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Simulation Research on Electromagnetic Shielding Characteristics of Carbon Fiber Car Body for Railway Vehicles

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Abstract

The carbon fiber composite materials have been widely used in the field of rail transit.Carbon fiber body is more advantageous than traditional material especially in weight.This paper introduces main characteristics of carbon fiber composites and outlines the principles of electromagnetic shielding effectiveness.Electromagnetic shielding characteristics of carbon fiber reinforced polymer (CFRP) was studied through electromagnetic shielding simulation technology and test compared with aluminum, aluminum alloy and carbon steel. Some suggestions are provided in terms of the CFRP electromagnetic characteristics. This research sets a foundation for the EMC design for railway vehicles.

Keywords:Railway vehicles;CFRP,Electromagnetic Shielding;EMC

1. Overview

Modern railway vehicles have undertaken improvement and optimization in the aspects of rail transit, intelligence, safety and comfort, especially the high-speed EMU trains. However, speed increase will not only rely on the design of powerful traction system but also on the lightweight design which plays a vital role in this aspect.For the weight, stainless steel is better than weatherproof steel. Aluminum alloy is better than stainless steel. However, carbon fiber

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reinforced composite has better advantages over aluminum alloy. The application of composites in the high-speed railway vehicles has been gradually enlarged from carbody interior, components and materials of equipment inside vehicles to the carbody structure. Carbon fiber composite will bring rail transit industry into a new stage[1]-[2]. Although CFRP presents excellent properties in various aspects, there are still more aspects of carbody materials to be satisfied for high-speed trains, such as fire performance, thermal insulation properties, corrosion resistance characteristic and electromagnetic properties. Upon comparison with previous car bodies made from steel and aluminum alloy, however less attention is paid to electromagnetic shielding properties of CFRP vehicles.

Now the high-speed trains are developed in the directions of highly compact and smart control of electrical control. The electrical cabling and wiring are very complex on the roof for high-and-low voltage applications, communication cables, passenger power supply and PIS (Passenger Information System). They run all over the roof, such as electrical cabinet inside vehicle, chambers in sidewall and under-car high-and-low voltage junction boxes. Each type of cables is one source for electromagnetic radiation. The electromagnetic radiation from such sources might cause interference to sensitive devices onboard the train, or they might jeopardize the health of passengers carrying implanted medical devices. They might also have serious impacts on the safe operation of high-speed trains.

This paper addresses the research on electromagnetic shielding properties of CFRP and outlines principle of electromagnetic shielding. Key issues to be considered in EMC design for CFRP as carbody materials will be summarized through computer simulation and tests comparative between aluminum, aluminum alloy, carbon steel and CFRP. This will make major sense in guiding through EMC design and optimization for rail transit vehicles.

2. Properties of CFRP

The most outstanding characters of CFRP are higher strength, high modulus and low density. Like carbon materials, they also offer good resistance against high temperature, corrosion and fatigue. They are well flexibleand easy to be formed.The application of cost-effective non-autoclave process enables CFRP to be the best solution for lightweight of rail transit [3]-[4].Carbon fiber has higher strength than titanium and steel. Its strength is next to that of a few types of fiber, such PBO. Its modulus is better than all metals, organic polymers and nonorganic ceramic fibers. Carbon fiber offers good properties in term of heat transfer, electrical conductivity and flame retardence. They have extremely low coefficient of thermal expansion in addition to low radiation level, non-magnetism and non-magnetization.The higher the crystallinity and level of crystalline orientation of the carbon fiber, the higher their coefficient of thermal transfer and the lower their electrical resistivity.The conductivity and electromagnetic shielding of electromagnetic materials are linearly increased as their thickness increases. When the volume of filled carbon fiber is 5% and the thickness is 3mm, 6mm and 9mm respectively, their effectiveness of electromagnetic shielding is 27.48～39.10dB, 28.61～41.87dB and 28.63～43.74dB respectively, which are at medium level [5]-[8].

3. Current Status of CFRP Application in Rail Transit Equipment

The research on CFRP used on carbody in Japan was quite early. E4 driver cab developed in 1994 incorporated CRFP, which reduced the weight by 30%. It also made effective improvement against deformation while reducing noise level and vibration [9].CFRP is also applied in railway industry in Korea. CFRP carbody was adopted for tilting train TTX（Title Train Express）, which was put into revenue operations in 2010.

At the early stage of the research on scheme, composite materials were adopted for roof, sidewall and end walls. Underframe was manufactured with hollowed and extruded aluminum alloy profiles. Both parts were connected by elastic adhesive and bolts to form the complete carbody [10] , as shown in figure 1.The cladding composite material consisting of CF123 carbon fiber and epoxy resin. In addition, stainless steel frame is imbedded to improve the structural rigidity of carbody, thereby forming the composite carbody by large-size autoclave forming process. Compared with conventional carbody of aluminum alloy, the total mass of the shell of the carbody of composite material is reduced by 40%. In addition, static strength, fatigue strength, fire safety and modular characteristics of carbody are fully compliant with the design [11].

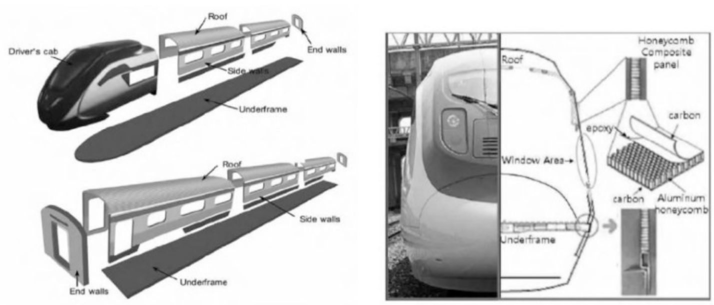

Fig.1 Korean CFRP carbody design scheme

4. Principle of electromagnetic shielding

The shield is able to reflect, absorb or offset the energy from external electromagnetic interference such as conductor, cable, element or circuit systems or internal electromagnetic wave. That is, the shield functions to reflect, absorb or take in electromagnetic wave.For good conductor, such as silver, copper and aluminum alloy, reflection is the main role of the shield. For iron and magnetic steel, which are materials of high magnetic-conductivity, their main roles are absorption and shielding. The interference rejection capability of the shield against radiation is measured by SE (shielding effectiveness), which is expressed in Decimal (dB). The formula for shielding effectiveness is [12]:

$$SE = 20\log_{10}\frac{E_1}{E_2} \qquad\qquad SE = 20\log_{10}\frac{H_1}{H_2} \tag{1}$$

Where in the above equation:

E1 (*H1*) is the strength of field from source of radiation to any point P in the space, when there is no shield.

E2 (*H2*) is the strength of field from source of radiation to point P in the space, when there is shield.

According to Chelkunoff principle of electromagnetic shielding, shielding effectiveness (*SE*) is the sum of absorption loss to the energy from electromagnetic wave, internal reflection loss and surface reflection loss.When absorption loss is more than 10 dB,internal reflection loss will be ignored. Calculations can be made with following formula when certain conditions are satisfied [13]:

$$SE = 50 + 10\lg(\rho_v \times f) + \frac{1.7 \times d \times f}{\rho_v} \tag{2}$$

Where in the above equation:

f is frequency of electromagnetic wave,Hz;

d is material thickness,mm;

ρ_v is volume resistivity, $\Omega \cdot cm$;

When frequency of electromagnetic wave is at fixed level, the shielding effectiveness will increase following the decrease in electrical resistivity. In other words, the shielding effectiveness will increase following the increase in electrical conductivity of shield conductors. Hence, one of the key characteristics of shielding materials is to increase electrical conductivity of the materials. For general purpose, the shielding effectiveness shall be 30～40dB, that is, the volume resistivity of material is below 1 $\Omega \cdot cm$ [14].

CRFP is to enable carbon fiber to form conductive network inside insulated plastic melt through different compound processes, thereby improving electrical conductivity of plastics while improving mechanical properties.

Vehicle operation safety is always the utmost priority. The properties of electromagnetic shielding of carbody will have direct impact on operation safety of rail vehicle and comfort for passengers inside the saloon.

5. Simulation Research

Various types of high-and-low voltage cables, high frequency signal transmission cables and return lines are arrange everywhere in electrical cabinets, sidewall and under the floor in the saloon of EMU. The electromagnetic radiation generated by them might impose threat to passengers with implantable medical devices. Good shielding materials are able to reflect most of the electromagnetic wave from the cables while absorbing a small portion. The electromagnetic wave entering into the materials will be dissipated at end of many reflection cycles. Only a small portion will penetrate the shielding materials. The electromagnetic interference is quite weak and can almost project no impact on passengers. Hence, electromagnetic shielding of materials for EMU carbody is one of the critical factors for their performance evaluation. In this paper, four types of materials for typical applications on railway vehicle carbody will be selected for simulation, including steel, aluminum, aluminum alloy and carbon fiber composites. Details of material sizes and specifications are shown in Table 1.

Table 1 Specifications for materials under test

Material	Model	Plate size (mm)	Density
CFRP	Honeycomb core	660*660*30	1500kg/m3
Stainless steel	Stainless steel 304	660*660*30	7930kg/m3
Aluminum	LY12CZ	660*660*30	2700kg/m3
Aluminum alloy	Carbody materials	660*660*30	2900kg/m3

4.1 Establishment of simulation model

Simulation model will be built according to the real test requirement.Tests on materials were conducted in the aspect of electrical field and shielding effectiveness in the lab according to test criteria in relation to shielding effectiveness of electromagnetic shielding materials. During test, ambient environment temperature is controlled at 15℃-30℃. Relative humidity shall be less than 80%. Range of the frequency is 10kHz-40GHz.

The shielded chamber is intended for test on shielding effectiveness at frequency of 10kHz-40GHz. The shielding effectiveness of the shielded chamber shall be minimum 6 dB greater than that of the materials under test. The window of the chamber shall be a square of minimum 0.6m*0.6m. The distance between center hole in the square and floor in the chamber shall not be less than 1m. The edge of square hole shall be minimum 0.5m from side wall. Simulation model is as shown in Figure 2.

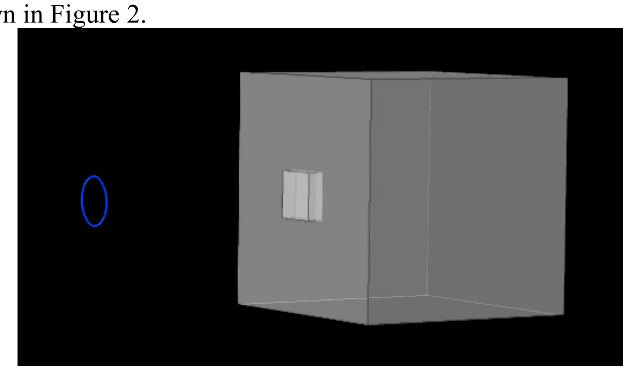

Fig.2 Shielding effectiveness simulation model

The transmission antenna is arranged outside the shielded chamber and used to generate electromagnetic field. The receiving antenna is arranged inside the shielded chamber and used to receive the strength of electromagnetic field entering into the shielded chamber blocked by shielding materials. Different test antennas and test distances will be used for different frequencies during test. Details of antenna types and test distances are given in Table 2.

Table 2 Types of antennas and test distances for different frequencies

Type of field sources	Frequency	Antenna type	Distance
Magnetic field	10kHz-30MHz	Circular antenna	0.3m
Electrical field	10kHz-30MHz	Vertical polarization single-stage antenna	0.3m
Electrical field	30MHz-200MHz	Double-cone antenna	1.0m
Electrical field	200MHz-1GHz	log-periodic antenna	1.0m
Electrical field	1GHz-18GHz	Horn antenna	0.6m
Electrical field	18GHz-40GHz	Horn antenna	0.3m

4.2 Simulation result and test result analysis

In order to verify the simulation results.We do the test to compare the simulation result and the actual test result.Test of material electromagnetic shielding will be performed in the shielded chamber.Tests are conducted on fore types of materials to obtain the shielding effectiveness of each material for electrical field, and shielding effectiveness curve for magnetic field, as shown a -d in Figure 3.

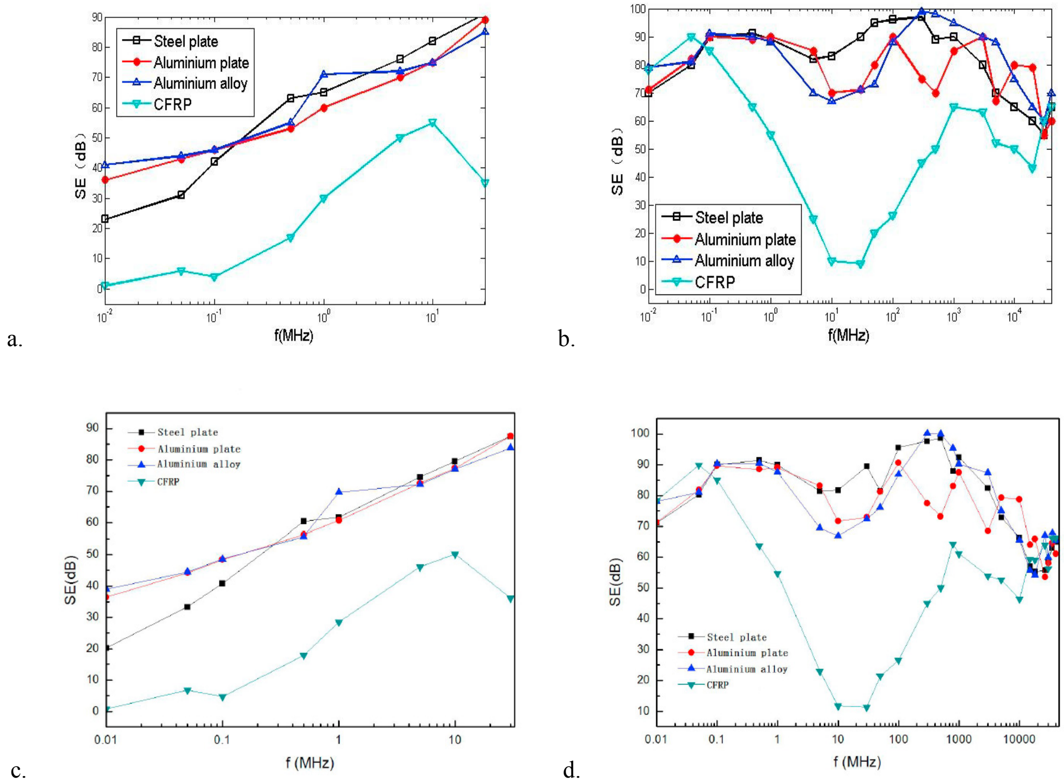

Fig.3 (a)Simulation SE curve of magnetic field ;(b)Simulation SE curve of electrical field

(c)Test SE curve of magnetic field; (d)Test SE curve of electrical field

As shown in Figure 3. Between the simulation curve and real test curve are same at the fluctuation tendency.For the SE of magnetic field,four types materials shows increase tendency following the frequency increment in range of

10kHz-30MHz. However, it shows tendency of decrease for CFRP at 10MHz. This mainly depends on magnetic conductivity of CFRP. As known, the shielding effect in the low frequency magnetic field mainly depends on magnetic conductivity and thickness of materials. For the materials with the thickness, the magnetic conductivity of CFRP is obviously is smaller than that of the other three types of metal. Although, the shielding effectiveness in the magnetic field of 0.01MHz-10MHz shows tendency of increment, the value for shielding effectiveness is about 20dB-30dB smaller than that of the other three metals.

For the SE of electrical field,The curves for three types of metals are very close to each other in the frequency range of 10kHz-40GHz, and the variation is quite small. The maximum variation does not exceed 50 dB within full range of frequency. For CFRP, its shielding effectiveness curve in the frequency range of 0.01MHz-0.1MHz is similar to that for the other three types of metals. However, the shielding effectiveness has substantial decay and increment in the frequency range of 100kHz-1GHz. The maximum variation exceeds 80 dB within full range of frequency. The main reason for above characteristic is the big difference in electrical resistivity between three metals and CFRP. CFRP offers poor shielding effectiveness at certain frequencies, thereby presenting substantial variation.

6. Conclusion

According to the simulation curve and test curve, SE is similar to that for the other three types of metals in the electrical field at 10kHz-100kHz. When CFRP is used for as carbody materials for high-speed trains, shielded cables shall be used for powerful communication cables at high frequency, which will be arranged inside carbody. For communication equipment cables for 100kHz-1GHz, the interior of their trough or chamber shall be subject to special treatment by adding metallic layer or applying galvanic treatment on the surface in different ways. Addition and reinforcement shall be provided for shielding and conductive properties so that shielding materials can be formed with equivalent conductive surfaces. For current advanced process, metallic spray coating and transfer process is adopted, that is, metallic coat will be applied on the mould followed by curing of composite materials. Once removed off the mould, metals will be transferred to the surface of products of composite materials. Such process will yield good effect for electromagnetic shielding for CFRP.

7. References:

1. Asokan R,Dinesh M,Arumugam V,etal.Acoustic emission monitoring of GFRP Composite lap joints[J].European Journal of Scientific Research,2012,77(4):485-494.
2. Liu Xiaobo,YangYing.Key Technologies of Light weight and High-Performance Carbon Fiber Composite Train Carbody[J].Synthetic Fiber in China.2013,42(10):29-34.
3. Catalanotti G,Camanho P P,Ghys P,etal.An efficient design method for multi-material bolted joints used in the railway industry[J]. Composite Structures,2011,94:246-252.
4. Oliver J A,Kosmatka J B.Evaluation of modal-based damage detection techniques for composite aircraft sandwich structures [C]. Nondestructive Evaluation for Health Monitoring and Diagnostics. International Society for Optics and Photonics,2005:264-273.
5. Kim S,Seo T.Sound insulation performance of honeycomb composite panel for a tilting train [J].Transactions of the Korean Society of Mechanical Engineers A,2010,34(12):1931-1936.
6. Giurgiutiu V,Soutis C.Enhanced composites integrity through structural health monitoring [J].Applied Composite Materials, 2012, 19: 813-829.
7. Kim J S,Lee S J,Shin K B.Manufacturing and structural safety evaluation of a composite train car body [J]. Composite Structures, 2007,78:468-476.
8. Jang H J, Shin K B, Sung Ho Han.A study on crash worthiness assessment and improvement of tilting train made of sandwich composites [J].Word Academy of Science, Engineering and Technology, 2012, 62:217-221.
9.LUO Ximin, LUO Yifeng.The Application of Several High Performance Fibers and Composite Materials in High Speed Train both in Abroad and Home[J].Hi-Tech Fiber & Application,2001,36(5):33-41.
10. QIU Guijie, YANG Hongzhong, GAO Guoqiang, CHEN Chun, XUE Zhongmin.The Status Que and Trend of the Application of Composites on High-speed Train Over the World [J].Hi-Tech Fiber & Application, 2005, 30(6):26-30.
11. Ding Sansan, Tian Aiqin, Wang Jianjun, TENG Le-tian. Research on application of carbon fiber composite in high speed EMUs [J]. Electric Locomotives＆Mass Transit Vehicles,2015,38 supplement:1-8.
12. Hou Junfeng.Study on Properties of Carbon-based Electromagnetic Shielding Fiberboard [D].Zhejiang A&F University, 2015.
13. Jin Wugang.Application of Carbon Fiber in EMS Composites [J].Modern Plastics Processing and Applications, 2003, 16 (1):24-27.
14. Wang Jincheng. Mechanism and development of electromagnetic shielding materials [J].New Chemical Materials, 2002, 30(7):16-19.