Investigation of Microwave Absorption Properties in ISP/ER Composite with Different Amounts of ISP

E. Khosravipanah[1, 2], A. Salemi Golezani[1, 2,*], H. Sabet[1, 2]

[1]Department of Materials Engineering, Ka.C., Islamic Azad University, Karaj, Iran.
[2]Institute of Manufacturing Engineering and Industrial Technologies, Ka.C., Islamic Azad University, Karaj, Iran.
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Abstract

Electromagnetic wave (EMW) absorbing materials working at GHz band have attracted increasing attention because of the increasing electromagnetic interference and radiation problems. In this study, iron spongy powder (ISP) used for microwave absorption. For the fabrication of composite samples, ISP and epoxy resin were used. In the composite compound, values of weight percentages 5, 10, 15, and 20 % were selected. Scanning electron microscope (SEM) was used to analyze the microstructure ISP. The microwave reflection loss (R.L.) have been investigated using a Vector Network Analyzer (VNA) at the X-band (8–12 GHz). The thickness of the ISP/epoxy composites was 2 mm. Compared with the microwave absorption performance, the minimum R.L. value is -7.4 dB with the 20 wt. % at 10.7 GHz. It was concluded the increase in the weight percentage of sponge iron powder had an impact on improving microwave absorption performance.

Keywords: Composite, Microwave Absorber Materials, Sponge Iron, Reflection Loss.

1. Introduction

Nowadays, with the fast progress of electronic techniques, excessive electromagnetic radiation in the microwave band leads to numerous serious hazards, e.g. electromagnetic interference (EMI) [1-3], electromagnetic leakage of classified information, and possible health problems for human beings, etc [4-6]. Electromagnetic contamination gradually becomes one of the non-negligible hazard factors to be addressed urgently [7-9]. Among the many methods of electromagnetic protection, the design and preparation of electromagnetic-wave absorption materials (EWAMs) has been proven to be a very effective technique for eliminating such troubles induced by excessive microwave radiation [10-12]. Electromagnetic wave (EMW) absorption materials such as MXene [13], rare earth [14, 15], and carbon materials [16–18] have attracted significant attention in recent years for their ability to efficiently convert incident microwaves into heat and other forms of energy [19-21]. Although conventional EMW absorption materials, including ferrites, ceramics, metal oxides [22], etc. exhibit excellent microwave absorption efficiency, they often suffer from high density and lack of tunability. Ideal EMW absorption materials should possess characteristics such as strong absorption capability, broad absorption range, thin thickness and low filling ratio, etc [23-25]. Moreover, given the widespread applications of EMW materials, the fabrication of microwave absorbers should also meet the requirements in the practical [26,27] or industrial realm, including accessible raw materials and facile preparation methods conducive to mass production [16]. The growing need for microwave absorbing materials requires effective and cost-effective solutions for both defense and civilian fields. Microwave absorbing materials impart stealth features which increase the possibility of survivability of the military equipment in the advent of any war. Apart from instilling stealth features to the military equipment, microwave absorbing materials also plays a significant role in suppressing the problem of electromagnetic interference (EMI) problem in this technology-driven era. EMI not only disrupts the proper functioning of electronic gadgets by interfering with the electronic circuitry but also acts as a source for hazardous health implications to human and other biological systems from chronic exposures to microwave radiations [28,29]. In response to the need, much attention has been focused on tailoring the structural parameters of the microwave absorbers to achieve enhanced microwave absorbing properties [30]. The importance of microwave absorbing materials has significantly drawn the keen attention of the searchers to develop new materials and techniques for achieving enhanced microwave absorption [31–33].

Iron powder and ferrite are magnetic materials are usually used as microwave absorbencies [34,35]. Previous research [36] reported that the thicknesses of microwave absorbing composites containing CIPs 0.3–0.6 volume content (77–92 wt %) were all 1 mm; such composites reached 10 dB R.L. at S, C, X, and Ku bands. Although their thickness was only 1 mm, containing too much CIPs would make the composites inflexible, heavy, and easily broken.

[*]Corresponding author
Email address: salemiali@kiau.ac.ir

Two US patents [37,38] and the Sandia report [39] denoted that iron powders with spongy and porous structures were usually used in heating compositions for thermo-piles and electrical energy accumulators, such as electrical Ni–Cd cells or Ni–metal hydride cells.
Since the spongy structure and porous characteristic, spongy iron powders (SIPs) possess high surface areas, which lead to plenty of interfacial polarization to weaken the energy of EM waves. In this study, the SIP was used to be bound with the epoxy for the preparation of microwave absorbing composites.

2. Materials and Methods

Initially, the required amount of iron powder was accurately weighed. Based on the target weight percentage, the powder was mixed with epoxy resin using a mechanical stirrer for 2 hours to ensure uniform dispersion.
The resulting mixture was then poured into a mold. After degassing to eliminate surface bubbles, the samples were allowed to cure at room temperature for 24 hours. Iron powder was mixed with epoxy to fabricate microwave-absorbing composites. A total of four samples with weight percentages of 5%, 10%, 15%, and 20% and dimensions of 0.9 × 2.4 in² were prepared. The microwave reflection loss (R.L.) in the X-band was measured. The device used in this study was an Agilent E8362B Vector Network Analyzer (VNA) operating in the X-band frequency range.
The reflection loss (RL) and transmission loss (TL) were measured by using a vector network analyzer (VNA) to study the microwave absorption properties in the frequency range of 8–12 GHz (X–band), as can be seen in Fig. 1. [40].

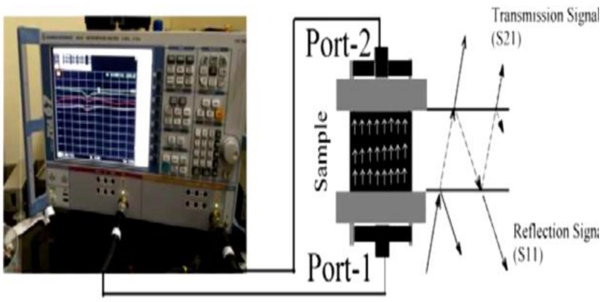

Fig. 1. The experimental vector network in the frequency of 8–12 GHz.

3. Results and Discussion
3.1. Morphological and Physical Properties of the ISP

Fig. 2. shows the SEM images of ISP, which was prepared in this study. They show that the structure of ISP is spongy, noodle-like, and porous.
Therefore, it could be suspected that the ISP may have a large specific area.

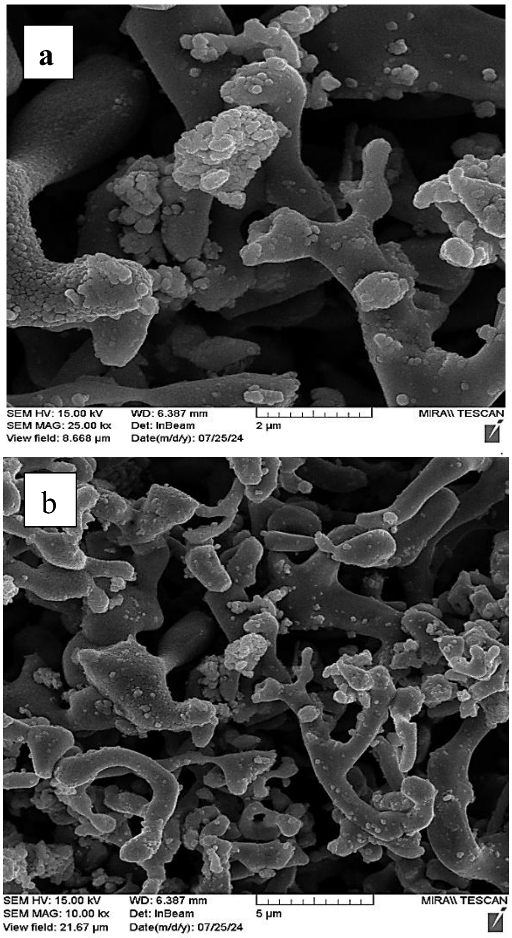

Fig. 2. The SEM of the ISP at two magnifications.

3.2. Microwave Absorption Performance

The spongy structure of ISP possesses a high content of pores. Since ISP possess a special structure and a large specific surface due to their porous character, the ISP would enhance microwave absorbency by the larger microwave interaction area. There are two parameters of flat microwave absorbing composites for controlling microwave absorbing frequency. One is the weight percentage of absorbencies, and the other is the thickness of microwave absorbing materials [41]. Particularly, in comparison with previous research on microwave absorbing, this study tuned the compositions and the thickness of samples to control the absorbing peaks at X-band.
According to the transmission line theory, the RL values can be calculated by the following equations [42,43]:

$$RL\ (dB) = 20 \log \left|\frac{Zin - Zo}{Zin + Zo}\right| \qquad \text{Eq. (1).}$$

$$Z_{in} = Z_0 = \sqrt{\frac{\mu r}{\varepsilon r}} \tanh\left[j\left(\frac{2\pi f d}{c}\sqrt{\mu r\, \varepsilon r}\right)\right] \qquad \text{Eq. (2).}$$

where Z_0 is the impedance of free space, Z_{in} is the input impedance of the absorber, f is the working frequency, d is the thickness of the absorber, c is the velocity of light, μ_r and ε_r complex permeability and complex permittivity of the absorber material respectively.

Fig. 3. shows the reflection loss curves of four groups of ISP composites with different weight percentage values in the frequency range of 8-12 GHz. From Fig. 3. it can be seen that the addition of ISP makes the composites have EM microwave absorption properties.

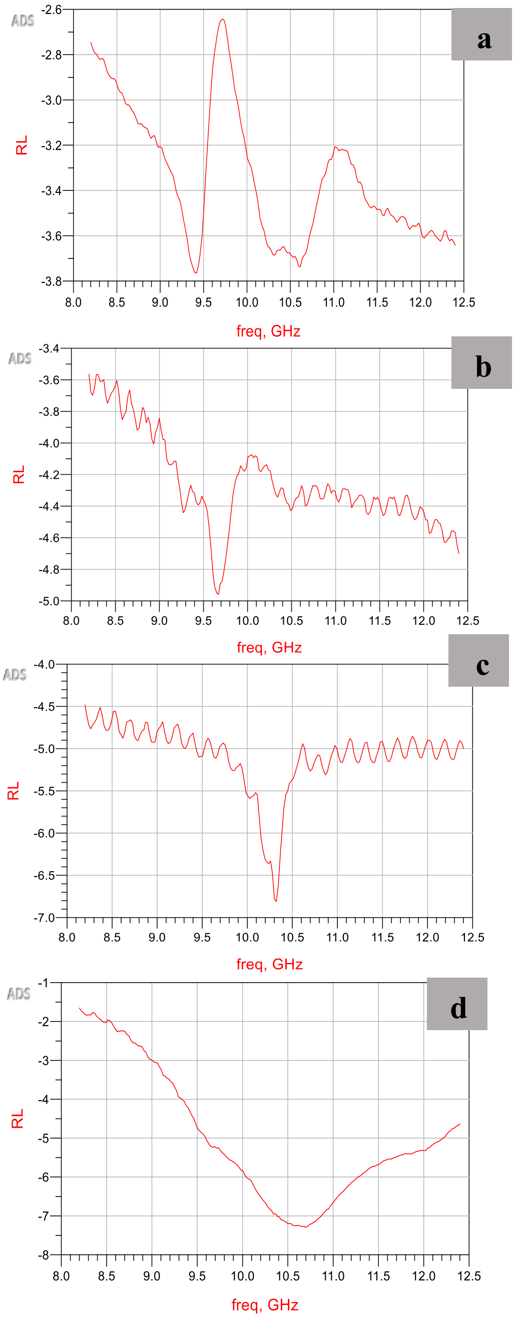

Fig. 3. Reflection loss curves of ISP/epoxy composites: (a) 5 wt%, (b) 10 wt%, (c) 15 wt%, (d) 20 wt%.

Among them, the composites with ISP content of 20 wt% have the best microwave-absorbing effect, and the minimum reflection loss of -7.4 dB at 10.7 GHz is achieved at a thickness of 2 mm. In addition, the reflection loss curves of the composites are mainly concentrated in the low-frequency range of 6~9 GHz, which indicates that the loss absorption of EM microwaves by the composites mainly occurs at the low frequency, and the experimentally prepared ISP/epoxy composites have a better advantage of low-frequency EM microwave absorption performance. It is important to note that the composite can be used directly to make the required structural absorbers rather than just as a coating material. Normally, EM microwaves are partially reflected when they are incident on the surface of a material.

$$\alpha=\sqrt{2}\pi fc\sqrt{(\mu''\varepsilon''-\mu'\varepsilon')+\sqrt{(\mu''\varepsilon''-\mu'\varepsilon')2+(\mu''\varepsilon''+\mu'\varepsilon')2}}$$

Eq. (3).

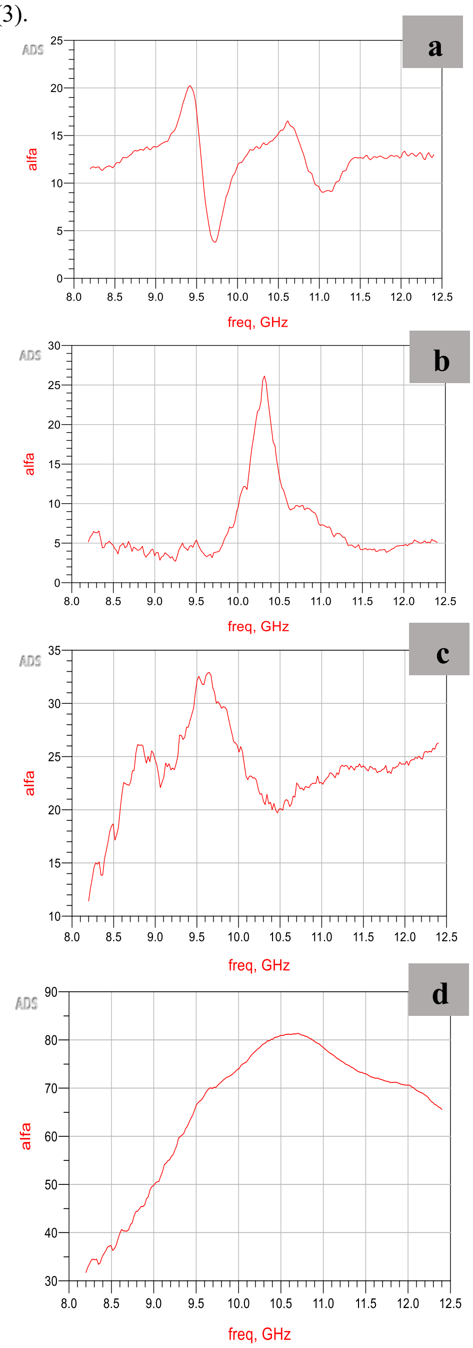

Fig. 4. The attenuation constant (α) of ISP/epoxy composites: (a) 5 wt%, (b) 10 wt%, (c) 15 wt%, (d) 20 wt%.

In order to make the EM microwaves better incident on the inside of the material instead of reflecting on the surface, good impedance matching is required; however, good impedance matching will, to a certain extent, make the material's ability to attenuate the EM microwaves lower. Therefore, the attenuation and impedance matching of EM microwaves need to be coordinated during practical application. The attenuation constant (α), representing the internal attenuation ability of the materials, can be calculated by the following equation [44]

Fig. 4. demonstrates the composite attenuation coefficient, showing normal variation with frequency. The trends of the peak values of the attenuation coefficients of the four groups of composites with different ISP contents are basically the same, among which the peak values of the attenuation constants of the composite with 20 wt% ISP content are significantly higher than those of the other groups, indicating that their microwave-absorbing performances are superior to that of the other groups, which corresponds to that of the composites with the best microwave-absorbing performances in the composite with the 20 wt% ISP content in Fig. 3. Good impedance matching is very important for microwave-absorbing materials; the more consistent the characteristic impedance of the material composite, the closer the synergistic effect is to the free-space characteristic impedance, the more EM microwaves will penetrate into the microwave-absorbing material, and the better the microwave-absorbing performance will be [45].

4. Conclusion

1. The studied material shows microwave absorption properties in the frequency range of 8–12 GHz.
2. The resulting R.L. and absorption values were −7.4 dB and 80% for ISP/epoxy composite with 20 wt%. respectively.
3. The production of composites with sponge iron powder is very cost-effective due to its low price.
4. Due to ISP's spongy structure and porous characteristics, the powders can be used as a microwave absorbent. Thus, the composites consisting of ISP could be applied as microwave-absorbing materials.

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