Abstract  Electromagnetic (EM) wave (EMW) shielding/absorbing concrete refers to the concrete with EMW defense capacity in a wide frequency region. The EMW shielding can be achieved by incorporating electrically conductive fillers into conventional concrete, and its mechanism is reflection. The EMW adsorbing can be implemented by the addition of magnetic loss, dielectric loss, and resistive loss fillers, and it results from energy conversion and dissipation of EM energy. Development of EMW shielding/absorbing concrete has become urgent since such issues as EM pollution, EM interference, information security, and military security are becoming more and more pressing. The EMW shielding/absorbing concrete has wide potential application in such fields as EM radiation protection of urban civilian infrastructures, and stealth and defense of military installations.

Keywords  Concrete · Electromagnetic wave · Shielding · Absorbing · Fillers

18.1  Introduction

With the development of high technology in modern society, electromagnetic (EM) radiations are becoming more and more pervasive. It is reported that we are exposed to 200,000,000 times more EM fields in our surroundings today than our ancestors. The severity of EM interference and EM compatibility caused by EM radiations is increasingly mounting and brings the following issues: (1) Damage the electronic instruments and electronic equipments or degrade their performances and affect operation of infrastructures. For example, mobile phone signals would interfere with the operation of electronic diagnosis instrument in hospitals. Flights are often delayed or canceled because of EM interference. (2) Pollute the environment and bring harm to human’s health. Besides the traditional three social effects of pollution, i.e., water pollution, air pollution, and noise pollution that threaten human, the EM pollution becomes another problem today. The invisible, silent, and ubiquitous “electro-smog” can damage brain cells and DNA, cause cancer, and adversely affect central nervous, cardiovascular, and immune systems.
(3) Threaten information safety and military security. Information carried by EM wave (EWM) would be given away secrets if EMW is leaked. In addition, EM weapon could directly target electronic equipment, power systems, and military facilities, causing temporary or even permanent failure of information system and damaging the human body function \[1-4\].

In view of the above, it is desired to develop effective EMW shielding/absorbing materials to prevent the problem of EM interference and EM compatibility, improve the security and reliability of electrical products and devices, protect EM weapon strikes, and ensure the security and smooth operation of communication system, network system, transportation system, and weaponry platform. Because infrastructures are the carrier of human activities, endowing them with intrinsically EMW shielding/absorbing capability is the best choice to achieve the above goals, and the emergence of EMW shielding/absorbing concrete provides material support to develop such infrastructures \[5-11\].

This chapter will provide a systematical introduction to two types of concrete including EMW shielding concrete and EMW absorbing concrete, with attentions to their principles, properties, current progress, and applications.

### 18.2 Electromagnetic Wave Shielding Concrete

#### 18.2.1 Definition, Mechanism, and Test of Electromagnetic Wave Shielding Concrete

EMW shielding concrete (also called EM shielding concrete, or EM interference shielding concrete) is a type of composites to defend or shield EMW through modifying conventional concrete or embedding metal components (e.g., steel bar and metal mesh). In EMW shielding concrete structures, external EMW cannot penetrate and the internal EMW cannot be easily leaked out. The primary mechanism of EMW shielding concrete is reflection to prevent the emissions of electronics. The reflection usually requires an interaction between mobile charge carriers and EM fields. However, concrete is slightly electrically conductive in nature, so there are no mobile charge mobile charge carriers inside conventional concrete. Incorporating electrically conductive fillers or components is essential for fabricating EMW shielding concrete. Consequently, EMW shielding concrete tends to be electrically conductive, although it does not need a complete connection in the conduction path \[3, 12\]. Meanwhile, the multiple reflections caused by interfaces between fillers and matrix inside EMW shielding concrete are regarded as another primary shielding mechanism. Generally, small fillers (e.g., nanoscale fillers) with high surface areas are beneficial for enhancing shielding performance of concrete due to the skin effect (i.e., the interaction of high-frequency radiation with only the material surface).
EMW shielding effectiveness (SE) is the index for characterizing EMW shielding capability, and it is positively correlated to the electrical conductivity of EMW shielding concrete. Commonly, EMW SE in the frequency range of 30 kHz–1.5 GHz can be measured using coaxial planar-spectrum analyzer method (as shown in Fig. 18.1) [13]. In addition, the attenuations upon reflection and transmission can be measured using the coaxial cable method (i.e., the transmission line method) [14, 15].

18.2.2 Current Progress and Applications of Electromagnetic Wave Shielding Concrete

Much work has been carried out to develop high-performance EMW shielding concrete. According to the type of electrically conductive fillers used, EMW shielding concrete can be classified into three different categories: EMW shielding concrete with carbon fillers, EMW shielding concrete with metal fillers, and EMW shielding concrete with hybrid fillers [7].

(1) **EMW shielding concrete with carbon fillers**

Generally, effective conductive fillers usually have the characteristics of small size, high conductivity, and large aspect ratio, which are beneficial to reflection, skin effect, and formation of conductive path [3]. Carbon materials have good electrical conductivity and compatibility with concrete. Therefore, carbon materials are usually used as conductive fillers to make EMW shielding concrete. EMW shielding concrete with carbon fillers has been reported since 1989 [5]. Frequently used carbon fillers include carbon fiber, carbon filaments, carbon nanotube (CNT), coke powder, graphite, and carbon black (CB).

Carbon fiber is the most used carbon filler for fabricating EMW shielding concrete. As early as 1989, Chiou et al. developed EMW shielding concrete by adding short carbon fibers. They found that the attenuation of EMW increased from 0.5 dB for plain concrete to 10.2 dB for EMW shielding concrete at the frequency of 1.5 GHz [16]. A group in Japan also developed conductive concrete with carbon fibers to obtain EMW shielding capability in 1995 [17]. The fabricated concrete showed the SE between 26 and 54 dB within the frequency range of 30 MHz–1 GHz.
Huang et al. studied the SE of CB-cement paste and found that CB can improve the SE of matrix when the mass fraction of CB attained to 6% of percolation threshold. The maximum SE reached 15 dB at the frequency of 1.5 GHz \[1\]. Muthusamy and Chung fabricated EMW shielding concrete with short carbon fiber made from pitch or polycrylonitrile and silica fumes. The polycrylonitrile-based fiber with diameter of 7 µm was effective for enhancing EMW shielding capability of cement paste, whose shielding capability was superior to that of the previously studied cement paste containing pitch-based fiber with diameter of 15 µm. In addition, adding sand into cement paste leads to a slight decrease in SE \[18\]. Because carbon filaments have tiny diameter, high aspect ratio (>1000), and good conductivity, Fu and Chung made EMW shielding concrete with carbon filaments. Their work showed that the use of the carbon filaments with 0.1 mm of diameter was much more effective than the use of conventional carbon fibers with 10 mm of diameter for enhancing SE. When loading of carbon filaments is 0.54 vol.% and shield thickness is 4 mm, a SE of 30 dB was attained at 1–2 GHz \[19\].

CNT is considered to be one of the most beneficial nanomodification materials. The combination of high aspect ratio, small size, low density, and unique physical and chemical properties makes it perfect candidates for fabricating EMW shielding concrete. Nam et al. tested SE of concrete containing multiwalled CNT (MWCNT) with varying weights. As shown in Fig. 18.2, the maximum SE was −3.27 dB at the frequency of 0.94 GHz, when 0.6 wt% of MWCNT was added into concrete \[14\]. Singh et al. \[20\] studied the EMW shielding performance of concrete containing MWCNT. The SE of concrete with 15 wt% loading of MWCNT was more than −27 dB in the frequency range of 8.2–12.4 GHz (as shown in Fig. 18.3).

Compared with carbon fibers, carbon filaments, and CNT with features of high price and easy agglomeration, graphite is cheaper and easier to disperse in concrete. Zhang et al. investigated the effect of volume percent of graphite on SE of EMW shielding concrete at low frequency. The fabricated concrete showed a SE of 10–40 dB in the frequency range of 200–1600 MHz when the graphite content was increased to 18.0 vol.% \[21\]. Cao and Chung studied the EMW shielding properties of concrete with colloid graphite and compared them with that of concrete with

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**Fig. 18.2** Variation of SE at 0.94 GHz of concrete with MWCNT (C0.0: MWCNT content is 0.0%, C0.3: MWCNT content is 0.3%, C0.6: MWCNT content is 0.6%, and C1.0: MWCNT content is 1.0%). Reprinted from Ref. \[14\], Copyright 2011, with permission from Elsevier
Fig. 18.3 Dependence of SE in frequency range 8.2–12.4 GHz showing effect of MWCNT concentration on SE valve of concrete. OPC: MWCNT content is 0%, CCNT1: MWCNT content is 1%, CCNT2: MWCNT content is 2%, CCNT3: 3%, CCNT4: 4%, CCNT5: 5%, and CCNT10: 10%, CCNT15: 15%. Reprinted from Ref. [20], Copyright 2013, with permission from Elsevier.

carbon fibers and carbon filaments. At a similar volume fraction of filler and at the frequency of 1 GHz, the SE was 22 dB for concrete with solid graphite, 15 dB for concrete with 15 μm diameter carbon fibers, and 35 dB for concrete with 0.1 μm diameter carbon filaments [2]. Coke powder was also used in EMW shielding concrete because it is naturally facilitating to disperse, less brittle, electrically conductive, and less expensive. Cao and Chung fabricated EMW shielding concrete with coke powder [22]. Coke powder was more effective than carbon filaments with 0.1 μm diameter [19], but less effective than steel fibers with 8 μm diameter [13]. SE values of concrete with 0.51 and 1.02 vol.% of coke powder were 45 and 49 dB at the frequency of 1.5 GHz, respectively [22].

(2) **EMW shielding concrete with metal fillers**

Metals, such as silver, copper, nickel, and steel, are attractive for EMV shielding due to their superelectrical conductivity. The advantage and disadvantage of candidate metal fillers for EMW shielding concrete are summarized in Table 18.1.

Table 18.1 Advantage and disadvantage of candidate metal fillers for EMW shielding concrete

<table>
<thead>
<tr>
<th>Types</th>
<th>Advantage</th>
<th>Disadvantage</th>
<th>Widely used in EMW shielding concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>Highest conductivity among metal</td>
<td>Expensive</td>
<td>No</td>
</tr>
<tr>
<td>Copper</td>
<td>Good conductivity</td>
<td>Easier to be oxidized; a little expensive</td>
<td>No</td>
</tr>
<tr>
<td>Nickel</td>
<td>Stable and resistant to corrosion</td>
<td>Lower conductivity than silver or copper; a little expensive</td>
<td>No</td>
</tr>
<tr>
<td>Steel</td>
<td>Good conductivity; cheap</td>
<td>High density</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Up to now, the researches on EMW shielding concrete with metal fillers are mainly focused on EMW shielding concrete with steel filler. Chung et al. studied the EMW shielding properties of concrete containing steel fiber with diameter of 8 μm and length of 6 mm in 2004. They did amount of researches which mainly include three aspects: (1) selecting the optimal amount of steel fiber; (2) finding out the effect of presence of sand on SE; (3) investigating the effect of presence of steel rebar on SE of composites. As shown in Table 18.2, the maximum SE of 70 dB at the frequency of 1.5 GHz has been attained in cement paste containing 0.72 vol.% steel fiber. The presence of sand essentially does not affect SE, and the fibers remain effective in the presence of steel rebars [13].

(3) EMW shielding concrete with hybrid fillers

In order to take advantages of different fillers and realize synergistic modification effect, some researchers tried to use hybrid fillers to develop EMW shielding concrete. For example, Huang et al. studied SE of cement past with hybrid CB and carbon fiber. The maximum SE of cement paste with hybrid fillers reached 27 dB, but the biggest value of SE of cement paste with CB alone and carbon fiber alone at 1.5 GHz is 14 and 21 dB, respectively [1]. Singh et al. fabricated iron oxide infiltrated vertically aligned multiwalled CNT (MWCNT forest) sandwiched with reduced graphene oxide sheets network to develop high-performance EMW shielding concrete. Such sandwiched network exhibited enhanced SE compared with conventional fillers. In Ku-band (frequency range of 12.4–18 GHz), the SE value of concrete with the network was more than 37 dB (>99.98% attenuation), which is greater than the recommended limit (about 30 dB) for techno-commercial applications [23]. Zhang et al. used electrostatic self-assembled CNT/nanoCB (CNT/NB) filler to enhance EMW shielding capability of concrete. As shown in Fig. 18.4, the maximum SE of the developed concrete was 1.09 dB at 2 GHz, which was 9.4 times that of concrete without filler. The SE of concrete with 2.40 vol.% of filler was 5.0 dB at 18 GHz, which was 2.2 times that of concrete without filler [24].

As mentioned above, the SE of EMW shielding concrete with different fillers is summarized in Table 18.3.

In addition, concrete also can achieve EMW shielding function by setting steel bar and wire-mesh reinforcement inside it.

EMW shielding concrete is mainly used to prevent EM signals leakage and external EM interference. Due to its excellent SE, EM shielding concrete is gradually applied to practical engineering. For example, precast blocks fabricated with EMW shielding concrete containing carbon fibers have successfully been applied to shielding enclosure structures of a nine-story building in Japan. Additionally, EMW shielding concrete has also been employed in construction of the Pentagon in the United States. More applications of the EMW shielding concrete can be found in such structures as launching pad, base station, microwave station, EM compatibility laboratory, buildings below high-voltage line, and military bunker. In addition, EMW shielding concrete has potential application for lateral guidance of automatic driving in highways due to its high radio wave reflectivity [25].
Table 18.2 Attenuation (dB) of radio wave (1.0 and 1.5 GHz) upon transmission and upon reflection.

<table>
<thead>
<tr>
<th>Rebar</th>
<th>Sand to cement ratio</th>
<th>Fibers (vol.%)</th>
<th>Specimen thickness (mm)</th>
<th>Transmission</th>
<th>Reflection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0 GHz</td>
<td>1.5 GHz</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0</td>
<td>4.36 ± 0.40</td>
<td>4.06 ± 0.13</td>
<td>2.35 ± 0.09</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0.09</td>
<td>4.45 ± 0.17</td>
<td>19.4 ± 2.6</td>
<td>19.2 ± 2.8</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0.18</td>
<td>4.54 ± 0.32</td>
<td>27.7 ± 3.0</td>
<td>29.7 ± 3.6</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0.27</td>
<td>4.47 ± 0.25</td>
<td>37.8 ± 4.6</td>
<td>43.3 ± 3.4</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0.36</td>
<td>4.39 ± 0.23</td>
<td>52.3 ± 2.8</td>
<td>57.6 ± 3.0</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0.72</td>
<td>4.47 ± 0.16</td>
<td>59.1 ± 3.3</td>
<td>69.8 ± 5.4</td>
</tr>
<tr>
<td>No</td>
<td>0</td>
<td>0.90</td>
<td>4.48 ± 0.20</td>
<td>58.0 ± 4.6</td>
<td>71.3 ± 5.8</td>
</tr>
<tr>
<td>No</td>
<td>1.0</td>
<td>0</td>
<td>4.39 ± 0.43</td>
<td>4.38 ± 0.52</td>
<td>1.75 ± 0.02</td>
</tr>
<tr>
<td>No</td>
<td>1.0</td>
<td>0.46</td>
<td>4.44 ± 0.38</td>
<td>56.8 ± 0.38</td>
<td>62.2 ± 0.40</td>
</tr>
<tr>
<td>Yes</td>
<td>1.0</td>
<td>0</td>
<td>9.04 ± 0.38</td>
<td>14.9 ± 3.1</td>
<td>8.66 ± 1.74</td>
</tr>
<tr>
<td>Yes</td>
<td>1.0</td>
<td>0.41</td>
<td>9.90 ± 0.48</td>
<td>60.8 ± 3.0</td>
<td>67.6 ± 5.5</td>
</tr>
</tbody>
</table>

Reprinted from [13], Copyright 2003, with permission from Elsevier
Table 18.3  SE of EMW shielding concrete with different fillers

<table>
<thead>
<tr>
<th>Rebar</th>
<th>Sand</th>
<th>Filler type</th>
<th>Filler content</th>
<th>Frequency</th>
<th>Shielding effectiveness (dB)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>Steel fibers</td>
<td>0.72 vol.%</td>
<td>1.5 GHz</td>
<td>70.0</td>
<td>[13]</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td>78.0</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Carbon fibers</td>
<td>0.21 vol.%</td>
<td>1.5 GHz</td>
<td>10.2</td>
<td>[16]</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Carbon fibers –</td>
<td></td>
<td>30 MHz–1 GHz</td>
<td>26.0–54.0</td>
<td>[17]</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Graphene</td>
<td>18.00 vol.%</td>
<td>200–1600 MHz</td>
<td>10.0–40.0</td>
<td>[21]</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Carbon filaments</td>
<td>0.54 vol.%</td>
<td>1–2 GHz</td>
<td>30.0</td>
<td>[19]</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Coke powder</td>
<td>0.51–1.52 vol.%</td>
<td>1.5 GHz</td>
<td>40.0 and 49.0</td>
<td>[22]</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>Colloidal graphite</td>
<td>0.92 vol.%</td>
<td>1 GHz</td>
<td>22.0</td>
<td>[2]</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>Carbon fiber</td>
<td>0.90 vol.%</td>
<td>1.5 GHz</td>
<td>21.0</td>
<td>[1]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hybrid carbon fiber and CB</td>
<td>Carbon fiber 0.90 vol. % + CB 9.0 vol.%</td>
<td>1.5 GHz</td>
<td>27.0</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>Short carbon fiber</td>
<td>2.00 vol.%</td>
<td>1 GHz</td>
<td>32.6</td>
<td>[18]</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td></td>
<td>2.00 vol.%</td>
<td>1 GHz</td>
<td>34.0</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>MWCNT</td>
<td>0.60 wt%</td>
<td>0.94 GHz</td>
<td>3.2</td>
<td>[14]</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>CNT/NCB filler</td>
<td>2.40 vol.%</td>
<td>18 GHz</td>
<td>5.0</td>
<td>[24]</td>
</tr>
</tbody>
</table>

Fig. 18.4  SE of concrete with different contents of filler in the frequency of 2–18 GHz. Reprinted from Ref. [24], Copyright 2016, with permission from Elsevier
18.3 Electromagnetic Wave Absorbing Concrete

18.3.1 Definition, Mechanism, and Test of Electromagnetic Wave Absorbing Concrete

EMW absorbing concrete (also called radar stealthy concrete) refers to the composite which can absorb or attenuate incident EM energy by converting EM energy into thermal or other energy [7]. EMW can be absorbed through magnetic loss, dielectric loss, and resistive loss. The magnetic loss is caused by natural resonance and eddy currents. The dielectric loss is produced by polarization, such as electronic polarization, ionic polarization, molecular polarization, and interface polarization. The resistive loss is implemented by macroscopic current induced by carrier. These loss mechanisms can be achieved by adding different types of absorbing agents with different EM parameters (e.g., magnetic permeability, dielectric constant, and electrical conductivity) [3, 4]. Magnetic fillers (e.g., ferrite) and resistive fillers (e.g., carbon materials and metals) are the most used absorbing agents for fabricating EMW absorbing concrete [26]. Some researchers also tried to use fly ash and expanded polystyrene as absorbing agents.

The absorption property of EMW absorbing concrete generally is represented by reflectivity. The test system as shown in Fig. 18.5 is the most commonly used to measure the reflectivity [6]. In addition, the reflectivity can be calculated by using EM parameters tested with coaxial method including complex permittivity and permeability.

Fig. 18.5 Diagram of test system for reflectivity. Reprinted from Ref. [6], Copyright 2010, with permission from Elsevier
18.3.2 Current Progress and Applications of Electromagnetic Wave Absorbing Concrete

According to the type of absorbing agents incorporated, EMW absorbing concrete can be classified into four types: EMW absorbing concrete with magnetic absorbing agents, EMW absorbing concrete with resistive absorbing agents, EMW absorbing concrete with hybrid magnetic and resistive absorbing agents, and EMW absorbing concrete with other absorbing agents.

(1) **EMW absorbing concrete with magnetic absorbing agents**

The most commonly used magnetic absorbing filler is ferroelectric material. Concrete with ferrite can convert the EMW energy into thermal energy by magnetic loss and dielectric loss, thus featuring a wide absorbing frequency band. Xiong et al. developed EMW absorbing concrete with Mn–Zn ferrite in 2007. This kind of ferrite had a good stability in concrete matrix. Its content has remarkable effect on absorption properties of composites. The reflectivity of cement-based composite with ferrite of 35% (by mass) was less than $-6$ dB. The reflectivity of specimen with coarse surface was less than $-7$ dB in the frequency range of 8–12.5 GHz. Minimum value of reflectivity can reach $-10.5$ dB [27]. Zhang et al. fabricated double-layer cement-based plates with EMW absorbing properties. They observed that absorbing properties of cement-based composites with mixed ferrites were better than those composites with single type ferrite. The maximum reflection loss of double-layer cement-based plates with the addition of 30% (in mass) mixed ferrite absorbing agents (the volume ratio of two types of ferrites is 1:1) reached $-16$ dB in the frequency range from 8.3 to 11.5 GHz and $-10$ dB in the frequency range from 12.3 to 18 GHz, respectively [28]. Cui et al. tested the reflectivity of EMW of concrete with different contents of graphene in 1–18 GHz frequency band. As shown in Fig. 18.6, the EMW reflectivity of concrete with 5% loading of graphene reached the minimum value ($-5$ dB) in the vicinity of 8 GHz. The absolute value of reflectivity increased by 38% compared with that of plain concrete. The excellent EMW absorbing property of concrete can be attributed to their high dielectric loss angle tangent and resonance absorption [29].

(2) **EMW absorbing concrete with resistive absorbing agents**

The most used resistive absorbing agent for EMW absorption concrete is steel fiber. Yang et al. investigated the EMW absorbing property of concrete containing steel fiber with diameter of 0.7–1.0 mm and length of 2–8 cm with steel fiber in 2002. Absorbing peak value of $-9.8$ dB in the frequency range of 2–18 GHz and $-4$ dB for the frequency bandwidth of 15.28 GHz was achieved [30]. Gao et al. performed an intensive research on absorbing property of steel fiber concrete. Absorbing property of concrete in low- and high-frequency range was improved by adding steel fiber. Length and volume fraction of steel fiber are two key factors for improving absorbing property of concrete. Absorbing property of steel fiber concrete decreased with the increase of temperature and humidity. Radar maximum detection range of steel fiber concrete
with optimum absorbing performance reduced to 84–89% compared with that of plain concrete in frequency range of 2.6–4 GHz [31].

Due to rapid development of carbon materials in recent years, more researchers turn their attention to the study of EMW absorbing concrete with carbon material absorbing agents. Ou et al. investigated the absorbing property of carbon fiber concrete in 2006. The maximum radar detection range of carbon fiber concrete with an optimum mixture ratio was 80–90% of plain concrete in the frequency range of 14–18 GHz [32]. Dai et al. [6] tested EMW absorbing effectiveness of concrete filled with CB. As shown in Fig. 18.7, the concrete with CB exhibited good EMW absorbing performance in the frequency range of 8–26.5 GHz because CB can improve the loss factor of concrete. The minimum reflectivity reached −20.30 dB

![Fig. 18.6 Reflectivity of concrete filled with graphene. Reprinted from Ref. [29], Copyright 2016, with permission from Elsevier](image)

(a) In frequency range of 8-18 GHz (b) In frequency range of 18-26.5 GHz

![Fig. 18.7 Absorbing performance of concrete with different concentrations of CB. Reprinted from Ref. [6], Copyright 2010, with permission from Elsevier](image)
when the content of CB is 2.5 wt%. The frequency bandwidth in which the reflectivity is less than $-10 \text{ dB}$ is from 14.9 to 26.5 GHz. Zhang et al. [24] used electrostatic self-assembled CNT/NCB composite filler to enhance EMW absorbing capability of concrete. As shown in Fig. 18.8, the fabricated composites exhibited strong EMW absorbing performances in the frequency range of 2–18 GHz. A minimum reflectivity of composite reached $-23.08 \text{ dB}$, and a reflectivity less than 10 dB in the frequency bandwidth ranged from 16.16 to 17.60 GHz when filler content is only 0.77 vol.% [24].

Zhang and Sun investigated the EMW absorbing properties of concrete incorporating steel fiber and carbon fiber. They observed that the absorption properties of concrete in the frequency range of 8–18 GHz can be improved through adding these fibers. The concrete with 0.5% of carbon fiber possesses the best absorbing property [32].

It should be noted that too much resistive fillers will do harm the transition of incident EMW because of reflection, thus attenuating the absorption performance.

(3) **EMW absorbing concrete with hybrid magnetic and resistive absorbing agents**

Some researchers intended to combine magnetic loss and resistive loss effects for enhancing EMW absorbing properties of concrete by mixing ferrite with resistive fillers as absorbing agents. One Japanese institute puts ferrite tiles and steel mesh into fiber-reinforced concrete board to obtain enhanced EMW absorbing properties. An absorbing effectiveness of 8 dB at the frequency of 2.45 GHz was achieved [7]. Ou et al. found the addition of hybrid carbon fiber and ferrite is beneficial to absorbing property of concrete [33]. Wu et al. fabricated W-type BaCo$_2$Fe$_{16}$O$_{27}$ hexaferrite and investigated EMW absorbing properties of concrete filled with this kind of ferrite and short carbon fiber. The research results showed that the maximum absorption value of concrete filled with the ferrite (35% mass fraction) was $-8.7 \text{ dB}$ at the frequency of 14.3 GHz, but it can reach $-23.7 \text{ dB}$ when concrete was filled with ferrite (35% mass fraction) and carbon fiber (0.2% mass fraction) [34]. Wu et al. also used hybrid W-type Ba(Zn$_{1-x}$Co$_x$)$_2$Fe$_{16}$O$_{27}$ hexaferrite and short SiC fibers to develop EMW absorbing concrete. They found that the performance of
Ba(Zn_{1-x}Co_x)_{2}Fe_{16}O_{27} hexaferrite is the best at x = 0.8. The maximum reflectivity of concrete filled with 35% (in mass) ferrite and 0.2% (in mass) short SiC fibers is −13.5 dB in the frequency range of 12–18 GHz [35].

(4) **EMW absorbing concrete with other absorbing agents**

Guan used expanded polystyrene with EM transparency to enhance EMW absorbing capability of concrete. The expanded polystyrene filler can effectively improve reflection loss of concrete, and its size has obvious effect on EMW reflection loss of concrete. When the volume concentration of expanded polystyrene with size of 1 mm was 60%, the reflection loss was all higher than 8 dB in the frequency range of 8–18 GHz and the bandwidth of 10 dB reached 6.2 GHz for sample with thickness of 20 mm. In addition, this kind of concrete is easily handled and has an advantage of relatively low bulk density [36]. Li et al. used fly ash as the cement replacement to enhance the EMW absorption of cement-based composites. Fly ash had the potentiality of wave attenuation due to its complex components (over 8 wt% of unburned carbon, 7.1 wt% of Fe_{2}O_{3}, 1.2 wt% of MgO, and 1.3 wt% of K_{2}O) and porous structure. However, the pozzolanic activity and packing effect of fly ash had a negative effect on the absorbing properties. In addition, the absorbing properties of concrete can be enhanced greatly by adding hybrid expanded polystyrene and fly ash. As 25% fly ash and 50% expanded polystyrene were added into concrete, the bandwidth in which reflection loss is less than −8 dB was enlarged to 10.95 GHz, and peak value of reflection loss reached −15.2 dB at the frequency of 5.5 GHz [9].

EM radiation cannot be eliminated or weakened by EMW shielding concrete. In addition, EMW shielding concrete can cause secondary reflection since the reflected wave may interact with the incident wave. Therefore, EMW absorbing concrete features more desirable property against EMW shielding concrete, thus having wider application. EMW absorbing concrete can be utilized in the field of anti-EM pollution and environmental protection buildings to purify EM environment and reduce EM damage to human’s health. The EMW absorbing concrete employed in building, bridge, and tower construction can prevent radar artifact. In addition, improved communication quality can be achieved if EMW absorbing concrete is used during the construction of communication base and parabolic antenna. For airport, dock, beacon, TV station, and receiving station, the application of EMW absorbing concrete is of great benefits to eliminate reflection interference effectiveness. To build wave absorbing chamber with the EMW absorbing concrete not only can eliminate interference and improve measurement accuracy, but also has the protection function to operators. The EMW absorbing concrete also plays an important role in the field of military stealth building, research department of EM interference prevention, precision instrument factory, and national security department [4, 7, 37].
18.4 Summary

EMW shielding concrete and EMW absorbing concrete are two types of EMW defense composites with different mechanisms. Generally, the latter has more desirable performance than the former. Different types of fillers are necessary for obtaining the required shielding/absorbing performances. As a result, the EMW shielding/absorbing concrete has such main drawbacks as depressed compressive strength, complex processing, and high cost. Especially, the shielding/absorbing bandwidth of concrete is limited by nature of shielding/absorbing fillers and selectivity of shielding/absorbing fillers to EMW frequency.

With the increase in popularity of electronic devices, the development of radiation sources in industrial production and resident life, and the upgrading of military confrontation, the subsequent EM pollution, EM interference information stealing, and military security are becoming more and more serious, so there is a growing interest in studies and applications of EMW shielding/absorbing concrete. Although significant achievements have been gained, existing EMW shielding/absorbing concrete still needs to be further modified. It is urgent to develop EMW shielding/absorbing concrete with the features of stable performances, high shielding coefficient, strong absorbing effectiveness, large frequency band, and low cost. In future, much research efforts on EMW shielding/absorbing concrete should be devoted to look for high-performance shielding/absorbing agents, set up effective design and fabrication methods for EMW shielding/absorbing concrete and structures, test long-term performance of EMW shielding/absorbing concrete and structures under environmental actions, and evaluate effectiveness of infrastructures made of EMW shielding/absorbing concrete.

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