Technical Performance of Composite Self-healing U-shaped Canal Based on Computer Simulation Technology

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Abstract. High-performance wood-based composite can be obtained by mixing carbon fiber with electrical conductivity and wood fiber. The composite is taken as the research object to establish a macro-micro mathematical model for its performance. Based on the computer simulation analysis technology, the effective correlation between macro description and micro finite element analysis is used to implement the digital research on the technical performance of the self-healing U-shaped canal and obtain the 3D potential and current density nephogram of the sample plate. In addition, the feasibility of the performance simulation analysis based on the modeling method is verified.

Keywords: Composite Material, Technical Performance of Self-healing U-shaped Canal, 3D Simulation, Modeling Method

1. Introduction
The filament wound composite pressure vessel has a broad application prospect in solid rocket motor⁴, aircraft/vehicle mounted high-pressure cylinder, petrochemical industry, natural gas storage and transportation, etc. With the rapidly increased applications of filament wound shell in the field of high-end science and technology, it has developed into one of the critical components of structural power and fuel system, accounting for a very high proportion in both structural mass and geometric space ³⁴. It is increasingly required that it can bear considerable load pressure while maintaining the high efficiency and light weight of the structure. Hence, the requirement of weight reduction and structural efficiency increase is one of the technical bottlenecks restricting the development of a new generation of advanced composite vessel structures. How to design the lightest filament wound shell, reduce the mass of the system, and improve the structural performance is the eternal goal of composite designers and researchers⁵⁶.

Giulio Scocchi et al. in Switzerland applied the finite element method to study the technical performance of the self-healing U-shaped canal of graphite polymer composite materials. By establishing a spatial model of the microstructure of composite materials, the technical performance of the self-healing U-shaped canal can be reasonably and accurately predicted. Based on the experimental calculation of conductivity, the computer simulation method is proved to be a good numerical simulation method, Lanli et al. at Shanghai Jiao Tong University used the computer finite element simulation method to calculate the polarization current of SiO/LDPE composite medium. The
feasibility of the computer simulation finite element method was verified by establishing a model of 3D dielectric constant and conductivity, and the measured data were compared by simulation. Niu Jianwei, et al. Of Harbin University of technology, used finite element software and Monte Carlo method to study the resistivity features of carbon nanotube cement-based composite materials. An effective medium equation was established to fit the data collected in the experiment, the results show that the resistivity of carbon nanotube cement-based composite materials affects the content of carbon nanotubes and the length diameter ratio of carbon nanotubes negatively. The results of the effective medium equation are consistent with the experimental data and the finite element numerical solution. With the progress of simulation technology, the research on composite materials has become a hot spot through the combination of experiment and simulation technology. It is convenient and accurate, and it can be implemented by the organic combination of micro model establishment and macro performance research. In this paper, MATLAB and 3D finite element simulation technology are combined to fit and verify the performance features of composite materials, reasonably analyze the self-healing U-shaped canal technical performance of composite materials, establishes a model to meet the performance analysis, and studies the realization of modeling methods. From the micro-electric field simulation analysis and prediction of the macro electrical properties, the macro-micro organic combination is implemented, which provides a digital basis for the modeling of composite process optimization and preparation.

2. Macro self-healing U-shaped canal technical performance parameter test of composite self-healing u-shaped canal technology

Preparation and method of composite self-healing U-shaped canal Technology

1) Experimental materials and instruments

Experimental materials: (1) wood fiber: poplar and a small amount of birch; (2) carbon nanofiber: carbon powder materials with a diameter of 30 nm and a length of 50 μm; (3) curing agent: ammonium chloride and neutralization curing urea for formaldehyde adhesive; (4) application agents: isocyanate resin adhesive, urea formaldehyde adhesive, anhydrous ethanol, acetone.

Experimental equipment: ultrasonic vibration instrument, drying oven, mixer, hot press, dielectric constant test system, digital source meter and electronic balance.

2) Board-making method

The size of the sample needed in the experiment is 34cm × 32cm × 1.1cm, which can be classified into the following categories: (1) veneer with 1:1 and 2:1 short-cut carbon fiber and wood fiber; (2) composite board with 10% and 20% short-cut carbon fiber; (3) composite board with 10%, 15% and 20% carbon nanofiber; (4) pure wood fiber board.

Preparation method: the carbon fiber added with ethanol is fully dispersed with ultrasonic vibration instrument and weighed for standby; the isocyanate glue is diluted with acetone and thoroughly mixed with carbon fiber in proportion; the wood fiber and urea-formaldehyde resin glue are fully mixed for standby in proportion; the treated carbon fiber and wood fiber are fully mixed in the mixer in proportion according to the conventional medium density fiberboard preparation method; Pave the material in the mold according to the set proportion, then place it in the hot press, and press it at 175 °C for 5-6min to complete the plate making. The sample prepared in the experiment is shown in Figure 1.
Due to the friction between the wound core mold and the fiber or between the adjacent fiber layers, the fiber laying path can deviate from the geodesic line to varying degrees, i.e. winding according to the nongeodesic line. This provides flexibility for the winding line design so that the fiber can not only meet the process stability requirements but also increase the design freedom.

In the figure, $R$ represents the radius of curvature of the central line of the torus, $R$ represents the radius of the torus, and $\rho$ represents the distance from the point on the torus to the axis of rotation. The basic parameter expression of the torus $s(\theta, \varphi)$ can be obtained as follows:

$$S(\theta, \varphi) = \begin{bmatrix} (R + r \cos \varphi) \cos \theta \\ (R + r \cos \varphi) \sin \theta \\ r \sin \varphi \end{bmatrix}$$

(1)

Where: $\theta$ and $\varphi$ represent the two main geometric parameters of the surface, as shown in Figure 1.

When winding on the curved surface, the tension produced by the tension of the winding machine's nozzle on the fiber will cause the fiber to slide laterally (perpendicular to the fiber direction). Let the slip coefficient be:

$$\lambda = \frac{K_g}{K_n}$$

(2)

$K_g$ represents geodesic curvature of fiber curve; $K_n$ represents the normal curvature of the curve.

From differential geometry, the first fundamental quantity of torus is:

$$\begin{align*}
E &= (R + r \cos \varphi)^2 \\
F &= 0 \\
G &= r^2
\end{align*}$$

(3)

$E$, $F$, and $G$ represent the coefficients of the first basic form of the surface.

3. Test and analysis of technical performance parameters of self-healing U-shaped canal

The technical performance of self-healing U-shaped canal is tested for the composite sample plate, and the dielectric constant, tangent value of dielectric loss angle and volume resistivity are tested and analyzed respectively. The change rule and characteristic trend of the technical performance of self-healing U-shaped canal are obtained.

3.1. Measurement and analysis of dielectric constant

Test method of dielectric constant: cut the test pieces into a sample plate with a width of 50 mm before measurement, and take out three pieces from the middle, with a diameter of 50 mm and a thickness of 2 mm. To obtain the relationship between the dielectric constant, the dielectric loss and the frequency, we observed five frequency bands. The equipment used is a $7 \sim 18$GHz sweep microwave dielectric complex dielectric constant test system and a high Q cavity method complex dielectric constant test.
software. Put the sample in the drying oven, dry at 120 °C for 18 hours, put the sample into the test system for testing, and then get the dielectric constant data corresponding to different frequencies in the test software. To improve the accuracy of measurement, we took the data mean of three plates as the dielectric constant and loss tangent of the sample. The fitting curve of the test data variation trend in the MATLAB environment is shown in Figure 2.

![Figure 2. Frequency dielectric constant curve](image)

Figure 2 shows that the curves of the pasted panel and composite panel mostly show an upward trend, and the dielectric constant increases with the increase of frequency. When it reaches a certain degree, it tends to be stable or slowly decreases. The frequency of different composite samples is in the range of 7500~10000MHz, which is in the critical position of electronic excitation. The dielectric constant value of the composite plate with 10% carbon nanofiber is slightly higher than that of other samples and fluctuates between 4.36 and 4.52, and the dielectric constant value is optimal. The analysis of experimental data suggests that the dielectric constant value of carbon nanofiber 10% composite plate is the largest, and the conductivity of composite plate obtained by uniform composite method is ideal.

3.2. Measurement and Analysis of dielectric loss angle tangent

The test method of dielectric loss is the same as the experiment of dielectric constant, and the data can be obtained directly from the test software. The dielectric loss tangent value of all the samples shows a downward trend at first, followed by increase after reaching the minimum value. Among them, the value of carbon fiber composite board is the smallest, the tangent value reaches 10-3 level, and the data of carbon nanofiber composite board are larger than that of a single-sided carbon fiber composite
4. Micro finite element analysis of the technical performance of composite self-healing U-shaped canal

Based on the experimental data, the GUI modeling method in ANSYS software is used to model the technical performance of composite self-healing U-shaped canal, and the distribution of potential and current density is analyzed. The steps are as follows:

1. Select the type of analysis. Select the electrostatic self-healing U-shaped canal technical performance analysis module electric;
2. Select the type of cells. The solid123 cell with fewer nodes and freedom voltage is selected as cell type;
3. Define the material properties. Set different parameters of the material as attributes of the model, set resistivity and dielectric constant for different test pieces, and select the material models command under the main menu;
4. Establish a solid model. Select the top-down method to establish a “solid” model;
5. Meshing. Choosing free mesh reduces the limitation of shape;
6. Apply the free mesh method.

The steady-state analysis is carried out by applying the boundary conditions to the model with the mode of DOF loading. The potential of 220V is applied to the upper surface and 0V to the lower surface, respectively. Subsequently, the potential distribution of the sample is observed by POST1. The external conditions are set as follows: room temperature, frequency 8007mhz. Due to the similar electric field distribution, it is impossible to accurately distinguish and visually compare the current density maximum value, and minimum value data analyzed by ANSYS are shown in Table 1.

Table 1. Maximum and minimum current density

| Plate type                  | Resistivity (Ω • m) | Minimum value | Maximum |
|-----------------------------|---------------------|---------------|---------|
| Single side 1:1             | 0.4896              | 9.61747       | 1239.38 |
| Single side 2:1             | 0.3660              | 12.8653       | 1657.93 |
| Carbon fiber mix 10%        | 0.5039              | 9.34454       | 1204.21 |
| Carbon fiber mix 20%        | 0.4451              | 10.57900      | 1363.29 |
| Carbon nanofiber mix 10%    | 0.3212              | 14.65980      | 1889.17 |
| Carbon nanofibers mix 15%  | 0.3065              | 15.36280      | 1979.78 |
| Carbon nanofibers mix 20%  | 0.1841              | 25.57690      | 3296.05 |
| MDF                         | 1×1013              | 1.01×10-15    | 7.88×10-13 |

Through experimental comparison, the required properties of solid element solid123 include dielectric constant and resistivity, but the resistivity has a strong impact on the performance. Because there is no conductive material inside the pure wood fiberboard, the potential value and current density value of the pure wood fiberboard are small, so it has no conductivity. Compared with the pure wood fiberboard, the carbon fiber can enhance the conductivity of the composite, which makes the composite board have an excellent current density value. Table 1 shows that for the samples of the same composite mode, the maximum and minimum current density of the corresponding samples increase with the decrease of the resistivity of the carbon fiber wood-based composites. The increase of carbon fiber content not only reduces the resistivity, but also increases the current density and range, thus enhancing the conductivity of the composite plate. Compared with carbon fiber and carbon nanofiber, the current density also increases with the decrease of resistivity, and the range of current density also increases. For the same ratio of carbon nanofiber mixing and carbon fiber mixing, the maximum and minimum current density of carbon nanofiber composite board is larger, and its range is also larger. Comparison with the optimal ratio of various composite modes suggests that the current density of carbon nanofiber composite board is the largest.
Through the micro model analysis of the current density of the carbon fiber wood-based composites, it is found that the current density values of the composite materials with different carbon fiber content and different composite methods are different. The reason is that the increase of carbon fiber content and the optimization of composite processes make the material mix evenly and distribute reasonably, and improve the conductivity of the composite template. Through the finite element analysis of micro current density and the macro experimental study, the technical performance features of self-healing U-shaped canal of composite materials can be better analyzed and predicted.

5. Conclusion

Based on the computer simulation analysis, the Ansys software is used to establish a microscopic model for composite materials. The changing patterns of different technical performance parameters for the self-healing U-shaped canal of composite plates under different conditions are detected. The macroscopic analysis is performed on the technical performance features of the self-healing U-shaped canal. The macroscopic experimental test is combined with microscopic modeling and simulation to analyze the predict the technical performance of the self-healing U-shaped canal of composite materials. For the dielectric constant, dielectric loss tangent, and volume resistivity of carbon composite measured in the experiment, macroscopic characterization is performed on the technical performance of the self-healing U canal. The modeling method is used to obtain the 3D potential and current density nephogram according to the established microscopic model for intuitive and digital comparative analysis. This technology can provide a novel and effective method and a scientific basis for optimizing the preparation process of new functional composites.

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