A Review on Experimental Testing of Cost Effective Broadband Radar Absorbing Cementitious based Composites with Conductive Additives as Carbonyl-Iron and Silica-Fume

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ABSTRACT

The electromagnetic absorbing effectiveness of proposed radar absorbing based specimen with different contents involve: Carbonyl Iron as ferrite, conductive filler as carbon fibres/carbon black and admixture of silica fume with Portland cement studied in this review paper. Double-layer cementitious composites filled with Carbonyl Iron ferrite as microwave absorbers. The addition of silica fume, use to improve the impedance matching between the cementitious composites and free space. The main objective of this paper to achieve good absorption with wide bandwidth corresponds to reflection loss, RL ≤ -10 dB for absorber layer thickness about 10mm for cost-effective production of radar wave absorber. An experimental evaluation of this cement based composite is tested under frequency range of 8 to 12GHz. A double layer approach is applied for obtaining good absorption. With more and more severity of electromagnetic environment pollution, the study on building materials that can prevent electromagnetic interference(EMI) has caused great attention. This paper mainly reviews the cement-based EMI shielding and wave absorbing building materials.

Keywords: Carbonyl iron, Silica fume, Carbon fibres, Carbon black, ferrites, Impedance matching, Layered cementitious composites, Microwave absorption, Reflectivity.

I. INTRODUCTION

Now people are living in a more and more complicated electromagnetic environment. Actually, electrical devices have greatly improved the quality of our lives. However, everything has its bad effects. For example, sometimes we have to shield the electromagnetic radiations from such devices as computers, mobiles, and military devices to avoid leaking out of important information or avoid radar tracing. In other cases, the reflection of electromagnetic waves from the enclosure of high buildings can lead to the disorder of TV signals around the buildings. Now people are aware that radiation of electromagnetic waves may do harm to the health of human beings. Thus, development of building composite materials containing low cost components such as carbon black (CB) which are able to absorb or shield electromagnetic radiations becomes more and more necessary in the modern society. The shielding effectiveness (SE) is the sum of three terms such as reflection loss, absorption loss and multi-reflections. So, SE is defined in decibels (dB) and its magnitude can be written as follows:

$$SE_T(dB)=10 \log (P_I/P_T) \quad \text{eq. (1)}$$

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where P_I and P_T are the electric fields that are incident on and transmitted through the shield. The reflectivity of -10 to -20 dB means that the incident electromagnetic waves have been reduced by about 70–90%. As the reflectivity of absorbing wave materials is less than -10 dB, they can be used in practice. Cement is slightly conductive, but its SE

is very low. To increase the cement materials SE by adding a small amount of a conductive additive such as graphite powder, carbon black, carbon fibers, carbon filaments or steel fibers. The need of preventing electromagnetic interference (EMI) has been increasing with the development and application of electronic science and communication technology [1] EMI prevention is particularly needed for underground vaults containing transformers and other electronics that are related to electric power and telecommunication [2]. Cementitious composites are one of the most common building materials used in engineering construction. Cement-based composites are complex systems that include hydration products, unhydrated cement particles and aggregates of different sizes. Generally, as a whole system cement-based material is slightly conducting, but its EMI shielding effectiveness and wave absorbing property are very low, so admixtures are needed to improve the ability to resist the electromagnetic wave interference. There have been many studies on the reflection loss of cement matrix composites by introducing fillings, such as expanded Polystyrene (EPS) and carbon fibers [3,4].

Ferrite is one of the most commonly used materials as a kind of electromagnetic wave absorber. Many studies have been carried out in Japan in Radio frequency (RF) area to investigate the electromagnetic absorption properties of buildings employing ferrite[5]. However, the application has been restricted by the narrow band characteristics of single-absorbers. It is known from many research studies that the microwave absorber with double-layer structure has wider absorption bandwidth and lower reflection loss (RL) than the single-layer absorber in GHz frequency [6].

For the purpose of preparing a low-reflecting absorber in the desired wide frequency range, two fundamental conditions must be satisfied [7,8]: the first is that the incident wave can enter the absorber to the greatest extent (impedance matching characteristic),and the second is that the electromagnetic wave entering into the materials can be almost entirely attenuated and absorbed within the finite thickness of the material (attenuation characteristic).The impedance matching is the principle that the electromagnetic wave is absorbed in the materials. There are several methods to improve impedance matching between material and free space. One of them is to use low dielectric constant materials to adjust the characteristic impedance of the absorber. Silica fume [9] is a kind of fine non-crystalline silica produced in electric arc furnaces as a by-product during the production of metallic silicon or ferrosilicon alloys, the SiO_2 content of which ranges from 85% to 98%. The microwave absorbing coatings with PVC (polyvinyl chloride) sheet as base plate are fabricated composed of CIP (carbonyl–iron particle) as absorbent and PU (polyurethane varnish) as matrix. The absorption properties of PVC-based coatings with different CIP content are investigated and compared with the corresponding Al (aluminium)-based coatings [10].

In order for a conductive filler to be highly effective for shielding, it preferably should have a small unit size, a high conductivity and a high aspect ratio. As to improving the conductive ability and shielding effectiveness of cement matrix composites, carbon fibres are more effective than particles such as carbon black and coke due to their large aspect ratio, which can help to make more conductive networks through intercalating [11–13]. With the decrease in carbon fibre cost and the increase of demand for cement based composites with high structure and multi-function, carbon fibre cement matrix composites are gaining in importance quite rapidly.In the carbon fibre reinforced cement based composites,the carbon fibre with a diameter of more than 0.1 lm is often called fibre, whereas that with the diameter less than 0.1 lm is often called carbon filament. Due to its higher aspect ratio, carbon filament is superior to carbon fibre in shielding [14,15].

When the carbon materials are used as the conductive fillers, it is necessary that the fillers be well dispersed, so it often needs to introduce some dispersants.

Dispersants are not conductive themselves, but their introduction can obviously improve the dispersion degree of conductive fillers so as to help make more efficient conductive networks. Among the various types of dispersants, styrene butadiene latex and silica fume are the most common for use in cement based composites. Moreover due to the weak strength between the carbon fibre and cement matrix, the introduction of latex, silica fume or methylcellulose can improve the bond between the fibre and matrix, thereby improving the mechanical properties of the cement composites[16,17]. A surface pretreatment of carbon fibre or treating silica fume with silane can improve the bond strength between carbon fibre and the cement matrix and the dispersion degree of conductive fillers, thereby increase the shielding effectiveness of the composites [18–20].

The mortar with silica fume can be used as an impedance matching layer to adjust the permittivity of the surface materials of the cement-based absorbing material in order to attain the impedance matching.The microwave reflectivity of the single-layer mortar filled with ferrite is higher than that of the plain mortar due to the mismatching of the impedance and the design of double-layer structure has excellent absorption property because of the impedance match of materials. The impedance match layer is made of silica fume mortar and the loss layer is added with 30 wt.% ferrite based composite [21].

The filling of CB improves the loss factor of the cement material remarkably, which makes CBCC absorb electromagnetic waves by polarization. The loss factor of CBCC increases with the CB content increasing and the Compressive strength of CBCC decreases with CB content increasing. Compressive strength decreased substantially when CB content is more than 3 wt.% [22]. Fig. 1 shows the influence of filling CB volume concentration on the reflectivity of CBCC in the range of 8–18 GHz. In Fig. 2, plain cement mortar has a low reflectivity of about -5 dB. All CBCC specimens except CBCC containing 1.0 wt.% and 3.0 wt.% of CB have lower reflectivity than plain paste.

It can be observed that CBCC containing 0.5 wt% of CB has the minimum reflectivity in 8–18 GHz. Its reflectivity decreases with the increasing frequency. At 18 GHz, its minimum reflectivity is -17.04 dB. The bandwidth in which the reflectivity is less than –10 dB is from 11 GHz to 18 GHz. Another worthwhile material is CBCC containing 2.5 wt.% of CB. At 17 GHz, its minimum reflectivity is -11.64 dB. The bandwidth in which the reflectivity is less than -10 dB was from 14.9 GHz to 18GHz. Fig. 2 shows the influence of filling CB volume concentration on the reflectivity of CBCC in the range of 18–26.5 GHz. All CBCC specimens except CBCC containing 1.0 wt.% and 2.0 wt.% of CB have lower reflectivity than plain paste.

It can be observed that CBCC containing 2.5 wt.% of CB has the minimum reflectivity in 18–26.5 GHz. At 20.6 GHz, its minimum reflectivity is -20.30 dB. In the whole frequency range of 18–26.5 GHz, the reflectivity is less than -10 dB.

The bandwidth in which the reflectivity is less than -15 dB is from 18 GHz to 24.2 GHz. Other worthwhile materials are CBCC containing 0.5 wt.% of CB and 3.0 wt.% of CB. In the whole range of 18–26.5 GHz, the reflectivity is less than -10 dB in CBCC containing 0.5 wt.% of CB. In CBCC containing 3.0 wt.% of CB, its minimum reflectivity is -13.86 dB at 25.3 GHz.

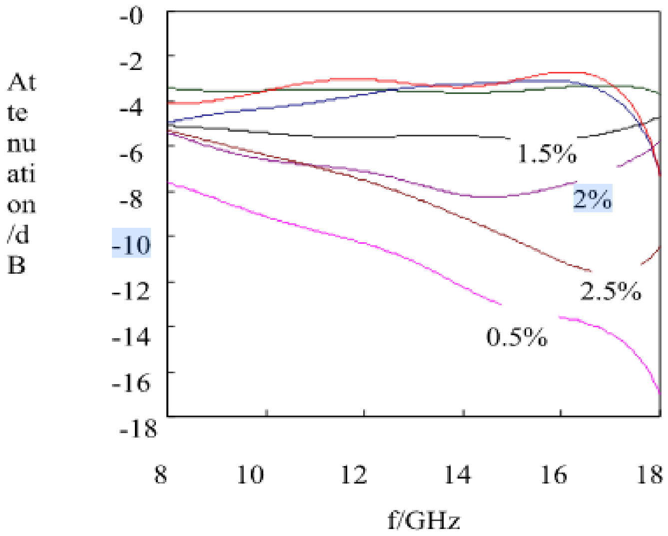


Figure. 1: The absorbing performance of CBCC with different concentration of CB in the frequency range of 8–18 GHz.

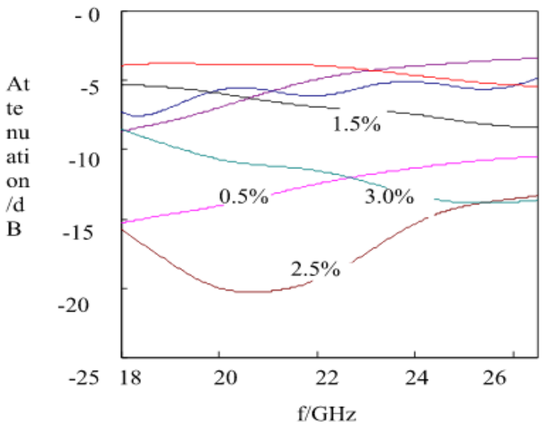


Figure. 2: The absorbing performance of CBCC with different concentration of CB in the frequency range of 18-26.5 GHz.

Table. 1: Minimum reflectivity and bandwidth of CBCC in the frequency range of 8–26.5 GHz.

Content of CB (wt%)	0.5	2.5	3.0
Minimum reflectivity (dB), at frequency (GHz)	-17.04 (18)	20.30 (20.6)	13.86 (25.3)
Bandwidth (reflectivity ≤ 10 dB, GHz)	11-26.5	14.9-26.5	19.2-26.5
Bandwidth (reflectivity ≤ 15 dB, GHz)	17.4-18.4	18-24.2	-

The microwave absorption property of material is typically characterized in terms of the power reflection of the plane wave reflected from an infinite slab of material which is backed by metallic surface [27]. The power reflectivity of the coating, is generally produced for normal incidence, is commonly expressed as R:

$$R=20 \lg | Z_{in} – Z_0/ Z_{in}+ Z_0 | \quad (2)$$

Where Z_{in} and Z_0 present the input impedance of coating and intrinsic impedance of free space with a value of 377 Ω, respectively. According to transmission theory, for a single-layer absorber backed by a perfect conductor, the input impedance of the absorber Z_{in} of a metal-backed microwave absorbing coating is given by:

$$Z_{in} = \eta \ \tanh (\gamma d) \quad (3)$$

$$\eta = Z_0 \sqrt{\mu/\varepsilon} \quad (4)$$

$$\gamma = j\ 2\Pi f/ \quad (5)$$

In order to characterize the microwave absorbing properties of the composite coatings based on Al or PVC sheet, the reflection loss (RL) curves versus frequency for different CIP content are simulated based on eq. (2)–(3), and shown in Fig. 3. The content of CIP varies from 1:3 to 1:7 (PU:CIP mass ratio). The thicknesses of coating and base plate are 2 mm and 3 mm, respectively. The sweeping frequency ranges from 2 to 18 GHz.

From Fig. 3(a), it can be found that the allowable reflection loss (RL ≤ −10 dB, for over 90% microwave absorption) can get in the frequency range of 5.5–13 GHz through varying the component content of the coating. It is worth noting that, in Fig. 3(b), the PVC-based coatings display good absorption properties in the lower frequency region (2–4 GHz, S-band), though the overall performance is poor compared with the Al-based coatings.

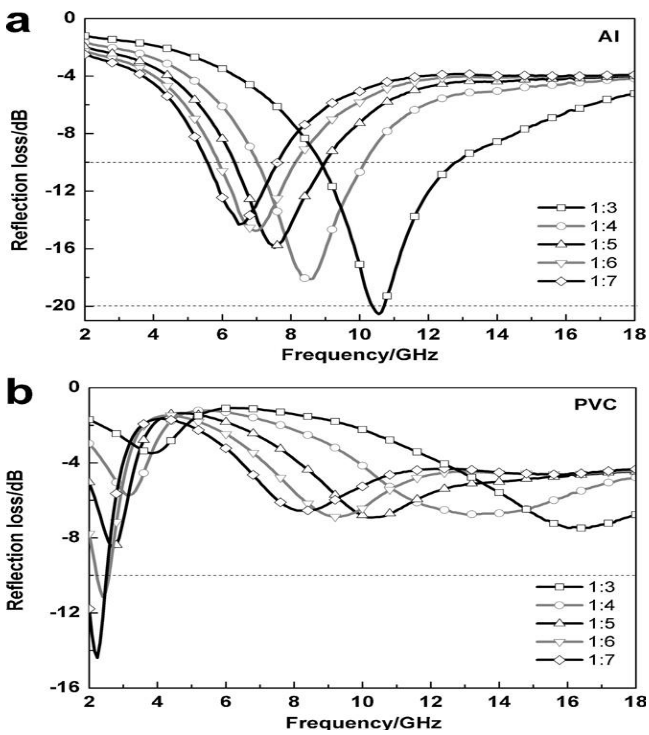


Figure. 3: Measured reflection loss curves versus frequency of the CIP/PU coatings with varied CIP content (PU:CIP mass ratio) based on Al (a) or PVC (b) sheet.

The mineral dust (M) and beach sand-based waste composite (C) material as broadband radar wave absorber in the frequency range of 8.2–12.4 GHz. A multilayer approach is applied for obtaining the good absorption, where thickness of different layers is optimized by genetic algorithm [29].

The result indicates that a thin broadband absorber, having coating thickness less than 2.0 mm and bandwidth (RL ≤ −10 dB) can be obtained by adopting multilayer absorber. The optimal coating thickness for single-layer absorber (M1) for which the maximum absorption takes place is 3.0 mm.

The measured RL value for single-layer absorber is −14.15 dB at 9.3 GHz. In two-layer absorber, the peak RL of −27.20 dB at 10.8 GHz can be obtained with a thickness of each upper and lower layer less than 1.0 mm.

The total coating thickness for two-layer absorber is less than 2.0 mm. Similarly, three-layer absorber possesses a RL of −32.58 dB at 11.2 GHz with 1.8 mm coating thickness.

The total coating thickness for both the multilayer absorbers is less than that of 2.0 mm, i.e. 1.9 mm for two layer and 1.8 mm for three layer, respectively and shown in Figure 4.

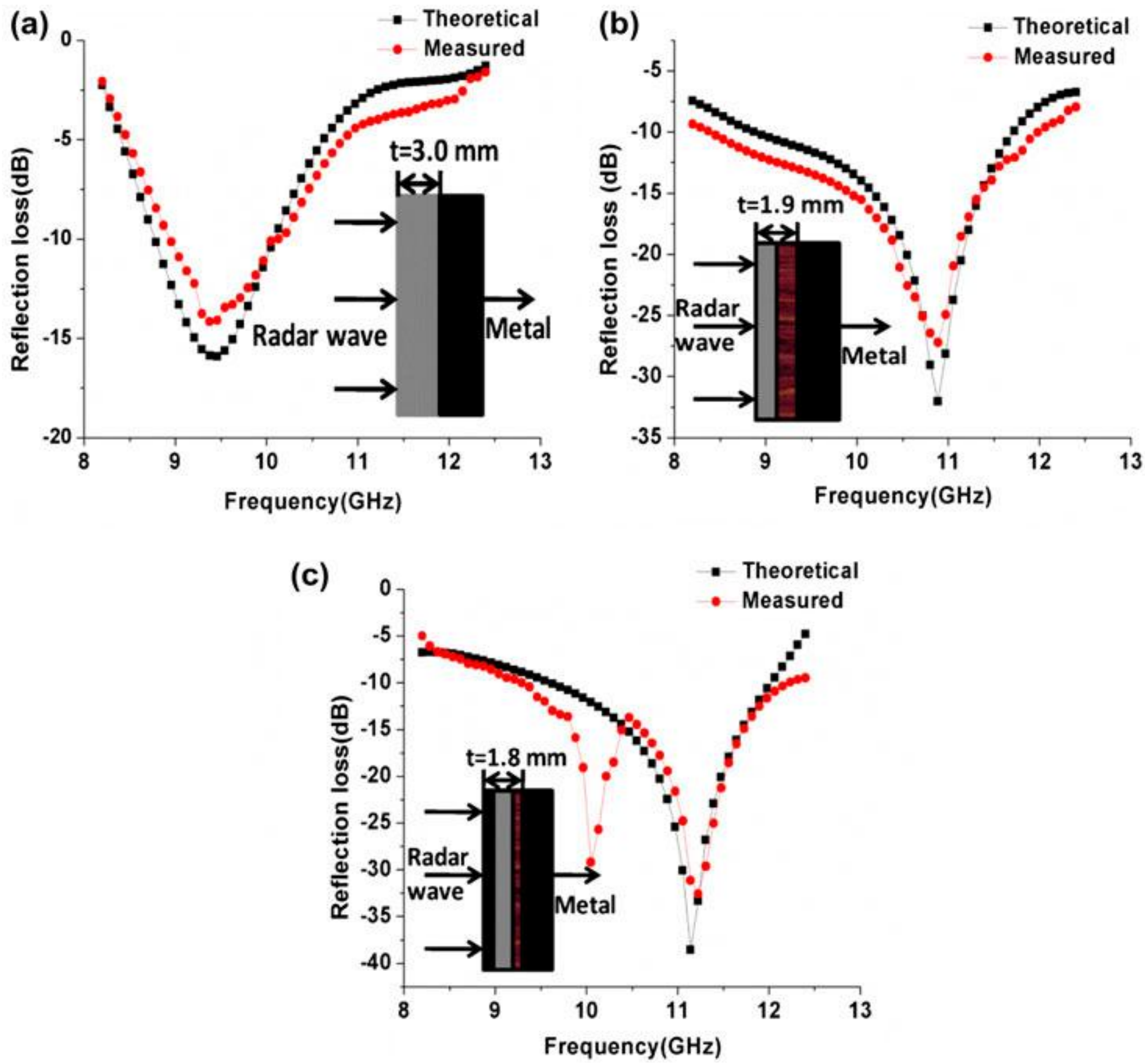


Figure 4. Measured RL of (a) single layer of M1 with thickness 3.0 mm (b) two layer consists of M1 (1.0 mm) and M2C (0.9 mm), and (c) three-layer absorber consists of M2 (0.5 mm), M1 (0.7 mm), and M2C (0.6 mm).

Comparison of different papers on the basis of its type, thickness, frequency and reflection loss shown in Table 2.

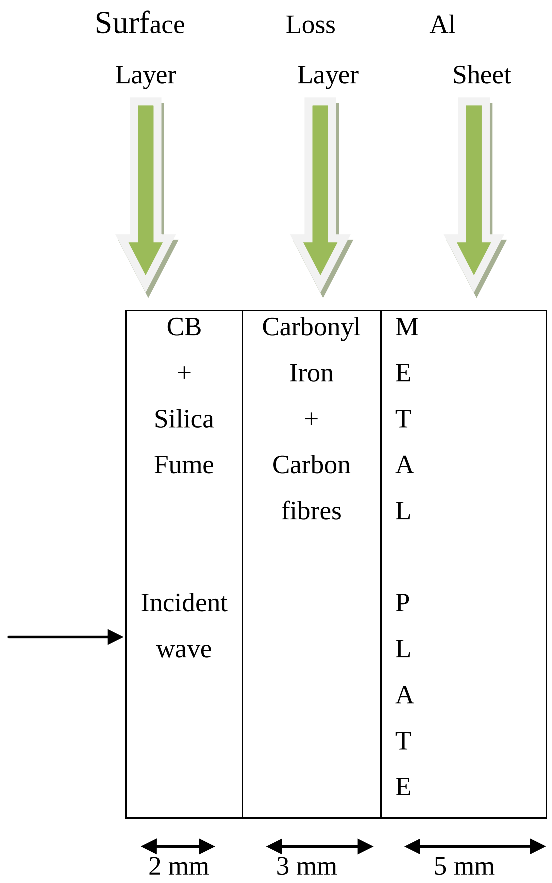
Table. 2: Comparison of different papers.

S.No.	**Paper**	**Material used**	**Information includes RL/BW/Frequency Range/Thickness/Base Material.**
1.	Microwave absorbing properties of double-layer cement Composites containing ferrites.	Silica fume and Ferrites	Minimum reflectivity reaches -15 dB at 12 GHz when layer thickness is 10 mm. Absorption bandwidth below -10 dB is 6.6 GHz ranging from 11.4 to 18 GHz when layer thickness is 5 mm.
2.	Study on microwave absorbing properties of carbonyl-iron composite based on PVC and Al sheet	Carbonyl iron Particle	Frequency range is 2-18 GHz, RL of -29 dB at 4 GHz and RL ≤ -10 dB band of 2-6 GHz through varying thickness of sheet and particles.
3.	Electromagnetic wave absorbing characteristics of carbon Black cement-based composite.	Carbon black	Frequency range is 8-26.5 GHz, minimum reflectivity of -20.30 dB, bandwidth in which the reflectivity is less than -10 dB is from 14.9 to 26.5 GHz.
4.	Microwave properties of high-aspect ratio carbonyl iron/epoxy absorbers	Carbonyl iron (spherical and flaked shape)	Frequency range is 2-18 GHz, thickness of 3 mm, the reflection loss at 5.5 GHz reaches -23.0 dB.
5.	Absorption properties of carbon black/silicon carbide microwave absorbers	Carbon fibres	Frequency range of 8.0–18.0 GHz, reflectivity of -19.3 dB (without) and -8.1 dB (with treatment)
6.	Complex permeability and permittivity variation of carbonyl iron rubber in the frequency range of 2 to 18 GHz	CB/SiC	2 mm thickness, maximum reflection loss becomes -41 dB at 9 GHz, and the -10 dB bandwidth reaches 6 GHz, frequency range is 2-18 GHz.
7.	Electromagnetic Radiation Absorbing Paints Based on Carbonyl Iron (CI) and Polyaniline	Carbonyl iron	Frequency range of 2 to 18 GHz
8.	Electromagnetic Radiation Absorbing Paints Based on Carbonyl Iron (CI) and Polyaniline	Carbonyl and Polyaniline.	Attenuation is 4 dB, about 60% of absorption. Frequency range is 8-12 GHz.

II. CONCLUSION

The single and double layer absorbers composed of cost-effective composites like CB,CF, silica fume and carbonyl iron with a different coating thickness and tested under the 8–12 GHz frequency range. Evidently enhanced absorption with good bandwidth (RL ≤ −10 dB) and less coating thickness is provided for double layer absorbers, probably caused by the matching of the impedance of the respective absorption layers. A double-layer cementitious composites filled with carbonyl iron and silica fume as microwave absorbers is design on the basis of impedance matching theory and electromagnetic wave propagation laws as study shows that silica fume can improve the impedance matching between cementitious composites and free space. The silica fume used to improve the impedance matching for cementitious composites. Two types of microwave absorbers used: single-layer microwave absorber composed of Carbonyl Iron and double-layer microwave absorber composed of mortar with silica fume mortar as the surface layer and Carbonyl Iron mortar as the loss layer.

Figure. 5: Structure of Proposed Cement-based Radar Absorbent



The significance of materials as follows:

a) Silica fume used to improve the impedance matching and having quality of best transmission line absorber [21]. The view and properties of silica as follow:

Table. 3: Specification of Silica-Fume

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss
95.48	0.27	0.83	0.54	0.97	0.80	1.11

Figure. 6: Silica-Fume

b) Carbonyl Iron has excellent absorptive abilities at lower frequencies and can widen frequency band when combined with other absorbents and having quality of good reflectors as it is used in the production of some ferrites.Typicaly applicable in radar absorbing material, EMI/RFI shielding product sand metal injection molded parts [9,10]. It's well known that carbonyl-iron particles (CIP), which possesses excellent magnetic-loss property, in the frequency range of 2-18 GHz, is widely blended in polymer matrix as microwave absorbing materials [23-26].

Table. 4: Specification of Carbonyl-Iron

Atomic Number	Molecular Weight (g/mol.)	Density	Specific Heat	Boiling Point (^{0}F)	Melting Point (^{0}C)	Thermal Conductivity
26	195.9	7.87	12	217	1536	12

Figure. 7: Carbonyl-Iron

c) Carbon fibres are more efficient than particles like Carbon black and coke due to their large Aspect ratio, which can help to make more conductive networks [11-15].Cement is slightly conductive, but its SE is very low. It is a simple and practical method to increase the cement materials SE by adding a small amount of a conductive additive such as graphite powder,carbon black, carbon fibers, carbon filaments or steel fibers.

Table. 5: Specification of Carbon-Fibres

Tensile strength (Gpa)	Density (g/cm^3)	Carbon Content (%)
≤3500	1.65-1.75	≤98

Table. 6: Specification of Carbon-Black

Surface area (m^2/g)	pH scale value	Particle Size
1056	8.0	33 nm

Figure. 8: Carbonyl-Black

Figure. 9: Carbon-Fibres

Therefore, the concept of waste composite-based Double layer coatings expected to be a good concept and results in the eventual formation to an efficient absorber. All these fascinating properties of developed coatings are quite encouraging and show their enormous potential for various practical EM applications.

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