ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 12, December 2013

Review on Nano particle synthesis for usage in Nano-Composites for EMI shielding

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Abstract:This review discusses about recent findings from literature about the synthesis of Nano particles and Carbon Nanotubes for usage as fillers in polymer composites for their application in EMI SHIELDING .Electrical conductivity, Magnetic permeability and mechanical strength are the primary characteristics that are necessary to be controlled for the application of radiation detection and shielding .EMI Shielding has a broad range of applications. In electromagnetic interference (EMI) shielding techniques, these material implanted Nano-composites are finding rapidly growing importance .Generally measurements in the EMI SE in the X-band range (8.2–12.4 GHz), are reported in the literature.

Keywords: EMI Shielding, Electrical conductivity, SWCNT, MWCNT, Nanocomposites, X-Band microwaves, Radiation detection.

I. INTRODUCTION

Electromagnetic interference (EMI) is an undesirable and uncontrolled off-shoot of explosive growth of electronics and widespread use of transient power sources. The addition of nanoparticles having specific properties inside a matrix with different configuration creates a novel material that exhibits hybrid and even better properties. The addition of any conductive nanoparticles to an otherwise insulating matrix leads to a significant increase of the electrical conductivity. But CNTs have a very high aspect ratio; a much lower content of CNTs is therefore required to get the same conductivity increase as the one obtained with more compact nanoparticles. This is especially interesting for EMI shielding materials since, it is desirable for such materials to have a high conductivity but a low dielectric constant. Hence, continued efforts have been made over past two decades to reduce EMI using a number of strategies and variety of materials including metals, carbon based materials, conducting polymers, dielectric/magnetic materials [1,3-8,11,12]. Based on results of various studies, it can be concluded that no single material can take care of all the aspects of shield e.g. strength, weight, cost, processability, level of shielding and stability under wide variety of chemical, thermal and radiative environment. Therefore, several attempts have also been made to utilize the good properties of above materials by using them in various combinations e.g. alloys, blends, composites, ceramics or layered/sandwiched structures [13-20]. The discovery of various nanomaterial and unique set of properties possessed by them has led to extensive research activities to identify the best materials for shielding. In particular, Nanocomposites have attracted enormous world-wide attention both due to promising properties as well as critical issues associated with them [21-24]. However, despite being so much progress, still a lot to be done to realize the theoretically predicted shielding performance of materials and to meet the other design considerations.

II. RELATED WORK

The literature surveyed in connection with the research project leading to the doctoral work. All the research papers connected with the work reported in this review are given in the list of references.

ISSN: 2319-8753

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III. SHIELD REQUIREMENTS AND MATERIAL CONSIDERATIONS

The careful analysis of theoretical shielding expressions revealed that in order to meet design requirements and for extending efficient shielding action, shield should possess either mobile charge carriers (electrons or holes)or electric and/or magnetic dipoles which interact with the electric (E) and magnetic (H) vectors of the incident EM radiation [27]. Metals are by far the most common materials for EMI shielding [3-5] owing to their high electrical conductivity. However, they suffered from problems [4,7] such as high reflectivity, corrosion susceptibility, weight penalty and uneconomic processing. Therefore, the development of state-of-the-art and commercially viable EMI shielding materials require dedicated efforts with strict control over above-mentioned electromagnetic attributes

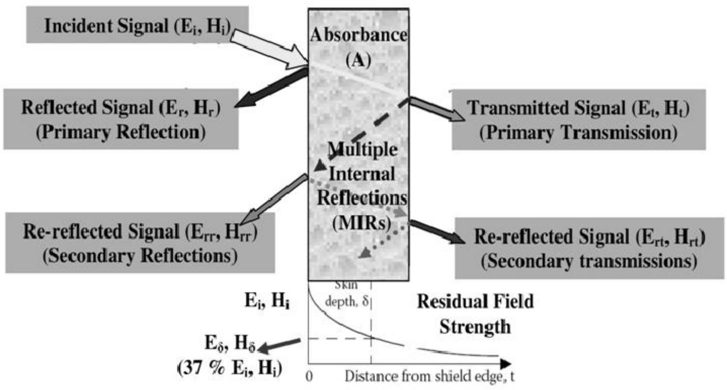

Figure 1. Graphical representation of EMI shielding. (Choudhary.V.et.al.,Ref [8] cited in the below list

IV. NANOCOMPOSITES

Nanocomposites represent a novel class of materials that possess unique combination of electrical, thermal, dielectric, magnetic and/or mechanical properties useful for efficient electromagnetic shielding response [21-23]. In general, there are two main material constituents in any composite: the matrix or continuous phase and reinforcement or dispersed phase. Besides, a third phase so-called interfacial region is also present which is responsible for communication between the matrix and filler. Interface possesses unique combination of properties that are not exhibited by filler or matrix alone and is responsible for the macroscopic properties of formed Nanocomposites. Wood and straw reinforced mud are simplest examples of natural and manmade bulk composites. In case of bulk composites, the concentration of interfacial regions is too low compared to matrix and reinforcement and often neglected. However, in case of Nanocomposites, fillers possess nanometres(1 nm = 10-9 m) range dimensions (~10,000 times finer than a human hair) and extend ultra-large interfacial area per volume to host polymer matrix. Therefore, at nano scale level, the concentration of bulk and interfacial regions become comparable. Consequently, significant changes in the properties of Nanocomposites are observed compared totheir bulk counterparts such as enhanced strength, better optical properties (e.g. improved clarity), good electrical properties and/or improved thermal/oxidative stability [22-24, 26-27].

V. POLYMER MATRIX NANOCOMPOSITES

Polymer is a versatile choice as a matrix material due to unique properties like low density, flexibility, facile processability, corrosion resistance etc. However, for electrical and electromagnetic applications, the most import requirement is the presence of electrical conductivity [1,3-8]. The primary mechanism of shielding is reflection for which shield should possess sufficient electrical conductivity. A secondary mechanism of shielding is absorption which requires the presence of electric or magnetic dipoles [8,15,27]. Therefore, in the recent past, a wide variety of filler materials have been used for making Nanocomposites [15,17-19,28-38] with a broad range of electrical conductivity **(σ)** and/or electromagnetic attributes such as permittivity **(ε)** or permeability **(μ)**. In this regard, though polymer based Nanocomposites offer distinct advantages against metals but the establishment of electrical conductivity and/or dielectric/magnetic properties is not a straight forward task because the high specific surface area of nanofiller leads to their agglomeration, non-uniform properties and failure to realize their full potential [21-24]. Therefore, the development of state-of-the-art and commercially viable EMI shielding materials require coherent strategies and dedicated efforts to achieve strict control over above-mentioned electromagnetic attributes. The properties of polymer based Nanocomposites are governed by the nature and concentration of its constituents (i.e. filler and matrix) and level of interaction between them. However, in most Nanocomposites, matrix mainly plays the role of holding the fillers and imparting processability to system. Further, most polymeric matrices have poor electrical, dielectric or magnetic properties and are transparent to electromagnetic radiations. Therefore, most of the electrical and electromagnetic properties of Nanocomposites are governed by the nature of filled inclusion. The selection of a particular filler depend on the desired properties e.g. when electrical conduction is important electrically conductive fillers are used, whereas for dielectric/magnetic properties fillers with magnetic/electric dipoles are preferred. Therefore, in the recent past a numerous nano-materials with good electromagnetic properties have been employed as fillers e.g. conducting polymers, carbon black, graphite, carbon nanotubes (CNTs), graphene and dielectric (titanates) or magnetic (ferrites) particles[15,18, 31-38]. The next section will focus on the recent progress made in the EMI shielding properties of polymer based Nanocomposites with special reference to above fillers.

VI. POLYMER NANOCOMPOSITES : PROBLEMS, CHALLENGES AND EMI SHIELDING PERFORMANCE

As already mentioned and shown in Fig. 1, the primary shielding mechanism is reflection. The theoretical shielding equations suggest that reflection can be achieved by using highly conducting materials with low values of permittivity/permeability. Therefore, addition of conducting fillers, that can form percolation network in the host polymer matrix, seems to be the solution for inducing electrical conductivity in the Nanocomposites. However, the incorporation of nanomaterial within polymer matrix is not a straight forward task because of the ultrahigh surface area and agglomeration tendencies. This often resulted in failure to efficiently translate the nanoscopic properties of these fillers into macroscopic properties of resultant Nanocomposites and inability to realize their full potential [15, 21, 22, 26, 27, and 39]. Therefore, handling and dispersion of nanofiller is the biggest challenge not only for Nanocomposites technologies but for nanoscience as a whole. Nevertheless, so much progress has already been made in the development of polymer based Nanocomposites and the same will be discussed in the next section. For reader's convenience, fillers have been classified into three broad categories: metal or carbon based, conducting polymer based, dielectric/magnetic functionality based.

VII. CARBON NANOTUBES (CNTS)

The real Nanocomposites technology started with the discovery of carbon nanotubes (CNT) by Iijima [40] and subsequent formation of first CNT based polymer Nanocomposites by Ajayan et al. [21] .CNTs are made up of graphene sheets rolled up in the form of single or multiple concentric cylinders constituting single wall carbon nanotubes (SWCNTs) or multiwall carbon nanotubes (MWCNTs) respectively. CNTs can be considered as ultimate carbon fibber's due to ultra-high strength (10 to 100 GPa) and modulus (~1.0 TPa) values along with exceptional electrical (**10^4-10^6 S/cm**) and thermal properties (3000-6000W/mK) [21,39,40,41]. The higher intrinsic conductivity and aspect ratio of CNTs (100-5000) compared to carbon black allows the formation of conductive composites at low loading of CNTs due to low percolation thresholds (minimum loading level at which a continuous network of conducting particles is formed) resulting in achievement of better electrical conductivity and electromagnetic response at the same loading level. CNTs form a three-dimensional conductive network within the matrix, hence electron can tunnel from one filler to another, and in doing so it overcomes the high resistance offered by insulating polymer matrix. Due to low percolation threshold of CNTs and comparatively less loading levels required for EMI, the bulk physical properties of polymer matrix are not disturbed to an extent to exert any harmful effect on mechanical properties of resultant Nanocomposites. Therefore, CNTs have shown definite potential for developing light-weight and mechanically strong EMI shielding materials [37-38, 43-45]. Several studies have been reported on the electrical and EMI shielding properties of CNT-polymer composites[15, 42, 46-53]. Additionally, it has been found that, depending on the loading level and achieved conductivity values (Fig. 3), CNT Nanocomposites may also find potential applications as antistatic/electrostatic discharge(ESD), electrostatic painting [15,41,42] etc. However, the effective utilization of CNTs for fabricating Nanocomposites strongly depends on the homogeneous dispersion of CNTs

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 12, December 2013

throughout the matrix without destroying their integrity. In the previous section we have seen that electrical conductivity of CNTs based polymer Nanocomposites depends on many factors including type of CNTs, intrinsic conductivity, aspect ratio, surface functionalization, processing method, loading level and nature of host polymer matrix. However, the direct effect of filler aspect ratio, loading level and sample thickness on experimental SE along with theoretical studies was shown by Al-Saleh et.al [54] taking polypropylene (PP)/MWCNT system. They reported that SE (in 8.2-12.4 GHz frequency range) of composite plates (1.0 mm thick) made up of 7.5 vol% MWCNT/polypropylene (PP) .The experimental results showed the involvement of absorption and reflection as major shielding and secondary shielding mechanism respectively. The modelling results demonstrated that multiple-reflection within MWCNT internal surfaces and between MWCNT external surfaces decrease the overall EMISE. The EMI SE of MWCNT/PP composites increased with increase in MWCNT content and shielding plate thickness.

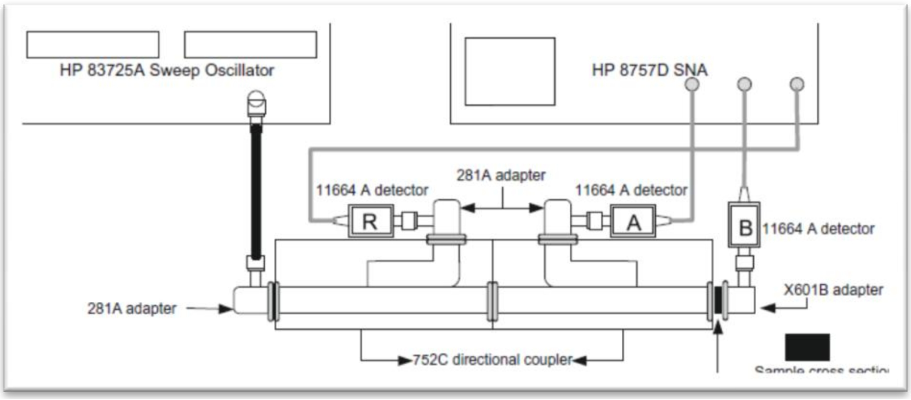

Figure2: Schematic sketch shows the instrument used to evaluate the EMI SE of the composites. .(Mohammed H.Al-S.et.al.,Ref [54] cited in the below list)

Mathur.R.B.et.al., [55] Synthesized MWCNT/PMMA composite film(7 layers) by solvent casting method A and MWCNT by CVD technique and MWCNT/PMMA bulk composite (2 layers) by solvent casting method B. Characterization techniques used were SEM, four point method and VNA. EMI SE up to 40 dB in the frequency range 8.2–12.4 GHz was achieved with SCF7 (thickness 2.1 mm) compared to 30 dB achieved with SCB2 (thickness 2.2 mm). A value of 40 dB achieved for MWCNT–PMMA composite of 2.1 mm thickness by stacking composite films containing 10 vol.% MWCNT is the highest achieved EMI value in the X-band so far. Doppler, weather radar, TV picture transmission, and telephone microwave relay systems lie in X-band. In the present studies, stacking method was used for the composite films and the bulk composite as well. Demonstration of SE value of ~ -40 dB can be achieved with seven layers of stacked composite films (SCF7) compared to -30 dB for two layers of bulk composite (SCB2) of the same thickness (2.1 mm). The stacking of thin film layers of the network over one another acts as a conducting mesh to intercept electromagnetic radiation resulting in multiple reflection and absorption phenomena within the layers. The layered structure increases the absorption component of the shielding effectiveness and hence the total EMI SE of the composite.

Changxin Chen et.al.[56] Synthesized composite based on multiwalled carbon nanotubes (MWCNTs)-filled styrene acrylic emulsion-based polymer in a water-based system. The MWCNTs were demonstrated to have an effect on the dielectric constants, which effectively enhance electromagnetic shielding efficiency (SE) of the composites. A low conductivity threshold of 0.23 wt% can be obtained. An EMI SE of ~28 dB was achieved for 20 wt% MWCNTs. The AC conductivity ($\boldsymbol{\sigma_{ac}}$) of the composites, deduced from imaginary permittivity, was used to estimate the SE of the composites in X band (8.2–12.4 GHz), showing a good agreement with the measured results. Characterization techniques used here are FESEM, Raman spectroscopy, 4 point method to measure DC electrical conductivity, and VNA for EMI SE. As the measured and the calculated results are in good correlation and increases with the increase in purified MWCNTs concentration and $\boldsymbol{\sigma_{ac}}$. These observations can be understood by a simple phenomenological electrical model of parallel resistors and capacitors formed in the Nanocomposites. In this model, MWCNTs have excellent electrical properties and high aspect ratio, which can be assumed to be an equivalent resistor. The styrene acrylic emulsion-based polymer matrix can be assumed to be a capacitor. The above-mentioned model can be demonstrated by the super capacitor structure made by incorporating defective CNTs into polypyrrole via an electrochemical method reported by Hughes et al. [58]. They believed that the acquired super capacitors are mainly ascribed to the presence of porous structures and the micro bilayer nature of the defective CNT-filled composite films. When the content of the MWCNTs increases, the number of equivalent parallel resistors and capacitors also increases, consequently, both the $\boldsymbol{\sigma_{ac}}$ and EMI SE increase. MWCNTs, with some defects after purification, favor uniform dispersion into an environmentally friendly, water-based styrene acrylic emulsion to form an efficient electromagnetic shielding composite and have a major influence on the dielectric and electromagnetic properties. An EMI shielding effectiveness of ~28 dB in X band was achieved for 20 wt% MWCNTs. The AC conductivity ($\boldsymbol{\sigma_{ac}}$) of the composites, deduced from imaginary permittivity (ε''), was used to estimate the SE and the electromagnetic shielding mechanism was explained by a parallel resistor–capacitor model. Suggested this composite can be applied for building shielding applications in high frequencies.

SundaraRamaprabhu et.al.[59] synthesized Novel hybrid nanofiller consisting of multiwalled carbon nanotubes and $\mathbf{MnO_2}$nanotubes reinforced PVDF composite by mixing the respective composite solutions at high-speed rotations per minute followed by solvent casting. The cross-sectional morphology of the composites were observed using field emission scanning electron microscope and transmission electron microscope. The crystal structure of polymer, MNTs, and *f*-MWCNTs has been investigated by powder X-ray diffraction. MNTs and *f*-MWCNTs acting as spacers in PVDF matrix helps in reducing the aggregation of the nanofiller and creates an excellent 3 D conducting network in the polymer. MNTs are acting as very good filler material when added to the entangled carbon nanotubes incorporated polymer. An EMI shielding effectiveness of approximately 20 dB has been achieved with 5 wt.% MNTs and 1 wt.% *f*-MWCNTs in polymer matrix in X-band region. The increase in EMI shielding effectiveness with the addition of nanofiller is attributed to the enhanced electrical conductivity of the composite due to the addition of *f*-MWCNTs and good homogeneity of the nanofiller in the polymer. The present hybrid polymer Nanocomposites are proposed as low-cost and efficient EMI shielding materials in X-band region.

Prabhakar R. Bandaru et.al.[60] synthesized a composite comprised of carbon nanotubes (CNT) integrated with a Reactive Ethylene Terpolymer (RET). Such composites were synthesized through the chemical reaction of the functional groups on the CNT with the epoxy linkage of the RET polymer. The main advantages of these composites incorporate good dispersion with low electrical percolation volume fractions (~0.1 volume %), yielding outstanding microwave shielding efficiency for EMI applications. The shielding effectiveness was characterized for both single-walled and multi-walled CNT based composites and was much enhanced in the former. The specific roles of absorption and reflection in determining the total shielding, as a function of the nanotube filling fraction, is also discussed and this study has provided an example of a nanotube (SWNT/MWNT)-polymer (e.g., RET) system which utilizes functional group interactions for achieving uniform dispersion with low electrical percolation concentrations and enhanced microwave shielding effectiveness. Analysis of the total observed EMI shielding was used for investigating the mechanisms of absorption and reflection in the composite, where a cross-over from reflection dominated shielding to absorption dominated shielding was observed at a CNT volume fraction of ~ 2.3%. It was also concluded that SWNTs were much more effective compared to MWNTs. Preliminary experiments probing the mechanical characteristics of the proposed CNT-RET polymer composites have indicated increased tensile strength as a function of increasing volume fraction of the CNTs. we have indeed observed a more uniform dispersion using functionalized SWNTs for both low (Fig. 3a) and high (Fig. 3b) CNT filling fractions, as observed through the Scanning Electron Microscopy) images of the fracture surfaces of the CNT/RET composite. The beneficial effects of our proposed functionalization scheme are also evident through a more homogeneous dispersion of the CNTs in the polymer matrix in comparison to the clumping observed (Fig. 3c) when un-functionalized CNTs are mixed into the polymer. In summary, proposed scheme of using functionalized CNT- polymer composites together with our obtained results could be used as a basis for light-weight, high shielding efficiency materials for EMI applications. The X-band is used for both civil and military communications with applications as diverse as weather monitoring, vehicular detection and air traffic control and defense tracking[61].

ISSN: 2319-8753

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Vol. 2, Issue 12, December 2013

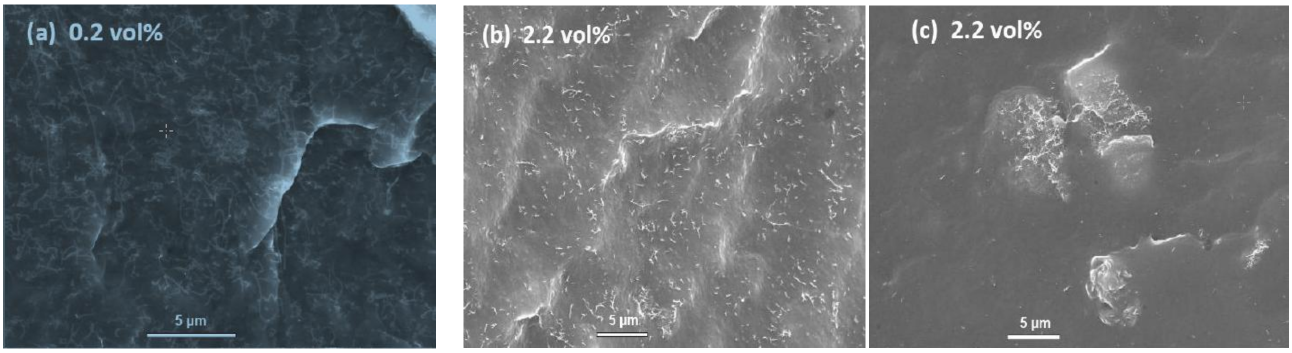

Fig.3. *Uniform* dispersion of functionalized SWNTs in the RET polymer is indicated, through Scanning Electron Microscope (SEM) micrographs, at both (a) 0.2 volume % and (b) 2.2 volume % filling fractions of the SWNTs. On the other hand, (c) non-functionalized SWNTs dispersed into the RET matrix exhibit clumping.(Prabhakar R. Bandaru .et.al.,Ref [60] cited in the below list)

Yongsheng Chen et.al. [62] Synthesized three types of single-walled carbon nanotube (SWCNT) homogeneous epoxy composites with different SWCNT loadings (0.01–15%) for electromagnetic interference (EMI) shielding effectiveness (SE) in the X-band range (8.2–12.4 GHz). The SWCNTs used in this study were produced using our modified arc-discharge method [63,64] and have diameters mainly in the range of 1.3–1.8 nm. Three types with different aspect ratios and/or wall structures were then used for the fabrication of the SWCNT composites. The effect of the SWCNT structure including both the SWCNT aspect ratio and wall integrity, on the EMI SE have been studied and are found to correlate well with the conductivity and percolation results for these composites. Characterization techniques used are 4 point probe method for DC electrical conductivity, VNA for EMI SE and XRD analysis. The conductivity and permittivity of the three SWCNT composites with the same loadings all show considerable differences. We were thus motivated to study and compare in more detail the changes in the EMI performance of the composites and their structure–property relationship for the three different types of SWCNTs.Figure8 gives the SE of these composites with 15 wt% of SWCNTs at 8.2–12.4 GHz. It can be seen that the SE of the ‘‘long-SWCNTs’’ composites is significantly higher than that of the ‘‘short-SWCNTs’’ composites at all frequencies. After the ‘‘short-SWCNTs’’ were annealed at high temperature, the SE for their composites increased significantly, but was still lower than that of the ‘‘long-SWCNTs’’ composites. For example, the EMI SE of the composites with15 wt% of ‘‘long-SWCNTs’’, of ‘‘annealed-SWCNTs’’ and of ‘‘short-SWCNTs’’ were 25, 21 and 16 dB at 10 GHz respectively.

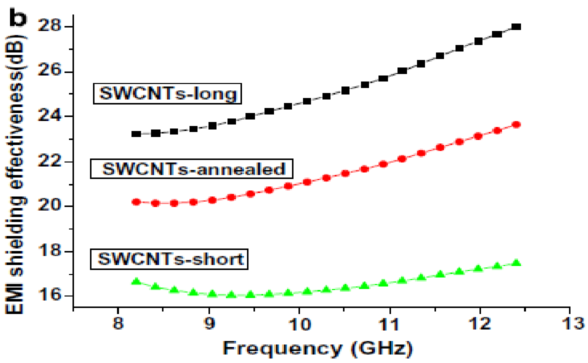

Fig. 4. EMI shielding effectiveness (SE) for SWCNT–epoxy composites. SE of SWCNT (15 wt %)-epoxy composites in the range of 8.2–12.4 GHz. (Yongsheng Chen et.al .,Ref [62] cited in the below list)

The composites show very low conductivity thresholds (e.g. 0.062%). A 20–30 dB EMI SE has been obtained in the X-band range for 15% SWCNT loading, indicating that the composites can be used as effective lightweight EMI shielding materials. With controllable synthesis of SWCNTs [63] a new approach to effectively tune the conductivity and EMI performance for SWCNT composites is now possible. These composites are thus very promising for use in both civil and military electrical applications as effective light-weight EMI shielding materials.

R. B. Mathur et.al.[66] fabricated MWCNT–epoxy composites were fabricated using a novel dispersion and compression molding technique which enabled dispersion of high loadings of CNTs(up to 20.4 wt%) uniformly. Characterization techniques used are SEM, d.c four probe contact method, VNA, HRTEM, The MWCNT content in epoxy matrix was determined using a thermo gravimetric analyser (TGA). A value of 9 **S/cm^{-1}** of electrical conductivity was achieved which helped in attaining high EMI shielding properties of such composites i.e., up to 60 dB in X-band which is the most desired range for commercial applications such as radar, TV picture transmission, and telephone microwave relay systems, etc. An addition of MWCNT in the epoxy also provided structural integrity to the composites with tensile strength of the order of 60 MPa along with improved thermal conductivity which is a prerequisite for efficient heat dissipation in microelectronics devices.

Kenneth[69] fabricated Four, eight-ply Nanocomposites panels from Cycom 5575-2 glass with multi-walled carbon nanotube (MWNT) plies for satellite structures as a solution to reduce system weight while retaining the desired survivability against electromagnetic interference (EMI).The control panel had eight plies of glass fabric reinforced composite only and will be referred to as *8G*. This enabled the comparison of all properties with and without carbon nanotubes (CNTs). The other three panels had differences in the placement of layers containing CNTs. The first one had four CNT plies on one half with four plies of glass on the opposite half and will be referred to as *4G/4CNT*, the second one had two plies of CNT on the exterior of each side with four plies of glass in the middle and will be referred to as *2CNT/4G/2CNT*, and the third one had alternating CNT/glass fabric plies across the thickness and will be referred to as *(G/CNT)$_4$*. These four configurations were measured for their respective EMI shielding properties after experiencing monotonic tension load, thermal cycling, and a combination of thermal cycling followed by monotonic tension load. EMI measurements were taken in terms of decibels (dB) before and after each thermal cycle or monotonic tension test. Tension tests involved increasing the load incrementally until ultimate failure. Thermal cycling was conducted with a cycle having a total soak time of 20 seconds. The first 10seconds were at +60 °C and the last 10 seconds were at -60 °C. The total number of thermal cycles was 17,500.Multiple EMI shielding effectiveness (SE) values were measured on metallic materials for comparison. The average EMI SE of type 2024 aluminum and type 7075 aluminum for the frequency range of 2 GHz – 18 GHz were 112.6 dB and 113.46 dB, respectively. In a previous study, EMI SE values for four distinct Nanocomposites containing nickel nan strands (NS) were measured and their averaged attenuation prior to testing are as follows: Control 1 – 58 dB, Exterior 1 – 73 dB, Exterior 2 – 66 dB, Interlaminar 1 – 64 dB, and Midplane 1 – 55 dB. The stacking sequence of the 8-ply, NS Nanocomposites was a quasi-isotropic lay-up of [0/90/±45/]s. The Control specimen contained no NS plies, the Exterior specimens had one NS ply on the exterior of the 0° ply for a total of two NS plies, Interlaminar had one NS ply between the 0° and 90 plies and one NS ply between the 45° and -45° plies for a total of four NS plies, and the Midplane specimen had one NS ply directly in the Midplane between the -45° and -45° plies. The EMI SE values for all four MWNT Nanocomposites configurations were measured prior to testing in the same frequency range and the averaged numbers are as follows: 8G – 0.33 dB, 4G/4CNT – 87.5 dB, 2CNT/4G/2CNT – 87.5 dB, and (G/CNT)$_4$ – 71.76 dB. The EMI SE performance of the Nanocomposites containing MWNTs exceeded those comprised of NS. This study found that the EMI SE properties for all four MWNT panels experienced varying degrees of reduction in EMI SE after thermal cycling and/or monotonic tension test until fracture. The final EMI SE values for all four MWNT Nanocomposites configurations were measured from 8.2 GHz – 12.4 GHz and were taken after testing was completed and the averaged numbers are as follows: 8G – 1.01 dB, 4G/4CNT – 60.98 dB, 2CNT/4G/2CNT – 83.49 dB, and (G/CNT)$_4$ – 68.45 dB. Please note the difference in frequency ranges between the EMI SE values prior to tests (2 GHz – 18 GHz) and during tests (8.2 GHz – 12.4 GHz). The MWNT Nanocomposites lay-up providing the best performance against EMI was the 2CNT/4G/2CNT configuration, which is in agreement with and comparable to the NS Exterior configuration with respect to placement of the nanofibers. The failure mechanisms were consistent for each MWNT Nanocomposites configuration. This occurred through the initial formation of transverse fiber matrix cracks that triggered the delamination of one or more CNT plies, which then led to the progression of transverse strand deboning. Increasing stress caused additional fill

ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

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strand separation and delamination of multiple plies resulting in ultimate failure, and for all configurations the multi-walled CNTs remained intact.

Isabel Molenberg et.al.,[70] fabricated polymer/CNTs Nanocomposites and characterized using a two-step diagnostic method. They were first characterized in their solid form, i.e. before the foaming process and the most interesting polymer matrices (with embedded CNTs) could be selected. This way, only the promising blends were foamed, therefore avoiding the unnecessary fabrication of a number of foams. These selected blends were foamed and then characterized.

Yonglai Yang *et a.,* [65] demonstrated the formation of a novel nanocomposite with superior microstructure and improved electromagnetic interference (EMI) shielding characteristic. Using a combination of dispersing low-cost carbon nanofibers and a small quantity of carbon nanotubes within the polystyrene matrix, This nanocomposite is very promising for use as an effective and practical EMI shielding material owing to its high shielding effectiveness, light weight, low cost, and easy processability.
R.B.Mathur et.al.,[2] fabricated Acid modified multiwalled carbon nanotubes (a-MWCNT) reinforced polyurethane (PU) composite films using a solvent casting technique with 0–10 wt% of a-MWCNTs. A Nano indentation study has been carried out on these films in order to investigate the mechanical properties. Incorporation of a-MWCNTs in a PU matrix led to a drastic increase in the hardness and elastic modulus. The maximum Nano indentation hardness of 217.5 MPa for 10 wt% a- MWCNT loading was observed as compared to 58.5 MPa for pure PU (an overall improvement of 271%). The nanoindentation elastic modulus for a 10 wt% a-MWCNT loaded sample was 1504.2 MPa as compared to 385.7 MPa for pure PU (an overall improvement of 290%). In addition to hardness and elastic modulus, other mechanical properties *i.e.* plastic index parameter, elastic recovery, ratio of residual displacement after load removal and displacement at the maximum load and plastic deformation energy have also been investigated. The enhancement in the mechanical properties was correlated with spectroscopic and microscopic investigations using Raman spectroscopy, SEM and TEM. Dispersion of a-MWCNTs in the PU matrix was studied using Raman mapping. Besides the improvement in mechanical properties, the electromagnetic interference shielding properties were also investigated in the 8.2–12.4 GHz (X-band) frequency range. A value of 29 dB for the 10 wt% MWCNT loaded sample having a thickness of 1.5 mm was obtained. Therefore, these polyurethane composite films shall not only be useful for hard and scratch less coatings but also for protection from electromagnetic radiation in making electromagnetic shielding bags for packaging of electronic circuits and for scratch less tape for laminating circuit boards.

Qian Liu.et.al., [9] fabricated Thin films of ordered mesoporous carbon (OMC) with various mass fractions (0–40 wt%) composited with poly(methyl methacrylate) (PMMA) *via* a solvent casting method for electromagnetic interference (EMI) shielding materials. The OMC (actually CMK-3) embedded inside the polymer matrix endows the composite films with high electric conductivity which goes up with the increase of the OMC mass fraction. Through a four-probe method, it has been found that this novel composite film has a typical percolation threshold of 12.8 wt% CMK-3. Furthermore, the measured EMI shielding efficiency (SE) in 8.0–12.0 GHz (X-band) of the OMC / PMMA composite films has a strong dependence on the OMC content. The contribution of the absorption to total EMI SE of the system is larger than that of the reflection, that is, the absorption is more than 70%. For the composite film with 40 wt% OMC (0.4 mm in thickness), the mean EMI SE reaches 18.5 dB, indicating its promising application in EMI shielding.

Bingqing Yuan et.al.,[10] prepared Single-wall carbon nanotube/polyaniline (SWCNT/PANI) and graphene Sheet/polyaniline (GS/PANI) composites by a simple alcohol-assisted dispersion and pressing process. The SWCNTs and GSs were synthesized by the dc arc-discharge method. The dc electrical conductivity and the electromagnetic interference (EMI) shielding effectiveness (SE) of these two kinds of composites were measured. The experimental results reveal that the conductivity and the EMI SE of the GS/PANI composite are better than that of the SWCNT/PANI composite, and the absorption proportion of the SWCNT/PANI composite is higher than that of the GS/PANI composite. The EMI shielding results (2–18 GHz) also show that both composites present an absorption-dominant mechanism and present a wide application prospect in the field of EMI shielding and microwave absorption.

Liang J et.al., [57] prepared Composites of acrylonitrile butadiene styrene (ABS), epoxy and soluble cross-linked polyurethane (SCPU) with various loadings of single-walled carbon nanotubes (SWCNTs) . Their electromagnetic interference (EMI) shielding effectiveness (SE) in the frequency range of 8.2-12.4 GHz (X band) was studied. Well-dispersed SWCNT composites were created in these three representative polymer matrixes. The choice of polymer matrix greatly affects the conductivity, percolation threshold, and EMI shielding properties of the SWCNT/polymer composites. Enhanced EMI SE performances were observed for the composites with better dispersed SWCNTs. Moreover, the EMI SE performances strongly correlated with SWCNT loading in the polymer matrix. The best SWCNT dispersion was achieved in the epoxy matrix: 20-30 dB EMI SE was obtained with 15 wt% SWCNTs

VIII. CONCLUSION

Therefore, different researchers have reported different percolation/conductivity/EMI shielding values even for the same matrix polymer. These observations suggest that SE of CNT filled polymer Nanocomposites depends on many factors including fabrication techniques, type of CNT, level of dispersion and nature of host matrix. It is clear from the theoretical predictions and previous studies that to maximize the electrical conductivity, mechanical properties and to achieve high EMI shielding, higher loading (>20 %) of CNTs is preferred. However, most of CNT composite with polymer matrix has maximum loading around40 wt% [67] and 10 wt% in epoxy [68]. Higher loading often leads to decrease of mechanical properties due to agglomeration.

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