption of the radiation by the shield, the shield should have electric and or magnetic dipoles which interact with the electromagnetic fields in the radiation. Due to their light weight, versatility, low cost and processability, CFRP are attractive materials for use in enclosures for electronic and electrical devices to satisfy electromagnetic compatibility requirements.

The present work aims to find out the shielding effectiveness of polypropylene carbon fiber composites in different compositions against electromagnetic waves at different frequency of microwaves

1.3 Motivation

In today's electronic age, electromagnetic fields are radiated from numerous sources. The emitted fields from these communications devices can interfere with the operation of other nearby electronic equipment. This situation is known as electromagnetic interference (EMI). Some adverse effects of EMI are connectivity problems in cellular phones, interrupted television signals and even data corruption on computer hard drives. Along with interfering with the operation of electronic devices, EMI may have harmful biological effects. The importance of electromagnetic interference (EMI) shielding has also increased in electronics and communication industries owing to widespread use of packed high sensitive electronic devices. Accordingly, EMI shielding has been the topic of much research in recent years. Recent increases in demand for faster, lighter, and more cost-efficient airborne vehicles have forced designers to integrate individual avionics boxes into a compact electronic system. The radiated electromagnetic disturbance from these electronic systems may affect other sensitive avionic devices. Thus, research on shielding enclosures is essential for protecting electronic equipment that is vulnerable to EMI phenomena. Some studies have found a correlation between length of exposure time to the EM fields emitted from power lines and leukemia occurrences. There is also increasing concern that EMI might adversely affect the operation of biological devices such as pacemakers.

1.4 Objectives

The main objective of this work is to analyze electromagnetic shielding properties of polypropylene carbon fiber composites. In this research, measurement methodology and standards are proposed to cover a broad range of frequencies for use within the electronics industry as suitable shielding for electromagnetic interference applications.

The main research objective for this work will focus on the following key areas;

- Development of polypropylene carbon fiber composites.
- Development of a suitable procedure for electromagnetic shielding effectiveness testing of polypropylene carbon fiber composites.

II. ELECTROMAGNETIC SHIELDING

Electromagnetic shielding is the process of limiting the penetration of electromagnetic fields into a space, by blocking them with a barrier made of conductive material. Typically it is applied to enclosures, separating electrical devices from the outside world, and to cables, separating wires from the environment the cable runs through. Electromagnetic shielding used to block radio frequency electromagnetic radiation is also known as RF shielding.

The shielding can reduce the coupling of radio waves, electromagnetic fields and electrostatic fields, though not static or low-frequency magnetic fields (a conductive enclosure used to block electrostatic fields is also known as a Faraday cage). The amount of reduction depends very much upon the material used, its thickness, the size of the shielded volume and the frequency of the fields of interest and the size, shape and orientation of apertures in a shield to an incident electromagnetic field

Electromagnetic interference (EMI) controlling methods are varied and largely dependent on the type of EMI and constraints within the emitting product or device itself. There are two main types of EMI to investigate those consisting of conducted interference, and those of radiated interference. With conducted radiation the EMI is conducted though cabling and circuitry. This kind of problem is best solved through electromagnetic (EM) filtering and designing devices with EM in mind. However this is beyond the scope of this investigation and is not something that will be considered here. Radiated emissions are more random and require waves penetrating into escaping and potentially achieved through encasing the device in a shield is impenetrable to EM waves. However conductivity not always required for shielding effectiveness. EMI problems range from equipment damage, erratic response and general malfunction. Different ways of shielding are

- Metallic Casings
- Polymer and Plastic Casings
- Metal Coated Plastic

Electromagnetic spectrum is the distribution of the electromagnetic rays according to the energy. EM waves are typically described by any of the following three physical properties: the frequency, wavelength, or photon energy. Wavelength is inversely proportional to the wave frequency. Photon energy is directly proportional to the wave frequency, so gamma rays have the highest energy and radio waves have very low energy.

2.1 Mechanisms of electromagnetic shielding

Electromagnetic shielding is the process of limiting the penetration of electromagnetic fields into a space, by blocking them with a barrier made of conductive material. Typically it is applied to enclosures, separating electrical devices from the outside world, and to cables, separating wires from the environment the cable runs through. Electromagnetic shielding used to block radio frequency electromagnetic radiation is also known as RF shielding. The shielding can reduce the coupling of radio waves, electromagnetic fields and electrostatic fields. The amount of reduction depends very much upon the material used, its thickness, the size of the shielded volume and the frequency of the fields of interest and the size, shape and orientation of apertures in a shield to an incident electromagnetic field.

EMI interrupts, obstructs, degrades or limits the effective performance of electronics/electrical equipment. It can be induced intentionally, as in some forms of electronic warfare, or unintentionally, as a result of intermodulation products for instance. This unwanted electromagnetic emission is caused by rapid changes in voltages and currents within wires or circuits. The EMI is transmitted in two forms: conducted and radiated. For radiated EMI, various shielding materials are applied to eliminate the noise; while for conducted EMI, filters have to be added when designing the circuit. For example, most power electronic equipments have grounded cabinets which shield both internal and external radiated noises. Radiated EMI is the consequence of reflection loss, transmission or absorption loss and internal reflection loss at existing interfaces of the incident electromagnetic waves in samples. In passing through a shielding material layer, an electromagnetic wave may be attenuated in three ways:

I. By absorption

II. By reflection at the surfaces

III. BY MULTIPLE INTERNAL REFLECTIONS

3. MATERIALS AND SAMPLE FORMULATION

3.1 Material selection

3.1.1 Carbon fiber

The mechanical properties of most reinforcing fibers are considerably higher than those of un-reinforced resin systems. The mechanical properties of the fiber/resin composite are therefore dominated by the contribution of the fiber to the composite. The four main factors that govern the fiber's contribution are:

1. The basic mechanical properties of the fiber itself.

2. The surface interaction of fiber and resin.

3. The amount of fiber in the composite.

4. The orientation of the fibers in the composite.

The carbon fiber was provided by Formosa Plastic Corporation with following details given in the table. Carbon fiber is produced by the controlled oxidation, carbonisation and graphitization of carbon-rich organic precursors which are already in fiber form. The most common precursor is polyacrylonitrile (PAN), because it gives the best carbon fiber properties, but fibers can also be made from pitch or cellulose. Variation of the graphitization process produces either high strength fibers or high modulus fibers with other types in between. Once formed, the carbon fiber has a surface treatment applied to improve matrix bonding and chemical sizing which serves to protect it during handling. Carbon fibers are usually grouped according to the modulus band in which their properties fall. These bands are commonly referred to as: high strength (HS), intermediate modulus (IM), high modulus (HM) and ultra-high modulus (UHM). The filament diameter of most types is about 5-7µm. Carbon fiber has the highest specific stiffness of any commercially available fiber, very high strength in both tension and compression and a high resistance to corrosion creep and fatigue. Their impact strength, however, is lower than either glass or aramid, with particularly brittle characteristics being exhibited by HM and UHM fibers.

Details of carbon fiber
Type (Rovings) TC33-6K
Density 1.8 g/cm3
Tensile strength 3450 MPa
Filament Dia 7µ

3.1.2 Polypropylene

The used PP was injection grade and manufactured by Reliance.

Name: Polypropylene Homopolymer Injection grade

Grade: H110MA

Brand: Reopol

Manufacturer: Reliance Industries Ltd

3.2 Compounding

Before compounding, the polymer granules were dried at 80˚C for 2hr in an air circulated oven and then mixed with Carbon Fiber.

The mixing speed of 60 rpm was maintained for all the compositions in the twin screw extruder. The melting temp used is 2250C

Composition 1
PP – 100%
CF – 0%

Composition 2
PP – 95%
CF – 5%

Composition 3
PP – 90%
CF – 10%

Composition 4
PP – 85%
CF – 15%

The extrudate of the compositions was palletized in palletizing machine.

3.3 Preparation of test specimen

The samples are prepared by using the injection moulding machine available at CBPST Kochi. The injection moulding was done with a temp of 210^0C.

Specimen made for Tensile and flexural test

Specimen for EM shielding Effectiveness

IV. EXPERIMENTAL AND CHARACTERIZATION METHODS

The following tests are to be conducted for analyzing the mechanical properties:

– Tensile Testing

– Impact Testing

– Micro-structural Analysis

– Flexural Testing

4.1 Tensile testing

- Machine Specifications:

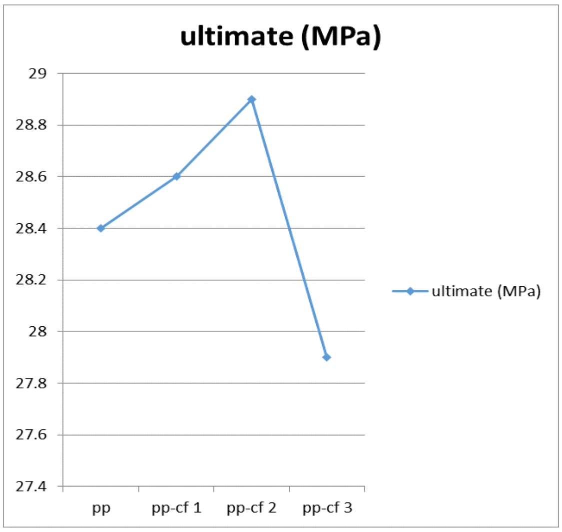
– UTM Tinius Olsen H75KS Computerized
– Max Loading Capacity – 50KN

- Specimen dimensions are as follows:

– Thickness of 3.6mm, &
– Length of 150mm
– ASTM 3039/D 3039M standard

SPECIMEN TYPE & ULTIMATE TENSILE STRENGTH (MPa)

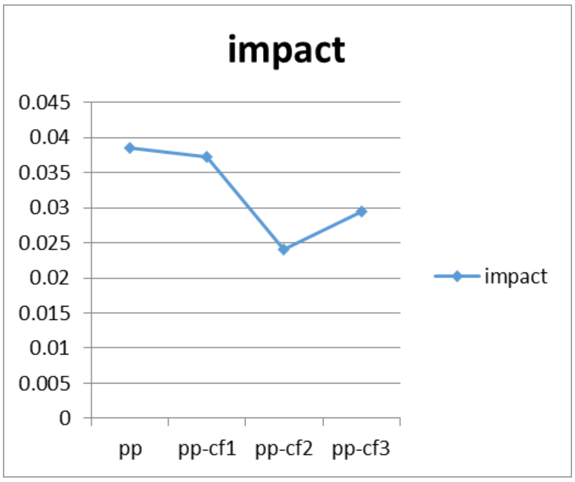
PP	28.4
PP-CF 1	28.6
PP-CF 2	28.9
PP-CF 3	27.9



4.2 Impact Testing

SPECIMEN TYPE & Impact Strength (J/mm2)

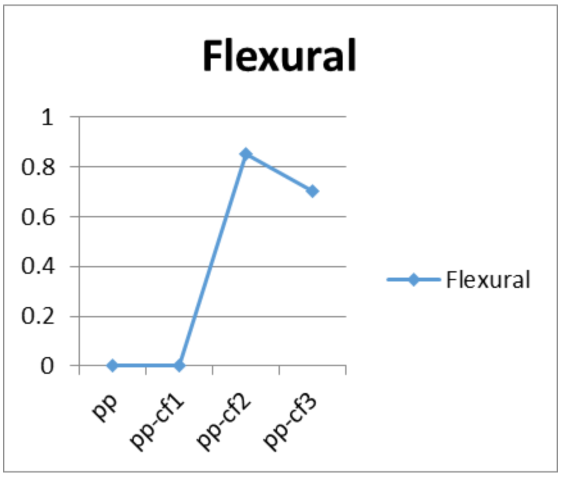
PP	0.03850
PP-CF 1	0.037198
PP-CF 2	0.024017
PP-CF 3	0.029444



4.3 Flexural Testing

SPECIMEN TYPE & Flexural Strength (KN)

PP	Nil
PP-CF 1	Nil
PP-CF 2	0.85
PP-CF 3	0.7



4.4 ELECTROMAGNETIC WAVE SHIELDING TEST

An experiment is being conducted on composite materials and their shielding effectiveness of Electromagnetic Interference (EMI). However, before any experimental data can be reviewed a detailed explanation of the experimental set-up must first be looked into. This thesis followed the ASTM D4935-10 standard. The testing equipment, procedure used, and the testing holder followed the ASTM standard. While the ASTM standard was followed, it was not followed directly; it was used more as a guideline. Microwaves can be generated by a variety of means, generally divided into two categories: solid state devices and vacuum-tube based devices. Solid state microwave devices are based on semiconductors such as silicon or gallium arsenide, and include field-effect transistors and bipolar junction transistors

Shielding effectiveness

It is the materials ability to prevent propagation of electromagnetic fields in order to isolate one region of space from another. Electrical conductivity is necessary but not a sufficient condition to provide signal attenuation. 30 dB of attenuation stops 99.9 % of an impinging signal. 20 dB to 30 dB of attenuation is considered acceptable for most industrial and consumer applications

SE (dB)	Attenuation %
20	99
30	99.9
40	99.99
50	99.999
60	99.9999
70	99.99999

Shielding effectiveness and attenuation

The ratio of power received without and with a material present for the same incident power. It is usually expressed by the following equation:

S.E. = 10 log10 (P0/P1)

Where: P0& P1 = received power with the material present and without material present.

If the receiver readout is in units of voltage, use the following equation:

S.E. = 20 log10 (V0/V1)

Where: V0 & V1 = respective voltage levels with and without a material present

Specimen	FREQUENCY GHz	Voltage without specimen V1 in mV	Voltage with specimen V0 in mV	Shielding effectiveness dB
PP	10.755	2850	1530	5.4
	10.855	1400	1500	0.59
	11.12	1900	1300	3.29
	11.22	865	760	1.12
PP-CF 1	10.755	2850	1200	7.51
	10.855	1800	900	6.02
	11.12	1900	1170	4.21
	11.22	1650	490	10.54
PP-CF 2	10.755	2850	250	21.13
	10.855	1800	243	15.56
	11.12	1900	360	14.44
	11.22	1980	208	19.57
PP-CF 3	10.755	2850	280	20.15
	10.855	1800	400	13.03
	11.12	1900	300	16.03
	11.22	1980	250	17.97

V. CONCLUSIONS

The goal of this investigation was to predict the shielding effectiveness of Polypropylene based CFRP. It has been shown that prediction of SE for composite materials depends on the electrical conductivity of the filler, volume percent and frequency of the impinging electric field. The interaction is dependent on the distance from the source, thickness of material and the frequency. Weight/volume fraction of conducting reinforcement can be adjusted so that resulting composite becomes more conductive and more effective in shielding EM radiations.

It is found that the shielding effectiveness increases with respect to thickness and it is also observed that shielding effectiveness is more at lower frequencies. It is found that as the frequency of the radiation increases the shielding effectiveness is decreasing. The Electromagnetic shielding test of the PP-CF 2 (10% CF) shows the maximum shielding of 21.13dB and it is in the recommended range of 20 to 30dB for the most industrial and consumer applications.

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