RESEARCH ARTICLE

STUDIES ON THE POTENTIAL OF SILVER-COATED CENOSPHERE-POLYCARBONATE COMPOSITES FOR ELECTROMAGNETIC INTERFERENCE SHIELDING

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ABSTRACT

Recently, plastic industries have been increasingly involved with electronic devices such as televisions, office automated appliances, computers, etc. These devices need housing which serve as shield to attenuate Electro Magnetic Interference (EMI) and Radio Frequency Interference (RFI). The technique of imparting shielding by polymers and composites has attracted wide attention. It is well known that polymer housing must be conductive in order to enhance the shielding effectiveness. This work deals with preparing polymer-conducting fillers composites and determining their effectiveness as EMI-shielding materials. Non-conductive hollow spherical fly-ash cenosphere particles have been used for electroless surface coating with silver to make it electrically conductive. Two different compositions of Polycarbonate (PC):Silver-Coated Cenosphere (SCC) (95:5 and 98:2 wt%) composites are prepared by the compression moulding method and characterized for material properties such as morphology, coating thickness, chemical composition and structural phases using Scanning Electron Microscope (SEM), Energy Dispersive X-ray (EDX) and X-Ray Diffraction (XRD). EMI-shielding effectiveness of the composites is tested by means of coaxial holder test facility. Silver is well-deposited on the pre-treated and activated cenosphere surfaces. Silver coating has been found to be chemically stable with uniform thickness varying from 1-1.5 μm. The structural phase analysis reveals the formation of silver coating in the form of pure element. Some compound formations are also seen. The EMI-shielding effectiveness of 5% PC-SCC composites between 100 KHz and 200 MHz are found to vary between 6 and 9dB. The composites exhibited peaking of shielding effectiveness up to 15dB at the frequency of 10 MHz.

INTRODUCTION

Electro Magnetic Interference (EMI) is a topic of current interest. EMI is a process by which disruptive electromagnetic energy is transmitted from one electronic device to another via radiated or conducted paths, or both. The interference sources may be internal or external to the electronic system and they may propagate by radiation or conduction[1]. As technology advances, the need to integrate large number of electronic systems into automobiles, airplanes, ships, etc., has dramatically increased. These systems include Control Area Networks (CAN), safety systems, communications, mobile media, infotainment systems including wireless headsets, DC motors and controllers. Placing a large number of electronic systems in a confined space poses the problem of keeping the EMI of these systems from interfering with each other. In an automotive electronic system, EMI can adversely affect the performance of an integrated circuit internally as well as that of the other electronic components in close proximity. Typical examples of EMI include corona discharge producing noise and disturbance around high-voltage transmission lines; distortion of TV picture observed when driven under high-voltage line with the disturbance varying from snowy picture to collapse of the picture; occurrence of loud static noise in a computer speaker if a cell phone is placed near the computer and when the cell phone begins to ring; hampering of airplane ground/air traffic control system and communication systems by using cell phones/laptops/CD players during take-off or landing of airplanes. Most of the EMI problems may merely be a source of uneasiness in daily work and will pass with minor corrections, the same can cause serious distress depending upon the situations, as in an airplane work systems. It can literally “crash” a computer system. If airbag, cruise control, anti-lock braking or other electronically-controlled assemblies are adversely affected by EMI, operation of the vehicle or its safety can become critical. Electro Static Discharge (ESD) also is an EMI problem which starts with a very slow build-up of energy, and upon reaching the threshold, rapid breakdown may occur. It is this fast breakdown that causes EMI problems in modern electronic systems. The energy discharge yields EMI frequencies of the order of hundreds of MHz. The high speed and frequency of ESD energy can damage circuits and cause upsets through electromagnetic coupling. The origins of EMI are electrical, with the unwanted emissions being either conducted (voltages or currents) or radiated (electric or magnetic fields). These electrical influences can be generated by either radiated or conductive EMI sources. Radiated sources include anything electrical or electromechanical, including motors, power lines, antennae and traces on Printed Circuit Board (PCB), and even the silicone components on the
PCB. Conductive EMI primarily shows itself as electrical “noise” on the power-supply lines of an application and can be caused by induced- voltage spikes from other devices within a system. For EMI to occur, the following three essential elements must exist:

- An electrical noise (EMI) source
- A coupling path and
- A victim receptor

The coupling path from the source to a receptor can be in one of the four categories: (1) conducted electric current, (2) inductive-coupled magnetic field, (3) capacitive-coupled electric field and (4) radiated-electromagnetic field[1]. If the electronic system design is unable to reject all the unwanted signals, then the equipment must be protected or shielded, in order to obtain the desired performance or to prevent catastrophic failure. Shielding is non-invasive and does not affect high-speed operation, and it works for both emissions and susceptibility. It can be a stand-alone solution, but it is more cost-effective when combined with other suppression techniques such as filtering, grounding and proper design to minimize the loop area. It is also important to note that shielding can usually be installed after the design is complete. However, it is much more cost-effective and generally cannot be added easily once the device has gone beyond the prototype stage. The use of shielding may take many forms, from Radio Frequency (RF) gaskets to Board Level Shielding (BLS).

An RF gasket provides a good EMI or Electro Magnetic Pulse (EMP) seal across the gasket-flange interface. The ideal gasketing surface is conductive, rigid, galvanic-compatible and recessed to completely house the gasket. Shielding from the deleterious effects of EMI is achievable by using EMI-shielding materials which provide an electrically-conductive seal for the electronic equipment openings and housing the covers to prevent or restrict electromagnetic interference. Electromagnetic shielding is the process of reducing the electromagnetic field by blocking with the barriers made of electrically conductive and/or magnetic materials. Shielding is typically applied to enclosures to isolate electrical devices from the ‘outside world’ and to cables to isolate wires from the environment through which cable runs.

Electromagnetic shielding that blocks radio-frequency electromagnetic radiation is also known as RF shielding. Following are the requirements for proper EMI shielding in a system:

- The material of the EMI shield should necessarily be electrically conductive. Metals though conductive, are generally not preferred because of their excessive weight and environmental issues such as corrosion being associated with them.
- Such EMI shielding materials are therefore, either replaced with (i) reinforced polymer matrix with conductive fillers or (ii) non-conductive material coated with conductive species which are of light weight and with minimum environmental concerns.
- Conductive species used as fillers in polymer matrix need to be uniformly spread throughout the matrix and possess good physical properties like low density, fine particle size, high surface area and the composite matrix, as a whole should have volume resistivity as low as possible. Nano-sized conducting fillers in polymer matrix are expected to give exceptionally good EMI shielding properties.

There are many types of EMI shielding materials such as electrically conductive elastomers, Silicone Rubber or Fluoro Silicone Rubber-Based Materials, Metallic Materials and Metal-Coated Plastics.

A cenosphere is a light, inert, hollow sphere made largely of silica and alumina, and filled with air or inert gas, typically produced as a by-product of coal combustion at thermal power plants. Cenospheres are also hard and rigid, waterproof, innoxious and insulative. Cenospheres have a size range from 1 to 300 microns with an average compressive strength of 3000 psi. Colours range from white to light grey. Cenospheres are easy to handle and provide a low surface area: volume ratio. Due to their inert properties, they are not affected by solvents, water, acids or alkalis. Cenospheres are currently used as fillers or extenders. Cenospheres are used to make lightweight composite materials with higher strength than other types of foam materials. Because cenospheres often replace mined materials, they can significantly lower production costs. Simultaneously, cenosphere can benefit finished product properties by increasing durability and better sound-proofing. As material recycled from fly ash, cenosphere are environmentally friendly. With improvements in performances of the end products and reduction of costs, Cenosphere has promising market prospect as well as utilization benefits.

In order to derive all the benefits of cenospheres and to explore its usability as EMI shielding materials (after providing a conductive, thin metal coating on its surface), this study examines the potential of developing a silver-coated cenosphere–polymer composite. It is expected that coated cenospheres or microspheres would enable significant RF attenuation (reduction of RF interference) in much the same way as traditional solid silver/nickel particles, by developing chains of contacting particles into a vast network within the chosen polymer matrix such as polycarbonate or a paint film. Coated cenospheres can also be incorporated into plastics, polymers, composites and rubber compounds during the forming or molding stage, thus providing excellent EMI shielding as an integral part of the finished product.

There are many methods available to coat ceramics such as: Electroplating, hot dipping, Metal Spraying, Vacuum metallizing, Electroless plating, etc. Among these methods, Electroless plating may be considered more suitable for the present study, since the substrates are in the form of powder (cenosphere) and the coating method is expected to provide with a thin, controllable and homogenized coating. In addition, electroless coatings provide additional benefits such as the following:

- Does not use electrical power.
- Even coating on parts surface can be achieved.
- No sophisticated jigs or racks are required.
- There is flexibility in plating volume and thickness.
- The process can plate recesses and blind holes with stable thickness.
- Chemical replenishment can be monitored automatically.
- Complex filtration method is not required.

This process involves deposition of silver on the surface of a material by means of a reducing chemical bath. The material on which the metal is deposited is known as the substrate. In recent years, the plastic industry has been increasingly involved with electronic devices such as television, office automatic instruments, computers, etc. Because of the need for these housings to attenuate EMI and Radio Frequency Interference (RFI), the technique of imparting shielding to EMI-transparent polymers has received a great deal of attention. It is accepted that polymer
housing must be made conductive to exhibit the required shielding effectiveness. Polymer-melt blending is an easy, economical and fast method to modify plastics. Therefore, various compositions of Polycarbonate (PC) are loaded with conductive fillers such as metal-coated cenospheres to make conductive PC composites possess effective EMI shielding. Then, the process ability, Shielding Effectiveness (SE) values and morphology of PC/metal-coated cenosphere composites are studied. There are many methods available to prepare electrically conductive composites that contain conductive filler dispersed in an insulating polymer matrix such as compression moulding, twin-screw extruder, injection moulding, hot press, etc. Among these methods, compression moulding and twin-screw extruder are used for the present study. In compression moulding, the moulding material is generally preheated and placed in an open, heated mould cavity. The mould is closed with a top force or plug member, pressure is applied to force the material into contact with all mould areas, while heat and pressure are maintained until the moulding material has cured. The process employs thermosetting resins in a partially cured stage, either in the form of granules, putty-like masses or preforms. In this study, it is proposed to make use of waste from coal-fired thermal power plants like cenosphere to function as filler for making polymer composites. The cenosphere is to be coated with Silver by electroless processing. Finally, the metal-coated cenospheres, in combination with the polycarbonate matrix, have to be evaluated for their physical, chemical, structural and electrical properties, and to correlate these properties with their performance as suitable EMI shields. The objectives of this study are:

- To carry out complete characterization of cenospheres obtained from thermal power plants.
- To prepare silver-coated cenosphere by electroless processing followed by comprehensive characterization.
- To prepare and modify polymer blends, add silver-coated cenosphere, determine relevant properties to function as a material polymer matrix composites.
- To determine materials and electrical properties of polymers, fillers and blends of polymers-silver coated cenospheres as composites.
- To evaluate the suitability of prepared polymer matrix composites for their potential to perform as EMI-shielding materials and to characterize them.

No literature is available pertaining to silver-coated cenospheres and on the compatibility of these materials as fillers in polymer composites as well as their usefulness as EMI-shielding materials. The Ag-coated cenosphere powder possessed good oxidation resistance and enough strength to resist being crushed during the preparation of composites. The adhesion between the silver film and cenosphere powders is good. There existed the shielding Effectiveness (SE) of silicone rubber composites filled with Ag-coated cenosphere powders. When the content of the Ag-coated cenosphere powders was 180 parts per hundred of the rubber (phr), the SE values of composites are typically above 80dB and close to maximum across the tested frequency range from 2.6 GHz to 3.95 GHz. MATERIALS AND METHODS

Cenospheres are a by-product from coal ash. These hollow light weight spheres are produced around the world. Most of the cenospheres produced today are recovered from ash ponds or lagoons typically onsite at the coal-fired power plant. Cenospheres used in the present project, is obtained from the Raichur Thermal Power Station, Karnataka.

Materials for Pre-treatment of Cenospheres

- 500 g of Raichur cenosphere
- Concentrated Sulfuric acid
- Distilled water

Method

About 500 g of cenosphere is washed with sulfuric acid which is prepared by dissolving 5 ml of concentrated acid in 5 lit for an hour. The solution is filtered using a 45 micron sieve to recover the cenosphere particles. The above steps are repeated 5 times. After the final wash, the sample is dried in a hot air oven at 90°C. The acid-washed cenosphere particles are then ready to be used.

Materials for Electroless Coating of Cenosphere with Silver

Fly-ash cenosphere particles having a low density of < 0.7 g/cm³, used in the present investigation, are supplied by Raichur Coal Plant, India. Fly-ash cenosphere particles are used for electroless Ag coating. The chemicals used for electroless Ag coating of fly-ash cenosphere particles include SnCl₂ (anhydrous min. 99%), PdCl₂ (99.9%, metal basis), Pd (59.78%), Silver nitrate, Ammonia solution, Sodium hydroxide pellets, D-glucose. The overall coating mechanism of silver coating is shown in Fig. 1. Generally, an activation step is performed in the alkali media and hence, the hydrolysis is promoted, the reaction being suppressed.

As a consequence of the hydrolysis, silver nuclei are not evenly distributed on the surface of cenosphere particles and furthermore, a decrease in the number of nuclei on the surface occurs. Indeed, at a given amount of silver species being generated from the reaction, if the number of silver nuclei formed on the cenosphere particles surface by the reaction is large enough, all of them would be attracted and then contributed to the growth of the original nuclei instead of creating silver fines in the solution. In contrast, many silver fines in the solution would be likely formed when the less number of silver nuclei is on the cenosphere particles, which is closely related to the trend of decreasing the surface energy.

Preparation of the Composites

The various types of composites prepared are Polycarbonate (PC) and Silver-Coated Cenosphere Composites (SCC).
Using Twin-Screw Extruder Compounding of PC/SCC

Materials
Poly carbonate and Silver-coated cenospheres.

Process
In the extrusion of plastics, raw thermoplastic material in the form of nurdles (small beads, often called resin in the industry) is gravity fed from a top-mounted hopper into the barrel of the extruder. The material enters through the feed throat (an opening near the rear of the barrel) and comes in contact with the screw. The rotating screw (normally turning at up to 120 rpm) forces the plastic beads forward into the barrel which is heated to the desired melting temperature of molten plastic (which can range from 200°C to 275°C depending on the polymer). In most processes, a heating profile is set for the barrel in which three or more independent PID controlled heater zones gradually increase the temperature of the barrel from the rear (where the plastic enters) to the front. This allows the plastic beads to melt gradually as they are pushed through the barrel and lowers the risk of overheating which may cause degradation of the polymer. At the front of the barrel, the molten plastic leaves the screw and travels through a screen pack to remove any contaminants in the melt. The screens are reinforced by a breaker plate (a thick metal puck with many holes drilled through it) since the pressure at this point can exceed 5000 psi (34 MPa). After passing through the breaker plate, molten plastic enters the die. The die is what gives the final product its profile and must be designed so that the molten plastic evenly flows from a cylindrical profile to the product's profile shape. Almost any shape imaginable can be created so long as it is a continuous profile. The product must now be cooled and this is usually achieved by pulling the extrudate through a water bath. Plastics are very good thermal insulators and are, therefore, difficult to cool quickly. The conditions for compounding of composites are given in Table 1.

Compression Moulding
After compounding, a batch of composites are sent into the frame, delivered into a pair of plates, and compressed using a press. After passing through the breaker plate, molten plastic enters the die. When the pressure is maintained for 10 min, and then cooled by water at the rate of about 10°C/min until the temperature fell below 50°C.

Materials for Characterization
Uncoated cenosphere particles, Silver-coated cenosphere sample and PC/SCC composite sheets.

EMI Shielding Effectiveness Test
The main measuring method is the coaxial holder method. This method uses a Specimen holder, transmission line (signal generator) and a vector network (data) analyser. The sample material is placed and fixed in the flanged circular coaxial transmission line holder. By measuring the S-parameters, S11 and S21 – reflection and transmission coefficients, it is possible to determine the contribution of the absorption and the reflection at the total shielding effectiveness. Generally, the maximum operating frequency is around 1 GHz. This measuring system is compact and allows automation and data processing by computer control. The difficulty of this measurement method arises from the sample preparation.

EXPERIMENTAL
Electroless Coating of Cenosphere with Silver

The as-received fly-ash cenosphere particles were stirred in the acidic SnCl2 bath, containing 5 g/L of SnCl2 and 30 ml/L of conc. HCl acid for 1 h (sensitization step). The sensitized particles were filtered off and then transferred to acidic PdCl2 bath containing 0.1 g/L PdCl2 25 ml/L HCl and 5 ml/L HNO3; and stirred in this bath for 1 h (activation step). The activated particles were filtered off and washed thoroughly with de-ionized water. The particles were then transferred to the coating bath involving 10 ml of 5% silver ammonia solution mixed with 5 ml of 10% NaOH solution and 10 ml of 5% D-glucose in order to reduce Ag+ to Ag for the actual Ag-deposition for 1 h at room temperature. The Ag-coated particles were dried in the vacuum oven at 110°C for 1 h.

Preparation of PC/SCC Composites
The Twin-screw extruder machine was preheated for two hours. When the temperature was on the setting values, PC was used to clean the extruder for 10 to 15 min. The PC/NCC/SCC/CCC was loaded to the machine by controlling the four step temperature at 260± 2°C each, and the rotating speed about 110 rpm. When the material content was increased, the temperature decreased. Compositions of composites prepared (% weight) were 98/2 and 95/5.

Characterization of Uncoated and Metal-Coated Cenospheres
Characterization studies were done for uncoated and metal-coated cenospheres using Scanning Electron Microscope (SEM), Energy Dispersive X-ray (EDX) and X-Ray Diffraction (XRD).

Characterization using SEM Analysis
In this work, regular type SEM requiring a conductive sample was used. About 1 spatula of each of the raw material sample was taken and spread on an aluminium stub. The sample was blown carefully on the stub; it was kept in a sputter coat unit. Gold coating was done to increase the conductivity. When the electrons struck the sample, the conductivity increased and the sample under study could be clearly viewed in the SEM. If gold coating was not done properly, the image appeared with blurred regions. Acetone was added so that the sample stuck on the aluminium stub. If it did not stick, then it would get dispersed inside the SEM and spoil the equipment. The samples were mounted in the SEM and the lid was closed. A vacuum of 0.975×10^-3 torr was applied. The equipment was started and the analysis was carried out. The image was finally obtained and the results were interpreted.

Characterization using EDX Analysis
The gold-coated specimen was bombarded with an electron beam inside the SEM. The bombarding electrons collided with the specimen atom's own electrons knocking some of them off in the process. The amount of energy released by transferring electron depended on the shell it was transferred from and also the one it was transferred to. Furthermore, the atom of every element released X-rays with unique amount of energy during the transferring process. Thus, by measuring the amount of energy present in the X-rays being released by a specimen during electron beam bombardment, the identity of the atom from which the X-ray emitted could be established.

Characterization using XRD Analysis
Powdered sample was taken on a sample holder and back loaded. While loading, the sample was compacted, spread uniformly over the specimen holder and then kept inside XRD set up. Back loading technique was done to avoid preferred orientation effects. When the powder was compacted on the sample holder, the natural orientation of the sample was disturbed. This orientation is
called preferred orientation. The back surface of the sample was disturbed whereas, the front surface of the sample was not disturbed. Hence, proper peaks and orientation of the sample could be observed on the front surface.

**Shielding Effectiveness Test**

Coaxial holder method was used for testing the shielding effectiveness of the composites. Composites were cut according to the dimensions needed to load into the coaxial jig, as shown in Fig. 2. The experimental setup for measurement of shielding effectiveness is shown in Fig. 3. Initially sample (a) was loaded into the coaxial jig.

One end of the jig was connected to the signal generator and the other end was connected to the network analyzer. In signal generator the power level was set to -27 decibels (dB) (keeping safety of instrument view) which was maintained constant for all the measurements with different input frequencies ranging from 100 KHz to 1 GHz and respective dB output values were noted. The measurements were repeated with samples (b) and (c) loaded together in the jig with the above frequency ranges and the dB values were noted. The difference in the output dB values with shield (sample a) and without shield (samples b and c together) was calculated. Graphs were plotted with frequencies in X-axis and the difference of dB values (which is the measure of shielding effectiveness) in Y-axis.

**RESULTS AND DISCUSSION**

**SEM/EDX Analysis of Uncoated Cenosphere**

SEM micrograph of uncoated fly-ash cenosphere particles are presented in Fig. 4. The as-received cenosphere particles have spherical surface morphology as indicated by Fig. 4. It can also be noted that the as-received cenosphere contains broken particles. Therefore, cenospheres must be filtered to separate the broken particles and this is done using 45µm mesh. The chemical composition of fly-ash cenosphere particles mainly composed of mixture of oxides such as SiO₂, Al₂O₃ and Fe₂O₃ as indicated by the EDX analysis (Fig. 5). Various trace elements, such as K, Ca, Mg, Ti and C are also present. No Ni, Ag or Cu is detected for uncoated particles.

![Fig. 4 SEM Micrograph of as-received Cenosphere Particles at 400 Magnification](image)

**Table 2 Pattern List**

<table>
<thead>
<tr>
<th>Ref. Code (ICDD number for the phase)</th>
<th>Compound Name (Phase name)</th>
<th>Displacement [°2θ] (indicates peaks are matching)</th>
<th>Chemical Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-079-1454</td>
<td>Mullite, syn</td>
<td>0.000</td>
<td>Al4.75 Si1.25</td>
</tr>
<tr>
<td>01-089-8937</td>
<td>Alpha - Quartz</td>
<td>0.000</td>
<td>Si O₂</td>
</tr>
</tbody>
</table>

**XRD Analysis**

The XRD pattern obtained is shown in Fig. 6 in which the major peaks of Mullite and Quartz can be seen. The intensities of the peaks indicate the crystallinity. From the XRD patterns it can be observed that the peak intensities are very low and the noise level is high indicating the cenosphere is highly amorphous in nature. Table 2 indicates the phases present in the raw cenosphere sample matching with International Crystalline Diffraction Data (ICDD) tabulated in the XRD standard.

![Fig. 5 EDX Analysis of Uncoated Fly-Ash Cenosphere Particles](image)

**Silver-Coated Cenospheres**

**SEM/ EDX Analysis**

Fig. 7 shows SEM micrographs of Ag-coated cenosphere particles at 300X and 1000X magnifications. The cenospheres have retained their spherical shape even after Silver coating. It appears that during electroless metal deposition, uniform silver coatings have been developed over the activated cenosphere particle surface.

![Fig. 7 SEM Micrographs of Ag-coated Cenosphere Particles](image)

**Table 1 Conditions for Compounding of Composites**

<table>
<thead>
<tr>
<th>PC/SCC Composition (wt.%)</th>
<th>98/2</th>
<th>95/5</th>
<th>95/5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Temperature (°C)</td>
<td>260</td>
<td>255</td>
<td></td>
</tr>
</tbody>
</table>
EDX Analysis

EDX analysis of Ag-coated cenosphere particle surface (Fig. 8) shows the presence of Ag along with the other elements such as Si, Fe, Al and K. It is also to be noted that peak corresponding to Ag is not present in Fig. 5 and it appears only after electroless coating process, indicating successful Ag deposition on the cenosphere particle surface by the present electroless technique.

Thus, SEM and EDX analysis suggest the successful Ag deposition on the surface of fly-ash cenosphere particles by the present electroless process.

XRD Analysis

The obtained XRD pattern is presented in Fig. 9, where the major peaks of Ag can be seen. The Ag peak confirms that silver has been successfully coated over the surface of the cenospheres. The sharpness of the peaks indicates the crystallinity. Peak corresponding to Quartz belongs to the cenosphere.

PC-SCC Composites

From the cross-sectional view of the SEM pictures (Fig. 10), it can be observed that coated cenosphere particles are embedded inside the polymer matrix. It is observed that the distributions of cenosphere particles are non-uniform which may be attributed to non-uniform mixing.
Shielding Effectiveness Test Results

5% PC-SCC Composites

Shielding effectiveness of 5% PC/SCC composites were tested and the readings obtained are shown in Table 3. From Table 3, it can be observed that the shielding effectiveness more or less constant at lower frequencies and increase to maximum at 10MHz and gradually decreases at higher frequencies. The overall shielding effectiveness of 5% PC/SCC between 100 KHz to 200 MHz is 5.68dB.

| Frequency (Hz) | Shielding Effectiveness (SE) with shield (dB) | Shielding Effectiveness (SE) without shield (dB) | Shielding Effectiveness (SE) Ag, dB | Shielding Effectiveness of without shield – SE of with shield (dB) |
|---------------|-----------------------------------------------|-----------------------------------------------|----------------------------------|--------------------------------------------------|---|
| 100K          | -87.00                                        | -92.27                                        | 5.27                             | 5.27                                             |
| 200K          | -81.27                                        | -86.94                                        | 5.67                             | 5.67                                             |
| 500K          | -73.27                                        | -78.65                                        | 5.38                             | 5.38                                             |
| 1M            | -67.99                                        | -72.59                                        | 4.6                              | 4.6                                              |
| 2M            | -62.40                                        | -67.81                                        | 4.1                              | 4.1                                              |
| 5M            | -53.81                                        | -59.40                                        | 5.59                             | 5.59                                             |
| 10M           | -34.56                                        | -49.32                                        | 14.76                            | 14.76                                            |
| 20M           | -44.85                                        | -49.31                                        | 4.47                             | 4.47                                             |
| 50M           | -37.23                                        | -41.49                                        | 4.26                             | 4.26                                             |
| 100M          | -36.06                                        | -39.59                                        | 3.53                             | 3.53                                             |
| 200M          | -30.04                                        | -33.59                                        | 3.55                             | 3.55                                             |
| 500M          | -31.67                                        | -33.47                                        | 1.80                             | 1.80                                             |
| 1G            | -40.44                                        | -40.81                                        | 0.37                             | 0.37                                             |

CONCLUSIONS

Cenospheres (45-100 micron size) were individually coated with silver by Electroless coating method. The Surface Morphological analysis, Chemical composition and Phase analysis of the metal coated cenospheres were carried out using SEM, EDX and XRD, respectively. The silver-coated cenospheres (2% & 5% by weight) were blended with polycarbonate to produce silver-coated cenosphere-polymer composites. Shielding effectiveness of the coated cenosphere-polymer composites were studied using the Coaxial Holder Method. From the characterization of coated cenospheres, the following conclusions were drawn:

From SEM Analysis
- The coated and uncoated cenospheres have true spherical morphology.
- Cross-section analysis showed the uniformity of the metal coating deposition on cenosphere surfaces and allowed the determination of their thicknesses. The thicknesses varied between 1 and 1.5µm.
- From the cross-sectional view of the SEM pictures of coated cenosphere-polymer composites, it was observed that coated cenosphere particles were embedded inside the polymer matrix. It was observed that the distributions of cenosphere particles were non-uniform which may be attributed to non-uniform mixing.

From EDX Analysis
- Electroless coating was carried out for silver which was successfully deposited on the cenosphere particles. The chemical compositions of the coating were revealed via detailed SEM and EDX analyses.
- The results of silver coating compositions revealed that the metals were well-deposited on the cenosphere surfaces. However, the thicknesses of the coatings were so small (~1.5µm) that the results were superimposed by the base material (cenosphere) compositions. Therefore, determination of the coating efficiency was not attempted.

From XRD Analysis
- Phase analysis by using XRD revealed the presence of silver in its elemental form. Also, their compounds (with oxygen and other elements) were also found to be present. That is, the coatings were not totally elemental as was the goal of the work. This aspect needed further detailed evaluation as well as modifications of processing parameters and coating methods.

From Shielding Effectiveness Test
- Shielding effectiveness of the Polycarbonate (PC)/5% Silver-Coated Cenosphere (SCC) Composites were studied using the Coaxial Holder Method. The shielding effectiveness of 5% PC/SCC composites between 100 KHz to 200MHz was 5.68dB.

References