Microwave Attenuating Polymeric Coatings

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ABSTRACT

In this research the effect of several parameters such as weight percent, length, distance and orientation of carbon fibres on microwave attenuating of polymeric coatings have been investigated and microwave attenuating behaviour of these composite coatings were evaluated in frequency range of 8-12 GHz (X-bond). The optimum length of carbon fibres was found to be about one-half of the wavelength of incident radiation. The results show that attenuation is increased by increasing the weight percent of carbon fibres up to the area limitation effect. The best orientation of the carbon fibres is multidirectional orientation.

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Key Words:
microwave;
radar;
attenuating;
coating;
conductive fibre.

INTRODUCTION

Radar absorbing coatings have undergone continuous evolution over the past several decades. Incremental changes in binders, magnetic/conductive fillers and film structural parameters have been driven by progressive advancement in wave propagation and detection devices and increased performance requirements for both commercial and military purposes. However, the basic logic of attenuating by coating has not substantially changed. Most of the works and achievements are con-

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centrated around optimization of multiple absorbing and scattering of the incident wave through the use of more efficient fillers, formulations and structural layouts of the composite film in the micro and macro scales [1-5].

Permittivity and permeability are two properties which, respectively, determine the electrical and magnetic characteristic of a material.

Adding filler to a binder can change the permittivity or permeability of the composite which consequently may enhance the electromagnetic wave absorption. So one of the common methods in radar signature reduction of reflective materials is by coating them with a dielectric having some amounts of conductive/magnetic fillers in it. This filler could be a one, two or three dimensional material depending on other functions that are expected from this filler. Therefore, in the literature it can be seen that different materials have been used for preparation of microwave attenuating coatings [6-12].

Shell and his co-workers made a radar absorptive coating composed of an acrylic polymer, a polyester, an isocyanate cross-linking agent and carbonyl iron as a pigment which was claimed to be a durable and flexible paint and suitable for aircraft coatings. The resulting finish was about 1140 microns thick and had radar absorbing characteristics [13].

In 1978, Ishino et al. provided coatings for preventing reflection of electromagnetic wave by dispersing the ferrite and iron powders in a suitable binder. In these coatings ferrite powder having a particle size of about 50 microns and iron powder having a particle size of about 6 microns were shown to be more suitable. Coatings containing ferrite and iron powders can effectively be used in a thickness of 1.5 to 2.5 mm for absorbing microwave of 7-11 GHz in frequency [14].

Dawson et al. made a coating that contained magnetic particles ranging in size from 0.5-20 microns dispersed in an insulating binder of thermosetting materials. The particles were either spherical magnetic materials or spherical glass balls coated with magnetic materials. The composition was applied by painting or spraying to form a coating of approximately 1000 microns for attenuating purposes in the frequency range of 2-10 GHz [15].

Papoulias et al. provided a radar absorber coating comprising an inner layer having a carrier material containing a carbonyl iron powder with a selected uniform grade size of about 4-5 microns, and an outer layer from the same carrier materials with a selected uniform grade size of about 0.5-1.5 microns. By using the two layers having selected grade size of carbonyl iron powder, the radar absorber provides a relatively, high radar attenuation magnitude over the selected broad band frequency range [16].

McCaughna et al. disclosed a mixture of materials which can be utilized to shield the object from being detected by radar applying the mixture as a coating to the substrate by painting or spraying [17].

In the above examples the researchers adopted the permeability control methodology by using magnetic additives to reduce radar cross section of the substrate. Although the above applications of radar absorbing materials have been found useful, there are generally some disadvantages in their application. Typically, the amount of the ferrite materials used in the binder or carrier exceeds 50% w/w. Thus, the resulting radar absorbing composition, such as radar absorbing paint, would be extremely heavy as a result of the concentration of the ferrite and the thickness at which the composition is applied. Furthermore, they have been known to be particularly effective at frequency ranges much lower than the necessary and primarily useful in the absorption of microwave radiation, with the exception of probable combination of absorption and scattering of incident radiation which is more desirable for the purposes of camouflage. In this respect, a new method has been suggested by Bond [17], which has overcome these disadvantages. Bond prepared a radar attenuating paint by uniformly mixing thin conducting fibres such as stainless steel or carbon fibres into a standard camouflage-type paint. The fibres act as electric dipole segments. This paint is used on the surfaces of different targets for the purpose of protecting them from being detected, located and/or recognized by radar at frequencies greater than about 5 GHz. These conductive fibres present in the paint have a wide range of size from 0.001 to 3 cm. They have generally been used in the range from 0.1 to 10.0% of the total weight of the radar attenuating composition [17].

In the present research to highlight quantitatively, the effect of different fibre related parameters on the attenuation, have been investigated. Polyurethane resin was used as a binder, and carbon fibres were added as

Table 1. Carbon fibre properties.

Properties	Values	Units
Tensile strength	3.2	kN/mm²
Youngs modulus(tension)	220	kN/mm²
Breaking strain	1.3	%
Density	1.78	G /mL
Fibre diameter	7	µcm
Spec.electrical resistivity	$5.3*10^{-5}$	Ω µm

conductive and strengthening component in the coatings. Several parameters such as fibres length, fibres weight percent, distance and orientation of fibres were optimized to minimize the electromagnetic wave reflections in X-bond.

Theoretical Aspects

Most methods discussing the scattering of electromagnetic wave by conductive particles have some kind of validity limitation. These are mainly related to the geometrical property of the particle and the incident wavelength. For example, the qualitative treatment of scattering is reliable only if the geometrical dimensions of the particles are much smaller than the incident wavelength. If the dimensions of the fillers are not negligible compared to the incident wavelength, Mie's theory can be applied, but only in the case of scattering by spherical particles [18]. In this theory the scattering has been found to increase by increasing the particle size of the filler/pigment up to a maximum level, and then it will decrease by further increasing the particle size. In this respect Weber s equation shows that in visible spectrum the optimum scattering happens when the particle size is about one-half of incident wavelength [19-20].

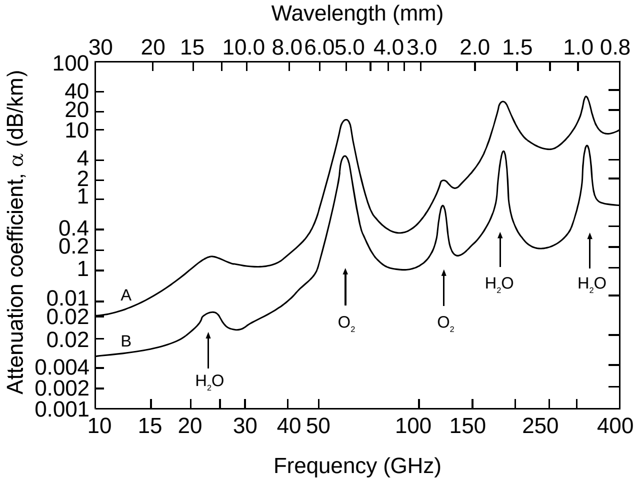


Figure 1. Attenuation coefficient of sea environment (curve A), and atmospheric environment (curve B) [21].

For non-spherical conductive particles where at least one of their dimensions is comparable with the incident wavelength, the theoretical treatment of field scattering by such a system is currently a very active area of research, specially in the microwave wavelength.

Microwave radiation over a wide spectrum from 5-18 GHz and at 35 – 1 GHz has been for long range surveillance to detect, locate and recognize tragets at distance of a few to hundreds of kilometers. The reason for the absence of frequencies between 18-34 GHz is due to atmospheric absorption. At radar frequencies higher than about 36 GHz, the microwave radiation is absorbed in a relatively short distance in the atmosphere except at specific frequencies of 94 – 1, 140 – 1, and 220 – 1 GHz due to the low attenuating coefficient of these points in environment (Figure 1) [21].

In microwave spectrum it has been argued that resonances can be sustained by a highly conducting unidirectional filler in free space when the particles' length is equal to an odd number of half-wavelengths. In this respect the interference pattern between a microwave beam and the scattered wave from a resonant dipole was studied [22]. The particle here was a metal rod ‰ wavelength long. It was observed that when the length of the rod is diminished below this value, reradiated or scattered power decreases rapidly.

So, what can be concluded from these studies is the existance of some sort of correlation between the scattering of the incident wave and the unidirectional fillers' size when the length is about half-wavelength or a multiple of its size.

EXPERIMENTAL

Polyurethane components obtained from DSM Company with commercial code of 104M. Polyol part was an acrylic base resin and the isocyanate part was TDI (toluene diisocyanate), and rutile TiO_2 was used as pigment in the paints, which due to its dielectric properties it will not have any cosiderable attenuating

Table 2. Polyurethane paint characteristic.

Characterstics	Values
Polyol component/isocyanate ratio	85/15
Solid content	%70+1
Drying time (touch free)	1 h
Pigment percent	%25

effect. Carbon fibres were used as conductive fibres with the properties as shown in Table 1.

The polyurethane paint was prepared by dispersing the pigment (TiO_2) in the polyurethane resin by conventional method, with the paint characteristic as shown in Table 2.

With respect to the discussion presented in the theoretical section regarding the dependence of particle size and wavelength[22], here the length of carbon fibres has been determined in a manner that illustrates some correlations with three frequencies of 8, 10, and 12 GHz in the X-band as shown in Table 3.

For radar attenuating measurement, the fibres filled coatings were tested by employing an osillator in the frequency range of 8-12 GHz, a powermeter and antenna set. For the accuracy of the results there should be a minimum distance between the sample and the antenna which can be calculated from the following equation:

$$d=2D^2/\lambda$$

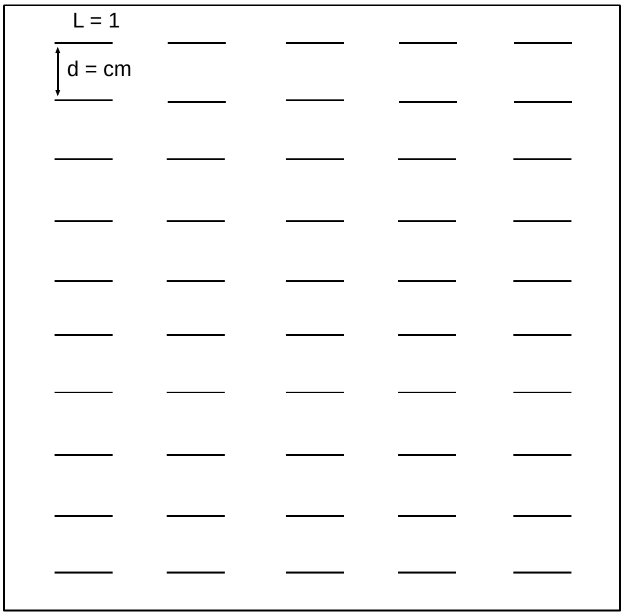


Figure 2. Orientation of carbon fibres.

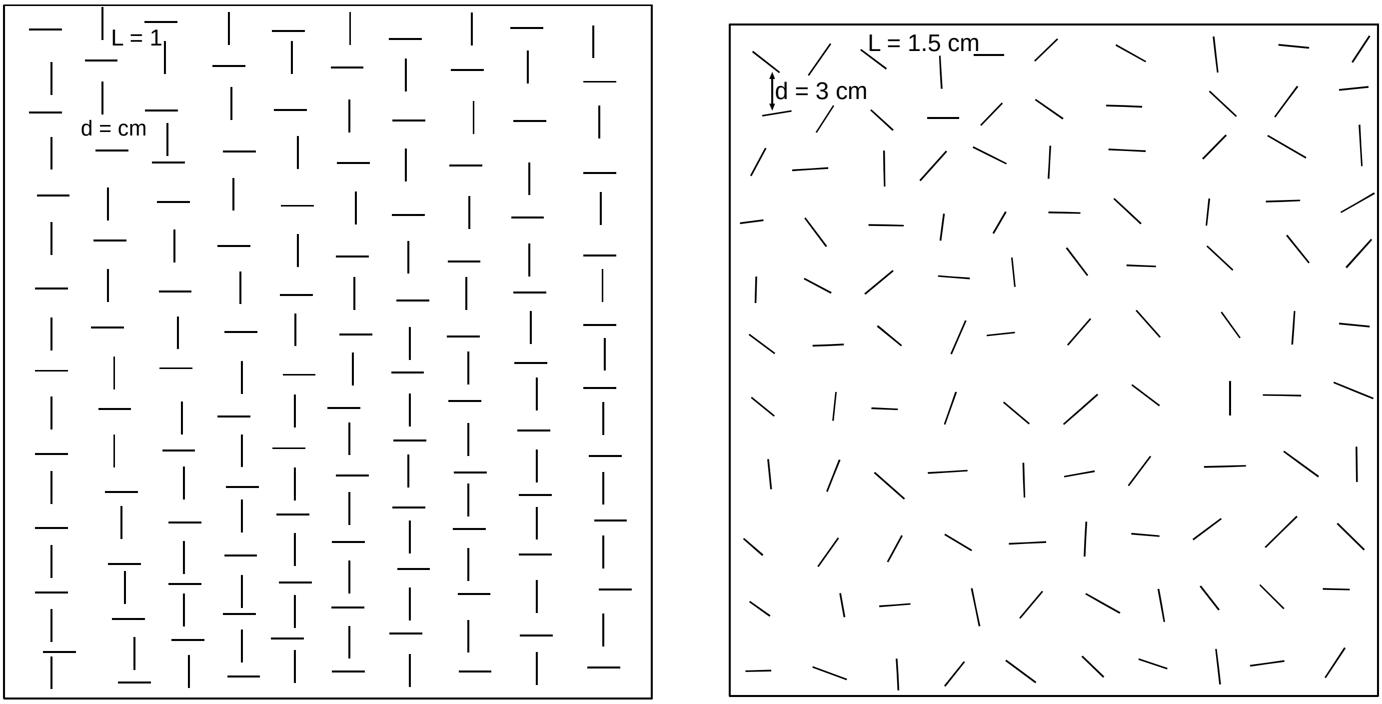
Table 3. Length of carbon fibres.

Frequency(f) (GHz)	Wavelength(λ) (cm)	Length of fibres (L) (cm)
12	2.5	1.25
10	3	1.5
8	3.75	1.87

where, d is the minimum distance between the sample and antenna, D is the maximum diameter of antenna, and λ is the wavelength of the incident waves. The calculated distances for frequencies of 12 and 8 GHz were 97 and 64.5 cm, respectively. So the distance between the samples and antenna was selected constant about 1.2 m. Square steel panels with dimension of 40 cm were selected as the substrate. This dimension reasonably eliminates the edge effects and prevents the occurance of error in this respect in radar attenuating studies. The coatings were applied to the cleaned substrate through the following procedure. At first, a thin layer of mixed resin components is applied with a thickness of about 40-50 microns. Then the fibres are placed in the predetermined locations and directions on the applied layer by the use of some sort of pre-designed templates. Finally, another layer is applied onto the plate. For each specimen special acts and care were taken out to make sure of having a good wetting of fibres by resin, without any noticeable dislocation of the fibres. The specimens are left for one week in laboratory atmosphere to cure and then are tested for their attenuation properties [23-24].

To evaluate the effect of fibres length on the radar attenuating, samples with three different lengths of 1.25, 1.5 and 1.87 cm of carbon fibres in the coatings were prepared according to the above procedure. The orientation of carbon fibres in all of the samples is show in Figure 2.

For evaluation of the carbon fibres contents in the coating for attenuation, several specimens with different carbon fibres percents were prepared. The fibres contents by weight percentage were 0.25, 0.5, 0.75,1 and 1.5%. In all of the samples, the length of the carbon fibres was 1.5 cm. The distance between the fibre s was also 1.5 cm in all the specimens except in the samples which contained 1.5% of carbon fibres due to area limitation. In these samples the distance of the fibres was 0.75 cm. The orientation of fibres in these coatings were similar to Figure 2.



(a) (b)

Figure 3. Bidirectional and multidirectional orientation: (a) bidirectional; (b) multidirectional.

Four series of specimens with carbon fibres distances of 0.75, 1.5, 3 and 6 cm were prepared to evaluate the effect of fibres distance on radar attenuation. In these samples the length of fibres was selected to be 1.5 cm. Specimens with three kinds of fibres orientation were made to study the effect of the fibres orientation on radar attenuation according to the described procedure. The orientations were monodirectional, bidirectional and multidirectional. Monodirectional orientation is shown in Figure 2, bidirectional and multidirectional orientations are shown in Figure 3.

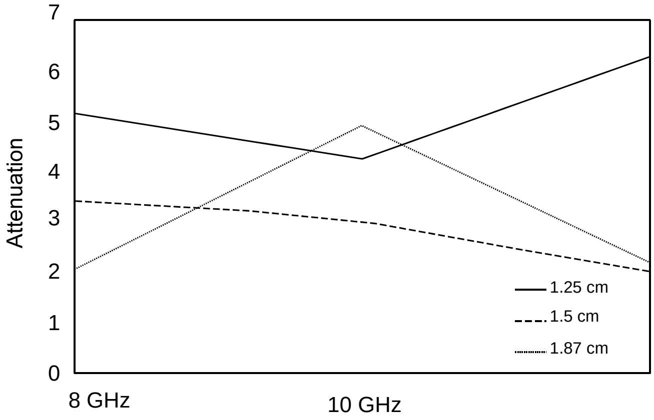


Figure 4. Effect of fibres length on attenuation.

RESULTS AND DISCUSSION

The samples were tested for their attenuation properties, and the obtained results are presented in the following sections.

Effect of Fibres Length

The experimental results of the influence of fibres length on the attenuation are illustrated in Figure 4. As the curves show in the frequency of 10 GHz where the wavelength is around 3 cm, the maximum attenuation occurs in the specimens containing carbon fibres of 1.5 cm length. This latter length corresponds to about one-half of the wavelength of incident radiation

Almost the same results were obtained from other series of coating specimens having fibres of the length 1.25 cm and 1.87 cm which illustrate better attenuation in 12 and 8 GHz frequencies, respectively. In all of the specimens a distinct performance is observed when the length of fibres are about one-half of the wavelength of the incident radiation. It seems that in specimens that the length of fibres are longer than $\lambda/2$ the entrance of the waves into the coating encounters with more barriers and some of them are reflected from the surface of the coating. In the specimens that the fibres length are

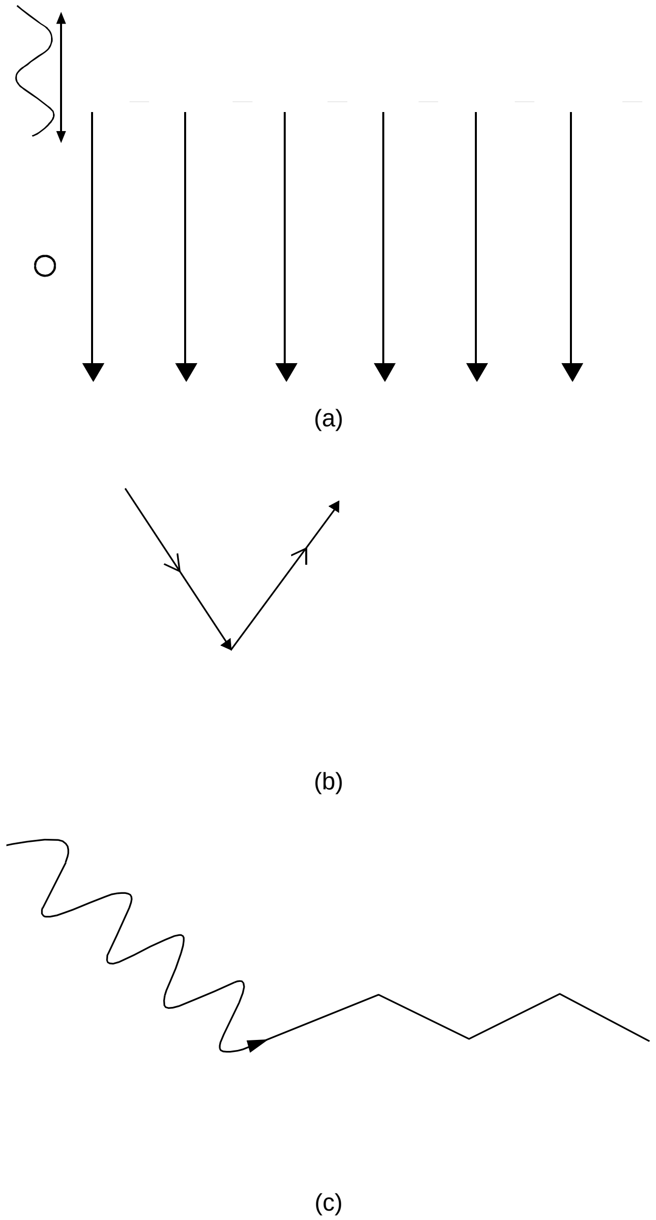


Figure 5. Interaction of waves and particles: (a) very small particle size; (b) very big particle size; (c) about one-half of the wavelength.

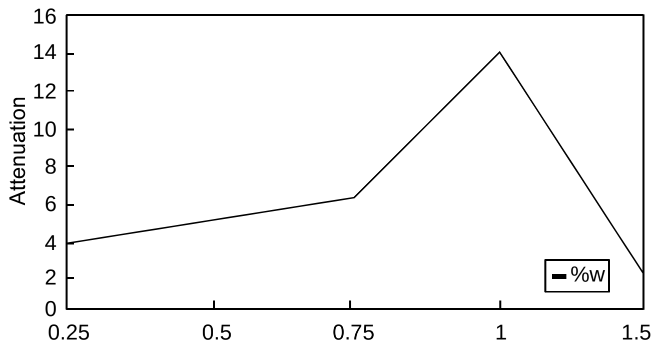


Figure 6. Effect of weight percent of fibres on attenuation.

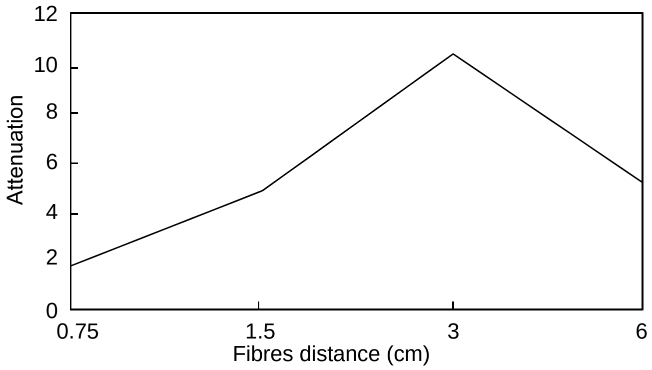


Figure 7. Effect of the fibre's distance on attenuation.

around λ/2 the interaction of waves and fibres looks high, so the attenuation seems to be much better. Figure 5 is an attempt to present schematically the interaction of incident waves with a dielectric having conductive particles of different sizes. In Figure 5a the particle size is very small compared to the wavelength of the wave, so the interaction is negligible, in Figure 5b the particle size is very big and the interaction is very high so a considerable portion of the incident waves are reflected from the coating surface. In Figure 5c the particle size is moderate, about one-half of the wavelength of the incident wave so the interaction and attenuation through multiple reflection, diffraction and absorption are improved [17-18].

Effect of Weight Percent of Fibres

Figure 6 shows the attenuation and percent weight relationships for coating specimens containing different weight percents of carbon fibres.

As shown, the attenuation is enhanced by increasing the weight percent of the fibres, except for the last series of the coating specimens in which the weight percent of the fibres was 1.5%. The former observations can be attributed to the build-up attenuating sites, while the latter one can be due to the shorter distance location of the fibres because of area limitation, which causes high surface reflectivity. If the incident beam on a substrate is not a single frequency, but instead has a broad band scanning nature, it is necessary to design the coating in a way that it displays a proper average attenuation. Therefore, it is recommended that the conductive fibres length to be consisted of a distribution of half-wavelengths of the radiated beams. From the practical point of view the fibres will consist of a category of sub-group fibres with different lengths. So with

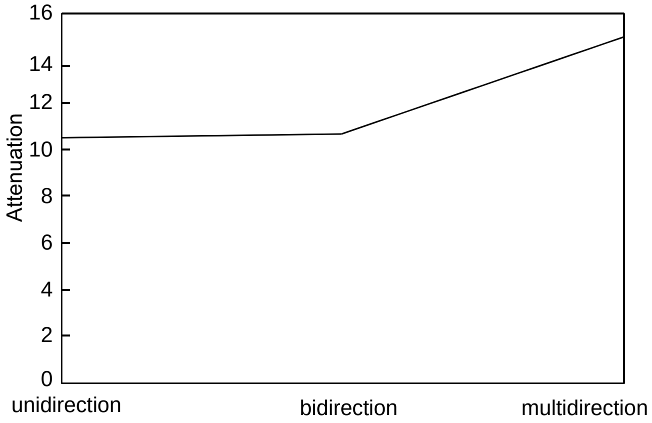


Figure 8. Effect of the orientation of fibres on attenuation.

respect to the sensitivity of the required scattering /absorption phenomenon, the number of length increments for the fibres can be adjusted. In such a system the total weight percent of fibres(X) will be a sum of different fibres contents of length L_i (x_i), in other words:

$$X = \sum_{i=1}^{n} x_i \Big|_{L_i}$$

where, n is the number of increments.

Effect of Fibres Distance

Figure 7 shows the effect of fibres' distance on the attenuating properties of the coatings.

According to these results, as the distance of fibres increases the attenuation is improved up to the distance of about 3 cm (here for an incident wave at 10 GHz). This can be related to the equivalent mesh (lattice) sizes of the formed fibres network which consequently can cause high scattering power or some sort of optimal wave-fibre s lattice interaction.

Effect of Orientation of Fibres

The effect of orientation of fibres on the attenuating properties of coatings is shown in Figure 8.

It can be seen that the maximum attenuation occurs in the multidirectional coating specimens. This can be due to the nature of electromagnetic waves, and their propagation. The multidirectional coating specimens affect the electromagnetic waves in all possible angles so the attenuation would be improved.

CONCLUSION

Polymeric coatings which were prepared with polyurethane matrix and conductive carbon fibres have successfully attenuated microwave radiation in X-band.

The optimum length of carbon fibres was found to be about one-half of the wavelength of incident radiation. The results show that attenuating is increased by increasing the weight percent of carbon fibres up to the area limitation effect. The optimum fibres distance is almost equal with wavelength of incident waves. The best orientation of the carbon fibres is a multidirectional orientation.

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