Yuanjun Liu[1,2,3,4], Yanfeng Yang[1], Zhanhua Yang[1], Yanyan Liu[2], Ying Su[1,2], Jiarong Niu[1,3,4,*]

Influence of the Thickness of Graphene Coating on the Electromagnetical and Mechanical Properties of Double-Layer Coated Basalt Fibre Fabrics

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[1] **Tiangong University, School of Textile Science and Engineering,**
Tianjin 300387, China,
* e-mail: niujiarong1976@163.com

[2] **Loftex China Ltd.,**
Binzhou 25660, China

[3] **Tianjin Municipal Key Laboratory of Advanced Fibre and Energy Storage,**
Tianjin 300387, China

[4] **Key Laboratory of Advanced Textile Composites of Ministry of Education,**
Tianjin 300387, China

Abstract
A double-layer coated basalt fibre fabric was prepared using polyurethane as the matrix and applying coating technology to the basalt fibre fabric. The influence of the thickness of the graphene coating on the electromagnetic properties and mechanical properties of the double-layer coated basalt fibre fabric was studied. Results showed that when the thickness of the graphene coating was 2.0 mm, the polarising ability, loss ability and attenuating ability of the fabric with respect to electromagnetic waves were all the largest. Along with the increasing thicknesses of the graphene coating, the electromagnetic shielding effectiveness of the double-layer coated basalt fibre fabric also increased, then the shielding ability against electromagnetic waves became stronger.

Key words: *double-layer coating, basalt fibre fabrics, dielectric constant, shielding effectiveness, thickness.*

Introduction

The harm of electromagnetic radiation is mainly electromagnetic environment pollution, electromagnetic interference and the leak of electromagnetic information [1-2]. It not only affects people's health and the normal operation of a variety of electronic equipment but also endanger the safety of state information and military secrets [3-5]. In electromagnetic shielding and absorbing materials, carbon absorbing material has been praised by the attention shown by researchers [6-8]. Many types of carbon absorbing materials have been widely researched, such as carbon black and carbon nano-tubes [9-11]. The electromagnetic shielding properties of graphite, which is used as relatively mature material in electromagnetic shielding and absorbing materials, mainly come from its excellent electrical conductivity [12-14]. The conductive performance of graphite is largely due to the internal structure of the graphite crystal. In the graphite crystal, a carbon atom and three carbon atoms are present in a mono-layer arrangement state of the cellular hexagon. The crystal is formed by a vertical superposition layer upon layer by means of the Van der Waals force, and π bonds between the layers, being the source of the conductive performance of the graphite. Due to its excellent performance, since the beginning of the 21st century, graphite has been widely used by various countries in the world in refractory materials, pencil manufacture, the metallurgy industry, and other industrial production fields [15-19].

Graphene is one type of two-dimensional honeycomb carbon material, which is composed of a single layer of tightly packed carbon atoms. Before physicists isolated graphene in 2004, which can stably exist, the graphene molecule had been considered as existing unstably and non-independently [20]. As one type of new carbon material, graphene is more likely to be the electromagnetic shielding and absorbing material widely used by people than the other carbon absorbing materials [21-23]. The difference between graphene and graphite is mainly that graphene is a single-layer material in a two-dimensional state [24]. Due to the characteristics of the molecular structure, which is a hexagonal thin film composed of carbon atoms, the thickness of graphene is the same as the thickness of a single carbon atom, thus meeting the requirements of a "light" and "thin" absorbing material; graphene is not only thin and the hardest nanometer material in the world, it also has excellent mechanical properties, with the tensile strength reaching 125 GPa, which greatly satisfies the characteristic of "strong" in absorbing materials [25-27]. The coefficient of graphene is far higher than that of carbon nano-tubes and diamonds, and combined with its electron mobility at room temperature, its thermal conductivity is also far higher than that of silicon crystal, which meets the requirement for

Figure 1. Structure model of double-layer coated basalt fiber fabrics: 1 – graphite coating (observe), 2 – basalt fiber fabric, 3 – graphene coating (reverse).

a "wide" absorbing material. Graphene is a light electromagnetic protective material with great development potential for the following reasons: On the one hand, compared with the rod-shaped or spherical structure of other materials, the flake structure of graphene is conducive to increasing the multiple reflection loss of fabrics. With its high conductivity graphene is uniformly dispersed on the surface of the fabric, so that the sheets of graphene are arranged closely and parallel layer by layer, where a conductive path is realised through surface-to-surface contact, forming an ideal conductive network, which can increase the reflection loss of electromagnetic waves. On the other hand, graphene is a nanomaterial, with a small size of nanoparticles, a large specific surface area, a high proportion of surface atoms, and increased dangling bonds [28-29].

In this study, a double-layer coated basalt fibre fabric was prepared using polyurethane as the matrix and applying coating technology to the basalt fibre fabric. The influence of the thickness of the graphene coating on the electromagnetic properties and mechanical properties of double-layer coated basalt fibre fabrics was mainly studied using the method of controlling variables.

Experiment

Main experimental materials

Main experimental materials: flame retardant cloth of basalt fibres (Plain woven fabric), provided by Chengdu Dianshi Xuanwu Fibre Technology Co., LTD. The main experimental drugs were as shown in ***Table 1***.

The graphene fineness was 5-15 um, with a purity larger than 95%, and the PU2540 polyurethane resin was a 40% waterborne polyurethane dispersion with excellent performance, which has the advantages of good toughness and bending resistance. The density of the PU2540 polyurethane resin was 1.04 g/cm^3. At 25 °C, the viscosity of the PU2540 polyurethane resin was less than 300 mPa·s.

Table 1. Main experimeantal drugs.

Drug name	Type	Manufacturer
Thickener	7011	Guangzhou Dianmu Composite Business Department
Polyurethane resin	PU2540	Guangzhou Yuheng Environmental Protection Material Co., LTD
Graphene powders	Analytically pure	Tianjin Kairuisi Fine Chemical Co., LTD.
Graphite powders	Q/HG3991-88	Tianjin Fengchuan Chemical Technology Co., LTD

Table 2. Experimental instrument.

Name of the instrument	Type	Manufacturer
Coating machine	XWR-150	Suzhou Xuanworui Functional Science and Technology Co., LTD
Electric blender	U400/90-220	Shanghai Micro &Special Motor Co., LTD
Digital viscosimeter	SNB-2	Shanghai Hengping Instrument And Meter Plant
Thickness gauge	YG141	Nantong Sansi Electromechanical Science and Technology Co., LTD
Electronic analysis balance	FA2004	Shanghai Shunyu Hengping Scientific Instrument Co., LTD
Electronic scale	CFC01-00	Qingdao Haier Intelligent Electronics Technology Co., LTD
High-temperature blast drying oven	DGG-9148A	Shanghai Aozhen Instrument Manufacturing Co., LTD

Main experimental instrument

The main experimental apparatus were as shown in ***Table 2***.

Preparation of double-layer coated fabrics

Structure model of double-layer coated basalt fibre fabrics

A structure model of double-layer coated basalt fibre fabrics is shown in ***Figure 1***.

Preparation of the coating slurry

The electric agitator was set at a low speed, then a small number of functional particles were added slowly to the resin, and after a certain weight of functional particles were fully integrated with the resin, the electric agitator was set to high-speed stirring. After stirring for 10 min at a high speed, a certain amount of thickener was added, and then stirring was resumed for 20 min at high speed in order to ensure even mixing. The viscosity was tested as to whether it had reach the specified range; if it was lower than the specified viscosity range, the thickener needed to be added repeatedly in a small amount a time and stirred at a lower speed, in order to prevent too many bubbles.

The coating

After the base cloth was fixed, a needle plate was attached to the coating machine, and a thickness gauge was used to measure the thickness of the base cloth. Then the coating thickness was set according to the thickness of the base cloth, next according to the size of the base cloth, the position of the sensor, which can stop the scraper going forward, was reasonably set, and the coating operation could be started. An adequate amount of the coating reagent was placed on the surface of the basalt fibre fabric. The speed of the scraper of the coating machine was set to less than 10 cm/min, the forward button pressed, and the status of the coating was observed. A glass rod could usually be used to adjust the leaking slurry.

Test of samples

The test of the dielectric constant

In accordance with the SJ20512-1995 standard: 'the test method of the complex dielectric constant and complex magnetic permeability of microwave

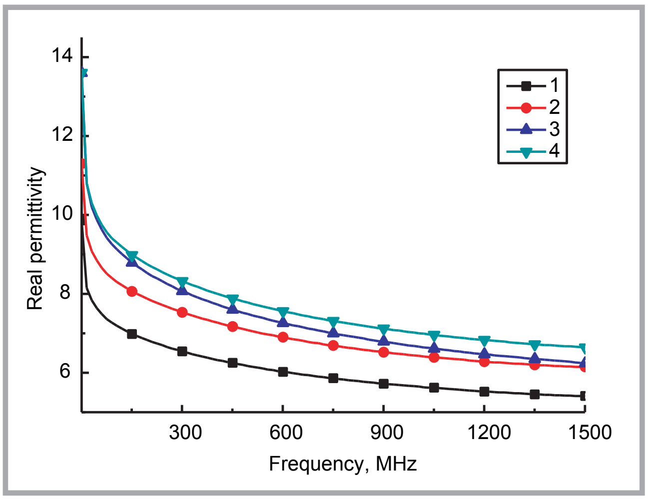

Figure 2. *Influence of graphene thickness on the real part of double-layer coated basalt fiber fabric.*

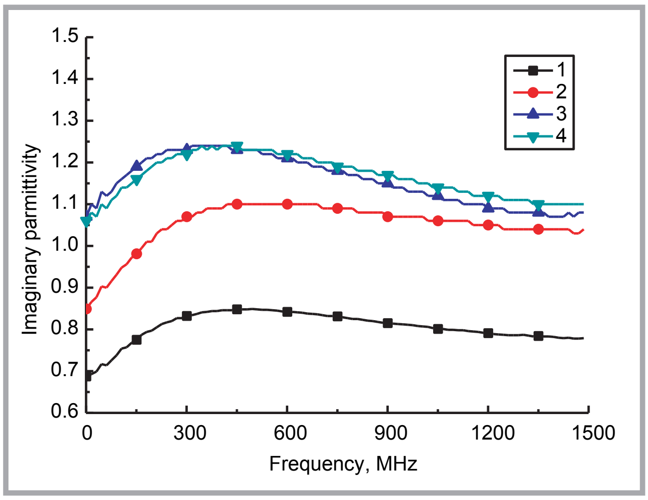

Figure 3. *Influence of graphene thickness on the imaginary part of double-layer coated basalt fiber fabric.*

large-loss solid materials", the samples were tested. The dielectric constant is one of the highly important electromagnetic parameters of absorbing materials. It is the value of the ratio of the situation of a substance serving as the dielectric substance to the situation of a vacuum serving as the dielectric substance at the same capacitance. Expressed as ε, the dielectric constant characterises the ability of dielectric materials to accommodate induced polarisation charges, or the macroscopic quantities characterising the polarisation properties. Its value mainly depends on the complexity of the polarisation process in the electric field stimulation; the more the material, and the more the polarisation and induced charges in the external electric field, the larger the value of the dielectric constant, and vice-versa. The dielectric constant is usually expressed as $\varepsilon = \varepsilon' - j\varepsilon''$, where ε' is the real part of the dielectric constant, and ε'' is the imaginary part of the dielectric constant, which are the macro parameters of the polarisation charges and dielectric loss. The real part of the dielectric constant represents the energy storage of materials in the exchange of the dielectric substance, while the imaginary part shows the energy loss in the electric field [30-34].

Shielding effectiveness test

The shielding effectiveness was measured using a ZNB40 vector analyser, where the sample was placed on the fixture as flat as possible, with the upper fixtures aligned with the lower. After the samples were clamped, we were able to start testing. The data was saved after the test was completed.

Tensile strength test

In accordance with the standard of the experiment method of GB1447283 tensile properties, a test of the tensile properties for each sample of coated fabrics was carried out on an INSTRON3369 universal material testing machine. The cutting specification for the samples was 5 cm × 20 cm; the clamping distance was adjusted to 10 cm, and the loading rate to 100 mm/min. After the samples were clamped, we could start testing. The data was saved after the test was completed.

Results and discussion

In order to study the influence of the thickness of the graphene coating on the electromagnetic properties and mechanical properties of the double-layer coated basalt fibre fabric, in this experiment, four pieces of graphite/graphene double-layer coated basalt fibre fabrics were prepared by changing the thickness of the graphene coating (the coating thicknesses were 0.5 mm, 1 mm, 1.5 mm & 2 mm, respectively) on the basalt fibre fabric. The specific process parameter is shown in ***Table 3***.

The content referred to the percentage of functional particles relative to the polyurethane. In this experiment, the stirring time was 40 min, the viscosity 38000 mps, the speed of the coating machine 10 cm/min, the oven temperature 80 °C, and the drying time 12 min.

Influence of the thickness of the graphene coating on the dielectric properties of the double-layer coated basalt fibre fabric

Curves of the real and imaginary parts of the dielectric constant and the loss tangent of the double-layer coated basalt fibre fabric with different thicknesses of the graphene coating are shown in ***Figures 2, 3*** and ***4***, respectively.

As shown in ***Figure 2***, as the thickness of the graphene coating increased, the real part of the dielectric constant for the double-layer coated fabric increased gradually, and the polarising ability of the coated fabric with respect to electromagnetic waves gradually rose. When the thickness of the graphene coating was 2.0 mm, the real part of the double-layer coated basalt fibre fabric was the largest, and the polarising ability of the coated fabric with regard to electromagnetic waves was the strongest.

Table 3. *Table of process parameters.*

Samples	Content of graphite of observe, %	Content of graphene of reverse, %	Set thickness of graphite coating, mm	Set thickness of graphene coating, mm
1	10	10	0.5	0.5
2	10	10	0.5	1.0
3	10	10	0.5	1.5
4	10	10	0.5	2.0

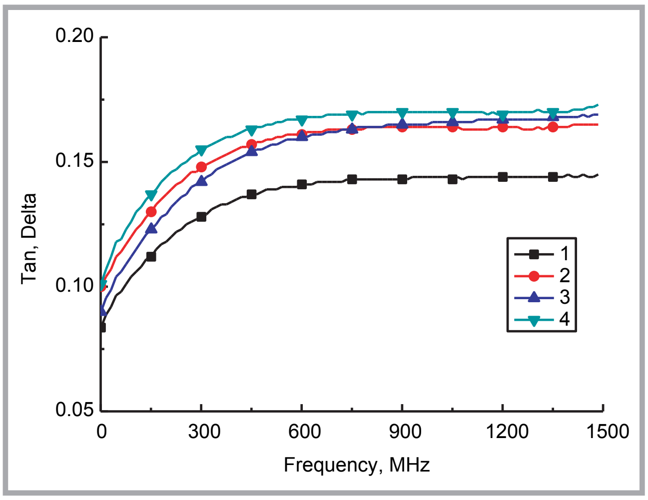

Figure 4. Influence of graphene thickness on the tangent value loss of double-layer coated basalt fiber fabric.

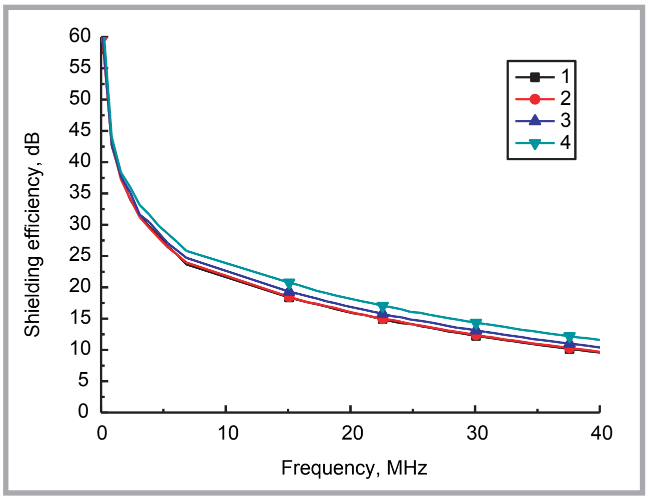

Figure 5. Influence of graphene coating thickness on the shielding effectiveness of double-layer coated basalt fiber fabric (0-40 MHZ).

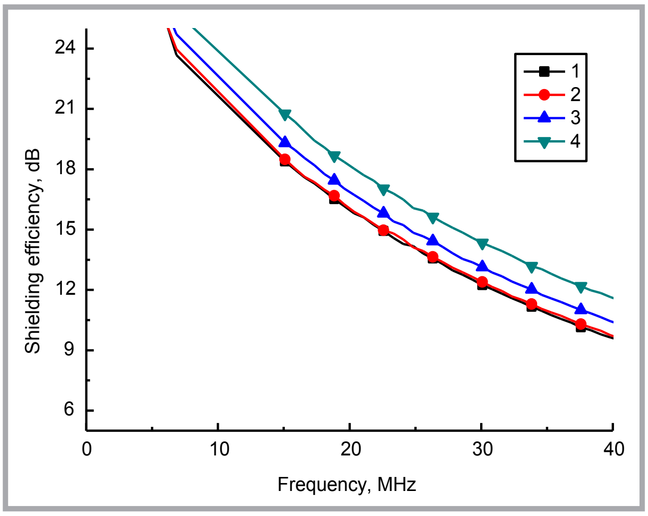

Figure 6. Influence of graphene coating thickness on the shielding effectiveness of double-layer coated basalt fiber fabric (5-40 MHZ).

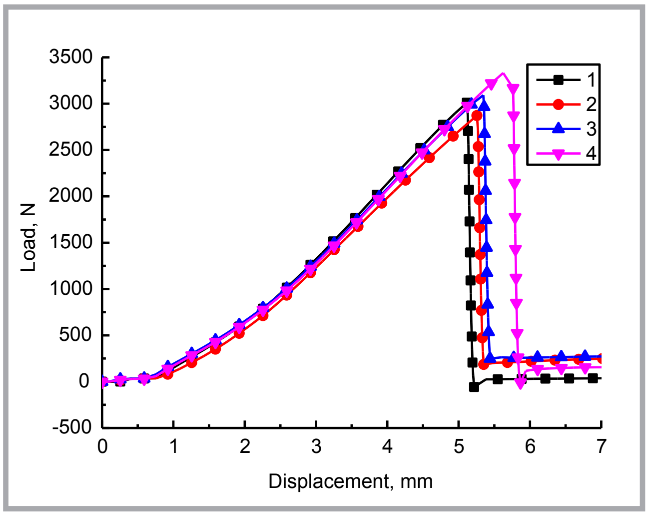

Figure 7. Displacement-load curve of double-layer coated basalt fiber fabric with different thickness of graphene coating.

As shown in ***Figure 3***, within the frequency range of 0 MHz to 1500 MHz, as the thickness of the graphene coating increased, the imaginary part of the dielectric constant of the double-layer coated basalt fibre fabric increased gradually, and the loss ability of the coated fabric with respect to electromagnetic waves gradually rose. When the thickness of the graphene coating was 1.5 mm, the imaginary part of the double-layer coated basalt fibre fabric was the largest, and the loss ability of the coated fabric with regard to electromagnetic waves was the strongest. If the thickness of the graphene coating was more than 1.5 mm, the imaginary part of the dielectric constant for the double-layer coated basalt fibre fabric decreased, and the loss ability of the coated fabric with respect to electromagnetic waves became weak. Within the frequency range of 1100 MHz to 1500 MHz, as the thickness of the graphene coating increased, the imaginary part of the dielectric constant of the double-layer coated basalt fibre fabric increased gradually. When the thickness of the graphene coating was 2.0 mm, the imaginary part of the double-layer coated basalt fibre fabric was the largest, and the loss ability of the coated fabric with regard to electromagnetic waves was the strongest at this time.

As shown in ***Figure 4***, within the frequency range of 0 MHz to 1500 MHz, as the thickness of the graphene coating increased, the loss tangent value of the dielectric constant for the double-layer coated fabric increased gradually, and the attenuation ability of the coated fabric with respect to electromagnetic waves gradually rose. When the thickness of the graphene coating was 2.0 mm, the loss tangent value of the double-layer coated basalt fibre fabric was the largest, and the attenuation ability of the coated fabric with regard to electromagnetic waves was the strongest. When the thickness of the graphene coating was 0.5 mm, the loss tangent value of the double-layer coated basalt fibre fabric was the smallest, and the attenuation ability of the coated fabric with respect to electromagnetic waves was the weakest.

Influence of the thickness of the graphene coating on the shielding effectiveness of double-layer coated basalt fibre fabrics

Curves of the shielding effectiveness of double-layer coated basalt fibre fabrics with different thicknesses of the graphene coating are shown in ***Figures 5*** and ***6***.

As shown in ***Figures 5*** and ***6***, with the increasing frequencies of electromagnetic waves, values of the electromagnetic shielding effectiveness of the graphene coated fabric with different thicknesses all showed a declining trend. Within the frequency range of 0 MHz to 40 MHz, as the thickness of the graphene coating increased, the shielding effectiveness of the double-layer coated fabric increased gradually, and the shielding ability of the coated fabric with respect to electromagnetic waves gradually enhanced. When the thickness of the graphene coating was 2.0 mm, the shielding effectiveness of the double-layer coated basalt fibre fabric was the largest, and the shielding ability of the coated fabric with respect to electromagnetic waves was the best at this time.

Influence of the thickness of the graphene coating on the mechanical properties of the double-layer coated basalt fibre fabric

The displacement-load curve of the double-layer coated basalt fibre fabric with different thicknesses of the graphene coating is shown in ***Figure 7***.

As shown in ***Figure 7***, the four pieces of fabrics all experienced rupture with the increasing displacements. The elongation at break of sample 1 was the smallest, while that of sample 4 was the largest. Moreover, with the increasing thickness of the graphene coating, the elongation at break showed an increasing trend. Regarding the breaking strength, that of sample 1 was the minimum, while for sample 4 it was the largest. Furthermore, with the increasing thickness of the graphene coating, the breaking strength had a significantly decreasing trend.

Conclusions

1. The thicker the graphene coating, the stronger the polarising ability, loss ability and attenuation ability with respect to electromagnetic waves. In this experiment, the coated fabric had the largest polarising ability, loss ability and attenuation ability when the coating thickness was 2.0 mm.
2. As the thickness of the graphene coating increased, the shielding effectiveness of the double-layer coated fabric increased gradually, and the shielding ability of the coated fabric with regard to electromagnetic waves gradually rose. In this experiment, the shielding ability with respect to electromagnetic waves of double-layer coated basalt fibre fabrics was the best when the thickness of the graphene coating was 2.0 mm.

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