Study on preparation and properties of aramid/stainless steel fiber blended electromagnetic shielding fabric

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Abstract: In order to develop electromagnetic shielding (EMS) fabric with high-performance, aramid / stainless steel fiber blended yarns were used to achieve it, and its electromagnetic shielding effectiveness (EMSE), flame retardancy and tensile properties were tested. The effects of fabric structure, fabric thickness, and fabric overlap angle on fabric properties were studied. The results showed that the plain weave fabric has the best EMSE among three kinds of fabrics with plain, twill and satin weaves. The EMSE of the satin weave is the worst. When the fabric thickness increased, the EMSE enhanced. The EMSE at the fabric overlap angle of 45° is the highest when the overlap angle is changed from 0° to 90°.

1. Introduction

In daily life and work, almost all electronic equipment used by people emit electromagnetic radiation, and electromagnetic pollution has become a major problem that endangers life and damages the operation of equipment [1]. In modern warfare, electromagnetic weapons are called ”super killers”. Once attacked by them, military secrets are likely to be stolen. Therefore, people have paid more and more attention to the research and development of electromagnetic shielding fabrics.

At present, the electromagnetic shielding fabrics which have been put on the market can be divided into the following types: metal plating fabrics, conductive coating fabrics and metal fiber blended fabrics [2]. Metal-plated fabrics have good shielding effects, but their coatings are not washable and easily oxidized [3, 4]. The shielding effectiveness of conductive coated fabrics is relatively poor, and it can only be used as a flexible electromagnetic shielding material with low electromagnetic wave reflection [5]. The shielding effect of metal fiber blended fabrics is good and durable. However, when the content of metal fibers increases, its comfort decreases slightly [6, 7]. In order to obtain electromagnetic shielding fabrics with excellent shielding performance, high added value and environmental protection, people tend to choose a method of blending metal fibers with ordinary

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fibers to prepare metal fiber blended electromagnetic shielding fabrics. Ayse Bedeloglu [8] used stainless steel fiber / acrylic / cotton blended yarn to weave electromagnetic shielding woven fabrics, and studied the influence of stainless steel fiber diameter and fiber blending ratio on the performance of electromagnetic shielding fabrics. S Palanisamy et al. [9] blended stainless steel fibers with polypropylene to make woven fabrics, and studied the effect of stainless steel fiber content on the breathability and bending properties of electromagnetic shielding fabrics. Krishnasamy Jagatheesan et al. [10] blended carbon fibers and stainless steel fibers into yarns and wove them into woven fabrics. The fabrics were then laminated with polypropylene films to study the effects of yarn structure, fabric structure, and composite methods on the electromagnetic shielding properties of fabrics. Mustafa Sabri Ozen et al. [11] blended stainless steel fibers and polyester into a non-woven fabric by needle punching, and studied the effect of fiber content and fabric thickness on the electromagnetic shielding performance of fabrics.

The technology for preparing stainless steel fibers is now relatively mature, and its price is slightly lower than other metal fibers. Aramid has the advantages of high modulus, high strength, and flame retardancy. Therefore, in this study, aramid/stainless steel fiber blended yarn was used to prepare EMS woven fabrics with high-performance. The influence factors of EMS fabrics were studied by changing the fabric structure, fabric thickness and fabric overlap angle. Its flame retardancy and tensile properties were also tested and analyzed. This paper provides a reference for the development of electromagnetic shielding fabrics.

2. Experiment

2.1. Materials
The yarn used in this research is aramid/stainless steel fiber blended yarn (provided by Fujian Qianglun New Material Co., Ltd.). Its blending ratio and linear density are 37/63 and 97.2tex, respectively.

2.2. Equipment
The main equipment used in the study are: SLo-01 semi-automatic weaving machine, Y511B fabric density analysis mirror, YG (B) 141D digital fabric thickness meter, DR-913G fabric electromagnetic radiation resistance tester, INSTRON universal material testing machine, YG (B) 815D-I fabric flame retardant performance tester and HS-B24 fully automatic computer-controlled high-temperature sample machine.

2.3. Sample preparation
Semi-automatic weaving machine was used to weave EMS fabrics with different structures, which are plain weave, 1/2 twill weave, and 5/3 warp satin weave. The fabric specifications are shown in table 1.

| Table 1. Fabric specifications. |
|-------------------------------|
| Fabric types | Warp density (number/10cm) | Weft density (number/10cm) | Fabric thickness (mm) |
|----------------|---------------------------|---------------------------|----------------------|
|                |                          |                          |                      |

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2.4. Test Methods

2.4.1. EMS performance test. According to the standard GB/T 30142-2013 flat electromagnetic shielding material shielding effectiveness test method, the shielding effectiveness (SE) of the sample was tested. According to 2.7.1 of the GB/T 26667-2011 term of electromagnetic shielding materials: SE is usually negative, but its absolute value is customary. When the sample is not blocked, the SE value is 0. The larger the SE value, the better the effect of preventing electromagnetic radiation.

2.4.2. Flame retardancy test. According to the standard GB/T 5455-2014 textile combustion performance vertical direction, the damage length, smoldering and afterflame time measurement, the flame retardancy of the sample was tested. The flame generated by the specified igniter is used to ignite the center of the bottom edge of the sample in the vertical direction, and the ignition time was 12s. When the ignition time was over, the igniter was removed and the flame was extinguished. At the same time, the afterburning time and the smoldering time were recorded, and the damage length was measured.

2.4.3. Tensile properties test. According to the standard GB/T 3923.1-2013 textiles, tensile properties of fabrics, part 1: determination of breaking strength and elongation at break (strip method), the tensile properties of the samples were tested. The sample was cut from warp and weft directions. The clamping distance of the instrument was adjusted. The tension value was determined according to the weight of unit area of the fabric. The tension clamp was selected according to the pre-tension. Then the breaking strength and elongation at break of the fabric were measured.

3. Results and discussion

3.1. EMS performance of aramid/stainless steel fiber blended fabric

3.1.1. Effect of fabric structure on EMS performance. The SE curves of fabrics with different fabric structures over frequency range of 30MHz to 3000MHz are shown in figure 1. It can be found that the plain weave fabric has the best EMSE among three kinds of fabrics with plain, twill and satin weaves. The EMSE of the satin weave is the worst. According to the transmission of electromagnetic wave, when electromagnetic wave reaches the surface of the fabric, part of the electromagnetic wave will be reflected, and the rest will be conducted through the connection between the fabric yarns, which is called absorption. In other words, the more complete the structure and the stronger the connection, the better the EMS effect. The plain weave belongs to the three-elementary fabrics with the smoothest surface. Its floating length is short and its porosity is low, so the electromagnetic waves are not easy to pass through. The floating length of the twill weave and its porosity are between the plain and the satin. Therefore, the EMS performance of the twill weave is not as good as the plain weave, but it is better
than the satin weave. The satin weave has the longest floating length among the three fabrics. Also, it has loose structure and high porosity, which results in the worst EMSE of the satin among the three fabrics.

![Figure 1. EMS performance of fabrics.](image)

3.1.2. Effect of fabric thickness on EMS performance. Three kinds of fabrics were overlapped to obtain 1-layer, 2-layer, 3-layer, and 4-layer fabrics, and the EMS performance was tested. It can be seen from figure 2 that the EMSE enhances as the fabric thickness increases. This can be explained by the Schelkunoff electromagnetic shielding theory: when an electromagnetic wave passes through the shielding material, energy loss occurs, which results in attenuation. This energy loss can be divided into two parts: reflection loss and absorption loss. When electromagnetic wave passes through a layer of shielding material, it passes through two interfaces. At the same time, two reflection losses and one absorption loss occur. When passing through two layers of shielding material, it passes through four interfaces. Meanwhile, four reflection losses and two absorption losses occur, and so on. In addition, when electromagnetic wave propagates in the shielding material, a part of the energy is converted into thermal energy, resulting in the loss of electromagnetic energy. Furthermore, as the thickness of the fabric increases, the incident depth of the electromagnetic wave increases, and the intensity of the electromagnetic wave decreases with an exponential relationship.

![Figure 2. EMS performance of fabrics with different thicknesses.](image)
3.1.3. Effect of fabric overlap angle on EMS performance. The three fabrics were overlapped in pairs with the angles of 0°, 45° and 90°, respectively, and the EMS properties were tested. As shown in figure 3, the EMSE of two fabrics with the same specifications overlapped at a 45° angle is better than that of the fabrics overlapped at 0° and 90° angles. The reason is that the fabrics overlapped at a 45° angle have a large number of warp and weft interlacing times, which reduced the porosity significantly, and therefore the electromagnetic wave transmission is reduced. However, the EMSE of the fabrics overlapped at 0° and 90° angles are almost the same. This is because, compared with 0° overlapping, 90° overlapping is equivalent to warp and weft yarn interchange, and porosity is almost unchanged.

Figure 2. Effect of fabric thickness on EMS performance.
3.2. Flame retardancy of aramid/stainless steel fiber blended fabric

According to the requirements of GB/T 17591-2006 flame retardant fabrics B1 grade performance indicators, the flame retardant protective fabric should meet the following requirements: damage length ≤ 150mm, afterburning time ≤ 5s, smoldering time ≤ 5s, no melting or drip. As shown in table 2, the sample has no afterburning phenomenon after the ignition. The damage length is short. The smoldering time is slightly longer, and there is no melting or dripping. This shows that the flame retardant performance of the aramid/stainless steel fiber blended woven fabric used in this study is relatively good.

| Fabric types   | Afterburning time (s) | Smoldering time (s) | Damage length (mm) |
|----------------|------------------------|---------------------|--------------------|
| Plain weave    | 0                      | 10.3                | 19                 |
| Twill weave    | 0                      | 7.8                 | 14                 |
| Satin weave    | 0                      | 9.5                 | 17                 |

3.3. Tensile properties of aramid/stainless steel fiber blended fabric

As shown in table 3, the aramid/stainless steel fiber blended yarn used in this study has strong tensile strength itself, so the tear strength of the fabric is great and its tensile performance is excellent. With the same fabric material, the tear strength of plain and satin is significantly higher than that of twill.

| Fabric types | Tear strength (N) | Elongation at break (%) | Tear length (mm) |
|--------------|-------------------|-------------------------|------------------|
|              | Warp direction    | Weft direction          | Warp direction   | Weft direction |
| Plain weave  | 844.33            | 806.71                  | 9.79             | 9.21           | 30.89    | 29.13 |
4. Conclusions

(1) The aramid/stainless steel fiber blended woven fabric prepared in this study has good EMS performance. The structure, thickness, and overlap angle of the fabric have a significant effect on its EMSE. In terms of the fabric structure, plain weave has the best EMSE among the three types of fabrics. This is due to the shortest floating, the largest number of interlacing, and the low porosity of plain weave. In multi-layer fabrics, the greater the number of overlapping layers, the higher the EMSE of the fabric. Because the thicker the fabric, the more effectively it can absorb and reflect electromagnetic waves. Among the fabrics that overlap at different angles, the EMSE at the fabric overlap angle of 45° is the highest. This is because the warp and weft yarns are interlaced a lot, and the fabric porosity is significantly reduced, which results in a decrease in electromagnetic wave transmission.

(2) The aramid/stainless steel fiber blended woven fabric in this study has no afterburning phenomenon after ignition. The smoldering time is short. The damage length is short. So it is a good flame retardant material.

(3) The aramid/stainless steel fiber blended woven fabric in this study has strong tensile strength, strong tear strength and excellent tensile properties, which can be used to prepare high-performance fabrics.

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| Twill weave | 735.25 | 699.53 | 11.35 | 10.84 | 33.28 | 32.05 |
| Satin weave | 935.28 | 897.69 | 8.87 | 8.29 | 28.45 | 27.22 |

| Twill weave | 735.25 | 699.53 | 11.35 | 10.84 | 33.28 | 32.05 |
| Satin weave | 935.28 | 897.69 | 8.87 | 8.29 | 28.45 | 27.22 |