The effect of Sn-Al-C composite powders on the electromagnetic interference shielding of capsule building materials

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Abstract. The Sn substrate composite powder technology for capsule building was tested in this study, and the trend of adding graphite was studied. Then, a series of materials with higher resistance to electromagnetic waves were investigated. Based on low-cost advantages and particular categories of architectural application, the Sn-Al-C (SAC) ternary system powder was studied using the coating method, which can be applied to cement or plastic surfaces. The effects of particle size, content ratio of C and Sn-Al additions, stacking effect, and influence of porosity and thickness on the electromagnetic shielding mechanism were analyzed and discussed in detail.

1. Introduction
Earth's energy reduction and stricter environmental requirements increase the demand for green and environmental-friendly building materials. This provides a lot of opportunities to nanotechnology development, especially in nanomaterials, new structures, properties and the nanomaterial function adjunct on known materials, as well as addresses innovative issues [1-3]. For current capsule buildings or hotels with small internal space and high-density arrangement, the material shielding from electromagnetic wave interference is essential. Furthermore, the outdoor capsule materials with low cost, high-temperature resistance, rust resistance, excellent electrical conductivity, and thermal conductivity, etc., are required to cope with the trend of environmental-friendly materials [4-6].

Based on the above considerations, such elements as Sn, Al and C have not only excellent EMI shielding properties but are also competitive in price [7]. A low-cost silver-white powder of Sn-Al-C (SAC) was prepared by a simple technique, and its electromagnetic wave interference shielding effect
versus particle size, C content ratio, and thickness of coating were examined by the coating method [8-9].

2. Experimental method

Improved powder microstructure by used powder test and coating test. First, discussed the correlation between Sn-Al-C (SAC) and the influence of shielding electromagnetic interference (EMI) based on the ternary system powder in the architectural application category. Besides, the content of graphite (C) in building materials was clarified, and related characteristics were analyzed to propose the optimum ratio of Sn alloy powder coating (film) mechanism for construction using [10-12]. A construction uses a ternary system as the main body to develop shielded electromagnetic wave powder (film) material for building construction. Through added graphite (C) to review the electromagnetic wave shielding effect of SAC before and after the heat treatment and magnetic evolution changed to the comprehensive mechanism and further clarified the characteristics of the composition, light transmittance, and conductivity, etc. Finally, integrity review and analysis were based on the EMI mechanism and the shielded electromagnetic wave film system to suggest the healthy building materials application reference [13-15].

In this study, system powders such as Sn-xAl (x=40 wt.%) - yC (x=5, 10, 15 wt.%) were selected for EMI-related experiments. A suitable amount of Polypropylene and Sn-Al-C (SAC) and system powder mix well (Polypropylene selected 15 wt.% ratio), let SAC powder was completely uniformly dispersed in Polypropylene. The SAC was mixed well with a Polypropylene by used blade forming apparatus, then composite colloid was coated on a glass substrate (glass substrate size 2 cm x 2 cm x 2 cm, total one piece), and solidify at room temperature for 48 h [16-17]. Estimated number of coatings in the experiment is two layers and three layers coating; each coating thickness was controlled at 25 ± 10 μm. To understand the characteristics of the microstructure. High-order instruments such as SEM were used to analyze the particle size of SAX powder and the appearance characteristics of the coating, to review the evolutionary correlation of shielding effect on electromagnetic waves between the Sn-Al-C and the system.

This study used a coaxial electromagnetic wave shielding effect tester with a scan frequency range from 300K to 3G Hz with an accuracy of ±10 ppm (250 ± 50). The measurement method of this experiment is used the plane wavelength of normal incidence to test; the measured frequency range is controlled from 50MHz to 3000MHz, all the data average values were 3~7 points. The shielding efficiency value was obtained by calculation [18-20].

3. Results and Discussion

3.1. Effect on EMI shielding mechanism characteristics of Sn-Al-xC powder coating structure and film structure
Sn-xAl-C was coated on a glass substrate in this experiment. After the film was prepared, the material properties (microstructure, interface) of the initial coating and powder were analyzed, and the electromagnetic wave shielding experiment was also performed. Then the properties of the sample microstructure were analyzed to compare the changes of the film before and after heat treatment. After powder coating experiment, when the Al content in the Sn-xAl coating was increased, the electrical conductivity was lowered, but the stacking effect could improve the electromagnetic wave shielding property under low-frequency conditions. The volume fraction of the intermetallic compound in the powder is reduced by decreased the Al content to increase the powder conductivity and improve the high-frequency electromagnetic wave shielding property. Besides, the channel effect of the Polypropylene was remarkable but single coating without electromagnetic shielding. The three-layered Sn-xAl coating used in increased porosity solidifying (up to ~15 vol.%), so the electromagnetic shielding was caused deterioration (confirmation: the more the number of layers is, the better the shielding effect is not). On the other hand, more importantly, in the Sn-Al film experiment increased film thickness and increased conductivity was an important finding in increasing the efficiency of EMI electromagnetic shielding.

According to reasonable inference, increasing the Al content in Sn-40Al-10 C powder can improve then shielding characteristics of low-frequency electromagnetic waves based on electromagnetic wave shielding characteristics of Sn-xAl powder coatings study. On the other hand, after annealing test, high-temperature crystallization process (crystallization phase homogenization) and high conductivity can be improved (as shown in table 1) EMI shielding property of the Sn-Al nanofilm (increased high-frequency shielding efficiency), as shown in table 2. Sn-40Al-10C (330nm) thin film EMI shielding experiment, Figure 1(a) was the electromagnetic wave shadowing effect evolution map (from 330nm, 560nm, and 780nm) by different sputtering film thicknesses. Similarly, table 2 also showed electromagnetic shielding testing result. Increased the thickness of the sputter film not only improved crystallinity (IOC) but also enhanced electromagnetic shielding efficiency. To avoid affecting particle size, crystallization rate, and coating formation, 330nm was annealed in a vacuum environment (200°C/1 h) and then cooled at room temperature (0.5°C/min.). And a control EMI masking experiment was performed for the 330 nm-H coating and the 330 nm coating. According to the result of EMI shielding effect of 330nm-H and 330nm, the EMI shielding efficiency of the (330nm-H) film after annealing was better than that of the 330nm film (fig. 1(b); table 2). From the above result, annealing experiment (200°C/1h) not only improved the film conductivity but also had better crystallization rate and lower resistivity. So that could enhance the high-frequency electromagnetic shielding effect. However, for building materials application, cost of the Sn-40Al-10C film had high competitiveness, and low-frequency shielding of the Sn-40Al coating was superior to high-frequency conditions. Considering the electromagnetic space environment has mostly low frequency the application of the Sn-40Al-10C film to the interface layer of building materials should be helpful for EMI shielding.
### Table 1. Four-point probe result of Sn-alloy.

|           | Sheet resistance |
|-----------|------------------|
| Sn-40Al-5C | 1.59×10^4 Ω·cm  |
| Sn-40Al-10C | 2.87×10^4 Ω·cm  |

### Table 2. The average dB value of coatings at different frequencies.

| Specimen | 300 MHz (-dB) | 900 MHz (-dB) | 1.80 GHz (-dB) | 3 GHz (-dB) |
|----------|---------------|---------------|----------------|-------------|
| 330nm    | -11.6737      | -13.8131      | -14.9646       | -21.1212    |
| 560nm    | -15.3353      | -19.2621      | -25.8131       | -21.2161    |
| 780nm    | -21.1113      | -22.1671      | -20.2212       | -24.2235    |
| 330nm-H  | -15.2259      | -16.2852      | -17.7233       | -24.3989    |

### Table 3. Four-point probe result of Sn-Al-xC.

| SAC      | Sn-40Al-5C   | Sn-40Al-10C  | Sn-40Al-15C  |
|----------|--------------|--------------|--------------|
| As-sputtered | 5.44×10^5  | 6.22×10^5   | 3.39×10^4 |
| Annealed  | 1.09×10^5   | 3.36×10^5   | 3.21×10^4 |

### Table 4. The average dB value of the Sn-40Al-C thin film.

| Specimen    | 300 MHz(-dB) | 900 MHz(-dB) | 1.80 GHz(-dB) | 3 GHz(-dB) |
|-------------|--------------|--------------|----------------|-------------|
| Sn-40Al-10C-780nm | -13.19914    | -16.3332     | -22.0809       | -14.8712    |
| Sn-40Al-10C-780nm-H | -7.3321      | -8.2356      | -15.1399       | -13.0101    |
3.2. Sn-40Al-xC coated film microstructure characteristic and EMI shielding mechanism

Sn-Al systems had excellent EMI electromagnetic shielding performance and had an advantage of price competitiveness. According to the literature and the above experimental results, Al content can affect the EMI shielding efficiency at different frequencies. Comparing the Sn-40Al-x C film, as shown in figure 1(a) (select x=10 and 40wt.% ratio), the Nanofilm was sputtered on the glass substrate (a total of one glass substrate, the substrate size is 2 cm x 2 cm per each glass, as shown in figure 2(a)), and the Sn-40Al film thickness is controlled to be 330 nm to 780 nm. It is worth noting that the Sn-40Al (330nm) film was annealed in a vacuum environment (330nm-H, 200°C/1 hr), the results show that the EMI shielding effect of Sn-40Al (330 nm) is better and the grain surface features are more detailed (as shown in figure 2(b), the particle size is about 20~25nm), as shown in figure 1(b). This is the reason for further planning will leading-in heat treatment to improve the uniformity. Since target material of Sn-Al-C had a more excellent high electrical conductivity (1.09 x 10-4 (cm) and reasonable price competitiveness as shown in table 3. Therefore, the experiment of the electromagnetic wave shielding effect was used SAC. According to previous studies, the effect of 300k ~ 3 GHz electromagnetic shielding in high-purity Sn substrate materials is optimum. Figure 3 shows a comparison of the coated Sn-40Al-10 C (780nm) film. After the experiment of the electromagnetic shielding effect, the EMI shielding effect of Sn-40Al-10 C (780nm) film is better than Sn- 40Al-10C (780nm) film (table 4). But it is worth noting that the Sn-40Al-10C (780nm) film does have a partial frequency shielding effect, which is another discovery in this experiment (figure 3).
According to the experiment, the film after annealing experiment can not only increase the conductivity but also improve the excellent EMI shielding effect. However, it is worth noting that the Sn-40Al-10C film has been deteriorated after annealing experiments. (figure 4 and table 4). More importantly is the thickness of the Sn-40Al-10C film is only half of Sn-40Al-10C (this result is different from the previous Sn-xAl film shielding effect). Besides, from SAC (780nm) film experiment, the EMI of the high-frequency shielding effect was degraded due to the increase in IMCs plot ratio and the double cause after the annealing process. The experimental results show that Sn-40Al is significantly improved in overall electromagnetic shielding after annealing treatment. It is noteworthy that low-frequency electromagnetic shielding is better than high frequency when C content is increased. Since Sn-Al-C has higher conductivity and magnetic strength, the electromagnetic wave shielding full-frequency shielding can be improved.

**Figure 2.** Sn-Al sputtering thin films (330 nm):

(a) Appearances  
(b) The surface characteristic

**Figure 3.** EMI shielding of Sn-40Al-10C (780nm) and Sn-40Al-15C (780nm).
4. Conclusions

- The conductivity is decreased when Al content in Sn-xAl-C coating is increased, but the stacking effect can be improved the electromagnetic wave shielding under low-frequency conditions. And the volume rate of intermetallic compound powder is reduced when Al content decreased so that the electrical conductivity is improved and the high-frequency electromagnetic wave shielding property can be effectively improved.
- The effect of conductivity and magnetic strength is significantly improved, the low-frequency electromagnetic shielding effect is better than high-frequency one when C content is increased.

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