

Evaluation of the microwave absorption characteristics for the PVA samples loaded with MWCNT

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Abstract- An electromagnetic shield is a conductive material, which attenuates electromagnetic energy. The amount of attenuation in the electromagnetic field by a shield is defined as shielding efficiency (SE). The total shielding effectiveness (SE_T) is defined as the ratio of incident to transmitted power and which is equal to SE due to absorption of EM energy (SE_A), SE due to reflection of EM energy from the material surface (SE_R) and multiple internal reflection of EM radiation. There are three mechanisms for control this electromagnetic pollution which is consisting of surface reflection, absorption and multiple reflections of the electromagnetic wave. Among them, absorption is the best mechanism for shielding of the electromagnetic wave and using microwave absorption materials is great technique to prevent EMI. An electromagnetic wave absorber attracts the attention of many workers that can be largely divided into two categories according to the absorbing principle: the absorber using the magnetic lossy and the dielectric lossy materials, and the corresponding lossy materials are identified as the magnetic absorber and the dielectric absorber respectively. If electrical conductive filler (Carbon black (CB)) is used, the composite properties can change from insulator to conductive ones. Electrical conductivity can change in the magnitude of several orders. The present study is aimed to study the microwave absorption characteristics for the PVA samples loaded with MWCNT. The materials used in this work were; polyvinyl alcohol (PVOH, PVA, or PVAI) which is a water-soluble synthetic polymer; carbon nanotube (CNT) which is allotropes of carbon with a cylindrical nanostructure (Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1); as well as sodium dodecyl sulfate (SDS or NaDS), sodium laurilsulfate or sodium lauryl sulfate (SLS) which is an organic compound with the formula $CH_3(CH_2)_{11}OSO_3Na$, it is an anionic surfactant used in many cleaning and hygiene products. Samples were prepared in three steps. First, the solution samples were prepared by dissolving 1wt% SDS in distilled water using magnetic stirrer (corning hot plate stirrer PC-351) at 25°C for 1 hr. In the second step different weights of

MWCNT in volume fraction (0.004, 0.009, 0.019, 0.029 and 0.038) were dispersed in the SDS/H₂O solutions by using a high power ultrasonic homogenizer at room temperature for 20min. Finally, solutions were prepared by dissolving 8wt % of PVA in sonicated solutions by using a magnetic stirrer at 80°C for 2hr. The combination of polymers with carbon nanotubes allows linking the properties of both materials to form new functional materials, with application in the microwave area. As obtained from the data of shield effectiveness due to absorption, and the total shield effectiveness due reflection and SE_L (the correction term induced by the reflecting waves inside the shielding barrier), the total shield effectiveness increased by increasing the volume fraction and frequency and the SE_A comprise a major portion of the EMI SE. The maximum value (89.9dB) of SE_T is obtained at (35GHz) for the composites with $V \geq (0.029)$.

Conclusion: The EMI shielding measurements revealed that, the main contribution of these composites to effective EMI shielding was due to absorption. The maximum value (100dB) of SE_T was obtained at 35 GHz for $V \geq 0.029$. The SE_T of the composites increases with both increasing volume fraction and increasing frequency. As expected from the above data on SE_R , SE_A and SE_L the trend of SE_T shows that SE_A comprises a major portion of the EMI SE.

Keywords—microwave absorption, PVA, MWCNT

I. INTRODUCTION

Electromagnetic interference (EMI) shielding refers to the reflection and/or adsorption of electromagnetic radiation by a material, which thereby acts as a shield against the penetration of the radiation through the shield. As electromagnetic radiation, particularly that at high frequencies (e.g. radio waves, such as those emanating from cellular phones) tend to interfere with electronics (e.g. computers), EMI shielding of both electronics and radiation source is needed and is increasingly required by governments around the world. The importance of EMI shielding relates to the high demand of today's society on the reliability of electronics and the rapid growth of radio frequency radiation sources [1–9].

EMI shielding is to be distinguished from magnetic shielding, which refers to the shielding of magnetic fields at low frequencies (e.g. 60 Hz). Materials for EMI shielding are different from those for magnetic shielding.

EMI shield is essentially a barrier to regulate the transmission of the electromagnetic EM wave across its bulk. In power electronics, term shield usually refers to an enclosure that completely encloses an electronic product or a portion of that product and prevents the EM emission from an outside source to deteriorate its electronic performance. Conversely, it may also be used to prevent an external susceptible (electronic items or living organisms) from internal emissions of an instrument's electronic circuitry. Shielding is the process by which a certain level of attenuation is extended using a strategically designed EM shield. The shielding efficiency is generally measured in terms of reduction in magnitude of incident power/field upon transition across the shield

II. MATERIALS AND METHODS

A. Materials Used in this Work

a-) Polyvinyl Alcohol

Polyvinyl alcohol (PVOH, PVA, or PVAl) is a water-soluble synthetic polymer. It has the idealized formula $[CH_2CH(OH)]_n$. It is used in papermaking, textiles, and a variety of coatings. It is white (colourless) and odour-less. It is sometimes supplied as beads or as solutions in water.

b-) Carbon nanotube

Carbon nanotube (CNT) is allotropes of carbon with a cylindrical nanostructure. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1. Nanotubes are members of the fullerene structural family. Their name is derived from their long, hollow structure with the walls formed by one-atom-thick sheets of carbon, called graphene. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs). Individual nanotubes naturally align themselves into "ropes" held together by van der Waals forces, more specifically, pi-stacking. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials. For instance, nanotubes form a tiny portion of the material(s) in some (primarily carbon fiber) baseball bats, golf clubs, or car parts.

c-) Sodium dodecyl sulfate

Sodium dodecyl sulfate (SDS or NaDS), sodium laurilsulfate or sodium lauryl sulfate (SLS) is an organic compound with the formula $CH_3(CH_2)_{11}OSO_3Na$. It is an anionic surfactant used in many cleaning and hygiene products. The salt is of an organosulfate consisting of a 12-carbon tail attached to a sulfate group, giving the material the amphiphilic properties required of a detergent. Being derived from inexpensive coconut and palm oils, it is a common component of many domestic cleaning products.

Sodium coco-sulfate is essentially the same compound, but made from less purified coconut oil.

B. Experimental

PVA powder ($M_w = 72000$ g/mol, 98% hydrolyzed) as a polymer was obtained from Merck and CNT (purity = 95%, diameter ~ 10 nm, Length: 30 μ m) were supplied from Neutrino Company. Sodium dodecyl sulfate (SDS) was obtained from Sigma-Aldrich. The solvent used for dissolving PVA and PVA/SDS/CNT dispersion was distilled water. All reagents used were of analytical grade and were used as received without further purification.

Preparation of Samples

Solutions were prepared in three steps. First, the solution samples were prepared by dissolving 1wt% SDS in distilled water using magnetic stirrer (coming hot plate stirrer PC-351) at 25 °C for 1 hr. In the second step; different weights of CNT were dispersed in the SDS/H₂O solutions by using a high power ultrasonic homogenizer (UP200, Germany) at 0°C for 20min. 8wt% of PVA in sonicated solutions by using a magnetic stirrer at 80°C for 2hr. The calculated CNTs concentrations in each composition of any sample are listed in Table 1

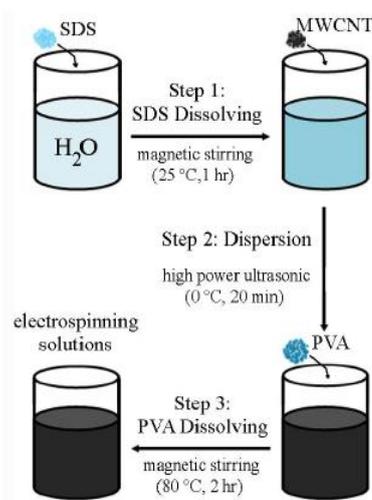


Fig. 1: Illustration of the dispersion process steps.

Table 1: Concentrations of CNT, SDS, and PVA in the mixed solutions

	Mass in 100ml H ₂ O			MWCNT Mass Ratio (wt%)
	PVA(mg)	SDS(mg)	CNT(mg)	
MWCNT-0	8000	920	0	0
MWCNT-1	8000	920	90	1
MWCNT-2	8000	920	180	2
MWCNT-4	8000	920	360	4
MWCNT-6	8000	920	540	6
MWCNT-8	8000	920	720	8

III. RESULTS AND DISCUSSION

An electromagnetic shield is a conductive material, which attenuates electromagnetic energy. The total shielding effectiveness (SE_T) is defined as the ratio of incident to transmitted power and which is equal to SE due to absorption of EM energy (SE_A), SE due to reflection of EM energy from the material surface (SE_R) and multiple internal reflection of EM radiation. Therefore the total SE_T of the sample is expressed as equation (1) [10-12].

$$SE_T = 10 \log \left(\frac{P_{in}}{P_{out}} \right) = SE_A + SE_R + SE_L \quad (1)$$

Where P_{in} and P_{out} are the power incident on and transmitted through a shielding material, respectively. The SE_T is expressed in decibels (dB). SE_A and SE_R are the absorption and reflection (from both sides of the material with neglect of the multiple reflections inside the barrier) shielding efficiencies, respectively. The third term (SE_L) is a positive or negative correction term induced by the reflecting waves inside the shielding barrier, negligible when: $SE_A > 15\text{dB}$. The terms in equation (1) can be described as:

$$SE_A = 8.86 \alpha l \quad (2)$$

$$SE_R = 20 \log \frac{(1+n)^2}{4n} \quad (3)$$

$$SE_L = 20 \log \left(1 - \frac{\exp(-2\gamma l)(1-n)^2}{(1+n)^2} \right) \quad (4)$$

Where the parameters α , n and γ are defined by the following equations, and (l) is the thickness of the shielding barrier.

$$\alpha = \frac{2\pi}{\lambda_0} \sqrt{\frac{\epsilon'(\sqrt{1+\tan^2\delta})}{2}} \quad (5)$$

$$n = \sqrt{\frac{\epsilon'(\sqrt{1+\tan^2\delta}) \pm 1}{2}} + i \sqrt{\frac{\epsilon''(\sqrt{1+\tan^2\delta}) \pm 1}{2}} \quad (6)$$

$$\gamma = \left(\frac{2\pi}{\lambda_0} \right) \sqrt{\frac{\epsilon'(\sqrt{1+\tan^2\delta}) \pm 1}{2}} + i \left(\frac{2\pi}{\lambda_0} \right) \sqrt{\frac{\epsilon''(\sqrt{1+\tan^2\delta}) \pm 1}{2}} \quad (7)$$

where λ_0 is the wavelength, ϵ' the real part of complex relative permittivity, the \pm and \mp signs are applied for positive and negative, using equations (2), (3), (4), and (5) and the values of ϵ' and $\tan \delta$ in the high frequency, the values of SE_R and SE_A for PVA/ Carbon nanotube composites were calculated. The SE_R and SE_A of the composites as functions of frequency are shown in Figures (2) and (3), respectively.

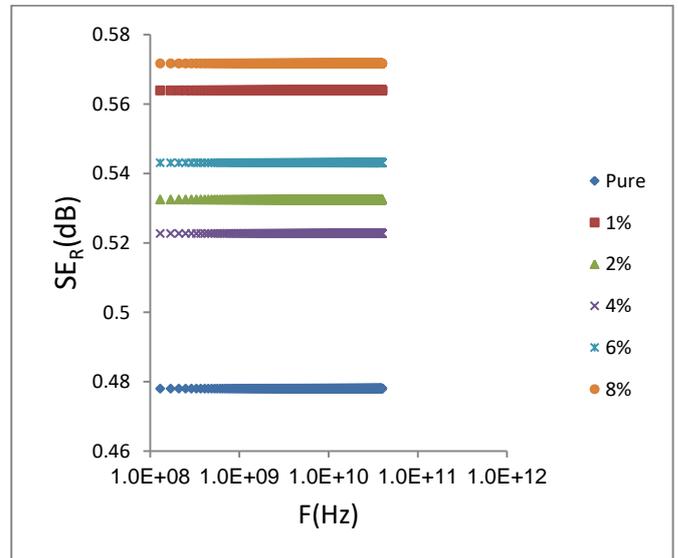


Fig. 2: The Shielding Effectiveness due to reflection (SE_R) of the composites as a function of frequency

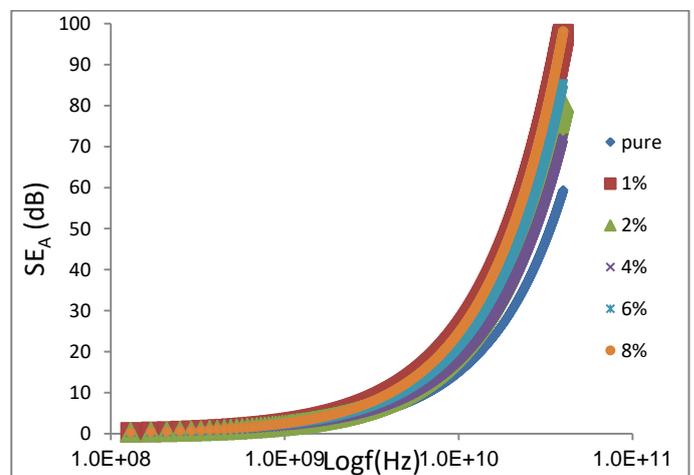


Fig. 3: The Shielding Effectiveness due absorption (SE_A) of the composites as a function of frequency.

The SE_R of the composites with $V \leq V_c$ decreases slowly with the increase of frequency, while SE_R of the composites with $V > V_c$ shows large variation with the increase of frequency.

The SE_R of the composites increases with the increase of V . A high value (0.57dB) of SE_R is obtained at frequency (2×10^8 Hz) for the composites with ($V=0.038$) because these composites have high values of ϵ' and $\tan \delta$. The SE_A of PVA/carbon nanotube increases with frequency because SE_A is directly

proportional to frequency as observed by equation (2) and (5).

The maximum value (95.6 dB) of SE_A is obtained at (3.8×10^{10}) Hz for composites with $V = 0.038$. Using equations (4) and (7), the values of SE_L were calculated. The SE_L of the composites with $V = 0$ to 0.038 was evaluated and it is shown in Figure (4).

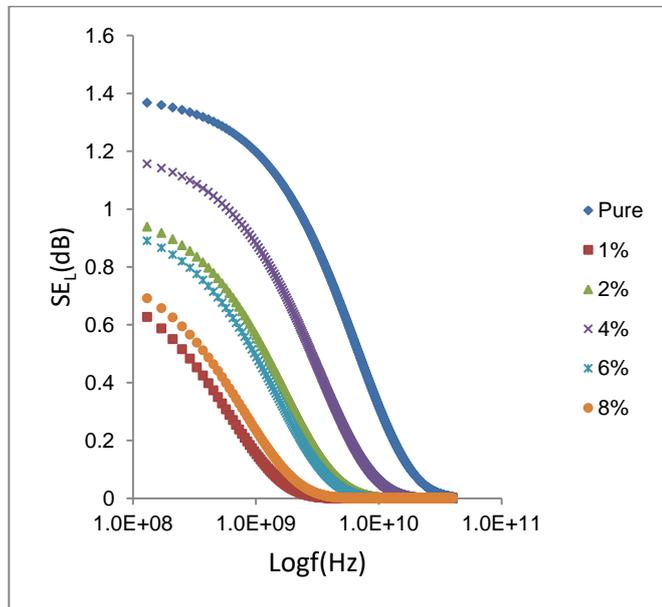


Figure (4): The correction term (SE_L) of the composites with $V = 0$ to 0.038

Using equation (1), the SE_T of the composites was calculated by adding SE_R , SE_A and SE_L . The SE_T of the composites as a function of frequencies is shown in Figure (5).

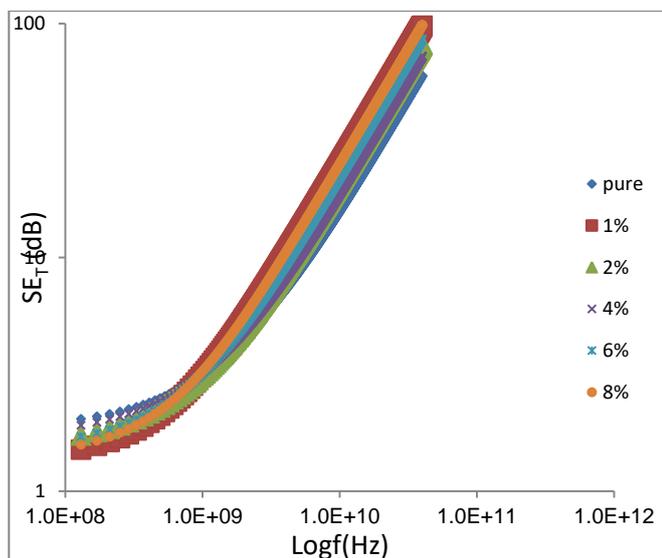


Fig. 5: The Total Shielding Effectiveness (SE_T) of the composites as a function of frequency.

The SE_T of the composites increases with both increasing V and increasing frequency. As expected from the above data on SE_R , SE_A and SE_L the trend of SE_T shows that SE_A comprises a major portion of the EMI SE. The maximum value (100 dB) of SE_T is

obtained at (35 GHz) for the composites with $V \geq (0.029)$.

The mechanism of EMI 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. The electric dipoles may be provided by $BaTiO_3$ or the materials having a high value of the dielectric constant. The magnetic dipoles may be provided by Fe_3O_4 or other materials having a high value of the magnetic permeability [8], which may be enhanced by reducing the number of magnetic domain walls through the use of a multilayer of magnetic films [13,14].

From the forgoing results and discussion we may conclude the following:

The EMI shielding measurements appears that, the main contribution of these composites to effective EMI shielding was due to absorption. The maximum value (100dB) of SE_T was obtained at 35 GHz for $V \geq 0.029$.

The SE_T of the composites increases with both increasing V and increasing frequency. As expected from the above data on SE_R , SE_A and SE_L the trend of SE_T shows that SE_A comprises a major portion of the EMI SE.

IV. CONCLUSIONS

The EMI shielding measurements revealed that, the main contribution of these composites to effective EMI shielding was due to absorption. The maximum value (100dB) of SE_T was obtained at 35 GHz for $V \geq 0.029$. The SE_T of the composites increases with both increasing volume fraction and increasing frequency. As expected from the above data on SE_R , SE_A and SE_L the trend of SE_T shows that SE_A comprises a major portion of the EMI SE.

REFERENCES

1. **D Bjorklof**. EMC fundamentals. Part Six: EMI filters and transient. Compliance Engineer 1998; 15(5):10.
2. **R Brewer, G Fenical**. Shielding: The hole problem. Evaluation Engineer 1998;37(7):S4-S10.
3. **P O'Shea P**. How to meet the shielding needs of a 500-MHz PC. Evaluation Engineer 1998; 37(6):40, 43, 45-46.
4. **S Devender, SR Ramasamy**. Review of EMI shielding and suppression materials. Proc. Int. Conf. Electromagnetic Interference and Compatibility 1997. IEEE, Piscataway (New Jersey, USA): IEEE 1997;459-466.
5. **B Geddes**. Putting a lid on EMI/RFI. Control (Chicago, Ill) 1996;9(10):4.
6. **S Hempelmann**. Surface engineering for EMI compliance. Process and practical examples. Galvanotechnik 1997;88(2):418-24.

7. **WD Kimmel, DD Gerke.** Controlling EMI with cable shields. *Medical Device & Diagnostic Industry* 1995;17(7): 112–5.
8. **HW Markstein.** Effective shielding defeats EMI. *Electronic Packaging & Production* 1995;35(2):4.
9. **KA McRae.** Electromagnetic shielding in today's environment. National Conf. Publication – Institution of Engineers, Australian, Vol. 2, No. 94/11, IE Aust, Crows Nest, NSW, Aust. 1994;495 – 498.
10. **J Joo and A Epstein.** *J. Appl. Phys. Lett.*, 1994; 65: 2278.
11. **Z Liu, G Bai, Y Huang, Y Ma, F Du, F Li, T Guo, and Y Chen.** *Carbon*, 2007; 45: 821.
12. **RB Schultz, VC Plantz and DR Brush.** *IEEE. Trans.*, 1988; 30: 187.
13. **CA Grimes.** EMI shielding characteristics of perm alloy multi-layer thin films. In: *IEEE Aerospace Applications Conf. Proc.*, IEEE, Computer Society Press Los Alamitos, California, USA: IEEE, 1994, pp. 211–21.
14. **WJ Biter, PJ Jamnicky, and W Coburn.** In: *7th International SAMPE Electronics Conference, Shielding improvement by use of thin multilayer films*, vol. 7, Covina, California, USA: SAMPE, 1994, pp. 234–42.