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Research on the Mechanism of Combination and Separation of Wax Deposition on the Surface of FRP Pipe

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Abstract

Glass fiber reinforced plastic (GFRP, commonly known as glass fiber reinforced plastic) has the characteristics of light weight, low roughness, corrosion resistance, strong temperature resistance, low thermal conductivity, and strong wear resistance. It has been obtained in petroleum production and transportation related fields at home and abroad. A large-scale application. In practical applications, wax deposition also exists inside the glass steel pipe, which increases internal energy consumption and increases the economic cost of pipeline transportation and operation. However, the current research on the mechanism and characteristics of wax deposition on the inner surface of FRP pipes is obviously not enough for its extensive use. Therefore, it is of high guiding significance to carry out research on the wax-FRP surface bonding and separation mechanism. Based on this, this article conducts the following research on the inner surface of DN50 FRP pipe: According to the composite material interface bonding theory, summarize and analyze the possible wax-glass reinforced plastic bonding interface mechanism theory, and design the corresponding cold finger experiment, pull-off adhesion experiment and shear force measurement experiment according to the mechanical locking theory and chemical bonding theory. From the three aspects of the interface bonding process and the failure process of several sides in the vertical or shear direction, the actual role and dominant position of the mechanism theory that may act on the formation and failure of the wax-glass reinforced plastic interface are discussed. The results show that both the mechanical locking theory and the chemical bonding theory affect the wax-glass-reinforced plastic bonding interface, specifically the interface bonding process, the interface failure in the vertical or shear direction, and the dominant mechanism theories are the mechanical locking theory, Chemical bonding theory and mechanical locking theory.

Keywords

FRP; wax deposition; interface bonding mechanism; experimental research.

1. Introduction

Glass fiber reinforced plastic (GFRP, commonly known as glass fiber reinforced plastic) has the characteristics of light weight, low roughness, corrosion resistance, strong temperature resistance, low thermal conductivity, and strong wear resistance. It has been obtained in petroleum production and transportation related fields at home and abroad. A large-scale application. In practical applications, wax deposition also exists inside the glass steel pipe, which increases internal energy consumption and increases the economic cost of pipeline transportation and operation. However, the current research on the mechanism and characteristics of wax deposition on the inner surface of FRP pipes is obviously not enough to be widely used in the background, so it is of high guiding significance to carry out the research on the wax-FRP surface bonding and separation mechanism. For the bonding mechanism between wax and metal pipe materials, you can refer to the connection mechanism between different materials. It is known that the connection between organic matter and metal mainly

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comes from the interaction between atoms or molecules at the interface of the two, which can also be called Main valence force and secondary valence force, and for the combination of wax and glass steel pipe material, it is necessary to refer to the connection mechanism between organic matter and polymer material [1].

2. Theoretical analysis of interface bonding mechanism

2.1. Analysis of physical bonding mechanism

(1) Adsorption and wetting mechanism.

The adsorption and wetting mechanism is based on the analysis of the adsorption principle from the perspective of physical adsorption between two electrically neutral liquids and solids. Although the wax molecules come into contact with the interface through the flow of liquid oil, due to the deposition of wax in the glass steel pipe It is deposited in a solid form, so this article believes that the adsorption and wetting mechanism is a prerequisite for wax molecules to be deposited on the surface of FRP, rather than the fundamental mechanism [2].

(2) Mechanical locking mechanism.

The mechanism of mechanical locking believes that the adhesion of the attachment is related to the friction between the attachment and the surface of the substrate, that is, the depressions, protrusions and wrinkles on the uneven surface are important reasons for the formation of adhesion on the interface. On the one hand, a non-smooth surface will increase the friction between the two, on the other hand, it will increase the contact area, which increases the probability of chemical bond formation. The existence of this theory requires the premise that the attachment has fluidity and a certain degree of wettability on the surface of the substrate to ensure that the attachment can flow into the irregular structure on the surface of the substrate. This premise happens when the wax molecules are integrated into the oil. The situation was satisfied. At the same time, the theory divides the irregular shape of the interface into three types. From the schematic diagram, it can be seen that the three kinds of interface irregular locking have a much greater influence on the shear strength of the shear direction than the vertical direction. Although the theory of mechanical locking mechanism has limitations in explaining wax adhesion on smooth surfaces, through the above analysis, this paper believes that this mechanism may be the cause of wax adhesion on the surface of FRP[1].

(3) The mechanism of mutual diffusion between atoms or molecules.

The mechanism of mutual diffusion between atoms or molecules believes that the atoms or molecules of the attachment and the matrix will cross the boundary between the two substances and diffuse each other. There are two specific diffusion methods. One is shown in Figure 4-3, where macromolecules pass through. The boundary enters another substance and the inter-molecular entanglement occurs, which usually occurs on the surface where the two fibers are polymerized. The other is shown in Figure 4-4, where the elements contained in the substance will diffuse through the boundary, which usually occurs at the interface of metal-based materials. According to the premise of the material type of the theory is not consistent with the considered situation, it is believed that the theory is not suitable for the research and discussion of the wax-glass reinforced plastic interface [3].

(4) The mechanism of electrostatic attraction.

The electrostatic attraction mechanism believes that the electrostatic attraction between the attachment and the substrate is the main reason for the interface bonding, which comes from the mutual attraction caused by the difference in the density of positive and negative charges between the interfaces. Since the FRP material is a non-conductor, this theory has no effect on the wax-FRP interface [4].

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2.2. Analysis of chemical binding mechanism

(1) Chemical bonding mechanism.

In the chemical bonding mechanism, the chemical groups on the fiber surface will connect with the compatible chemical groups in the attachment to form new chemical bonds. The molecular formula of FRP is CaNaO4P, which contains a large number of electronegative O ions, and the molecular formula of paraffin wax is C31H64, which contains a large number of -OH groups (hydroxyl groups). Electronegative O ions and hydroxyl groups can easily form OH...:O hydrogen bonds (5.0 kcal/mol), so this article believes that the chemical bonding mechanism may be the cause of wax adhesion on the surface of FRP[5], OH...: O hydrogen bonding method is shown in the figure below:

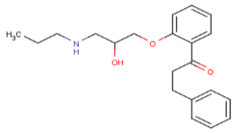

Figure 1 Paraffin wax structure

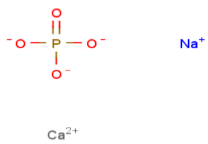

Figure 2 Glass fiber reinforced plastic structure

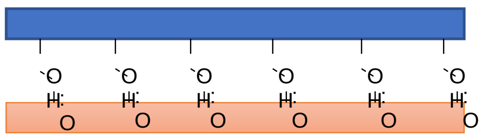

Figure 3 O-H...: Schematic diagram of O interface bonding

(2) Combination mechanism of reactive compounds.

The theory of reaction compound binding mechanism specifically refers to the situation where a chemical reaction can occur between the attachment and the substrate, and the reaction leads to the formation of new compounds at the attachment interface. This theory usually occurs on the surface of metal matrix composites, but for ceramic and composite matrix composites, there is no chemical reaction between the internal structure of the fiber and the matrix, so it is considered that this theory is not applicable to the wax-glass fiber interface problem [6] .

Based on the above discussion, it can be concluded that the bonding and separation mechanism of the wax-FRP adhesion interface may come from the mechanical bonding mechanism at the physical level and the chemical bonding mechanism at the chemical level. Based on this, the paper designs corresponding experiments to discuss the two mechanisms.

3. Experiment on the adhesion mechanism of the wax layer on the surface of FRP

3.1. Experimental sample preparation

In order to explore the influence of different bonding mechanisms on the combination of wax and glass fiber reinforced plastics, it is necessary to change the morphology and microstructure of the surface of the glass fiber reinforced plastic. This article first uses 400 mesh, 1000 mesh, and 2000 mesh sandpaper in order to polish the surface of the material. After polishing, use diamond pastes of W2.5, W1, and W0.5 in turn for polishing. At the same time, in order to ensure uniform polishing and polishing process, this section uses the same glass steel plate as the pipe material for material sample sampling. The length and width are 100mm X 30mm. The wax block attachment is processed by cutting. First, put a sufficient amount of section paraffin into the beaker, and put the samples of different roughness into the beaker. To facilitate peeling, the outside of the sample must be covered with tape in advance, and the inside is deposited for data measurement. After the temperature is lowered, the sample is taken out and cut with a cutter. The length, width, and height of the wax block are 30mm×30mm×30mm.

3.2. Experimental method

The experiment is mainly divided into two parts: wax adhesion of FRP slices and vertical peeling of wax blocks. The two parts of the experiment are briefly introduced below:

(1) The wax adhesion experiment part of FRP slices.

This part of the experiment is carried out using a cold finger device. The configured simulated oil is used as the reaction solution to polish 400 mesh sandpaper, 400 mesh and 1000 mesh sandpaper, 400 mesh, 1000 mesh and 2000 mesh sandpaper, and three types After sandpaper polishing, a total of four glass steel sheet slices were put into the cold finger device, and the reaction environment temperature was set to 20℃, 22℃ and 24℃. The whole reaction process was 24h. During the process, the slices were taken out once every 12h. Before weighing, wipe with absorbent paper and place it in a drying dish for 12h drying. During the drying process, use air conditioning to try to keep the indoor temperature similar to the ambient temperature of the reaction process to avoid large experimental errors [7].

(2) The wax layer pulls apart the adhesion test part.

Refer to the Chinese national standard "GB/T 5210-2006 Paint and Varnish Pulling Method Adhesion Test" for experimental measurement. According to the standard requirements, the experiment should be carried out in 6 groups, and the sample should be at a temperature of 23±2℃ and relative humidity before the experiment. Let it stand and dry for 16 hours in a 50±5% environment, and ensure that the experimental environment is also at a temperature of 23±2°C and a relative humidity of 50±5%. At the same time, the adhesive requires that its cohesion and adhesion are greater than that of the wax coating. It is suitable according to the standard quick-drying epoxy adhesive. The stress rate does not exceed 1MPa/s, and the damage of the experiment needs to be completed within 90s. The resulting failure strength is calculated according to the following formula, and the results need to be averaged for 6 times: σ_1 ——Breaking strength, MPa;F_1 ——Destructive power, N;A_1 ——Contact area, mm^2.

$$\sigma_1 = \frac{F_1}{A_1} \tag{4-1}$$

3.3. Experimental results and analysis

(1) Observation of microscopic morphology of material slices

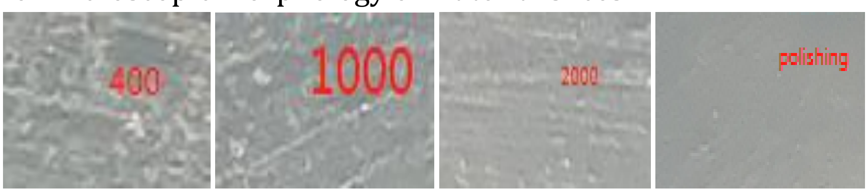

Figure 4 400-fold microscopic morphology of glass steel pipe with green background color

According to the picture observation, it can be clearly found that after different degrees of polishing, the smoothness of the surface of the FRP pipe has been significantly improved. As the degree of polishing deepens, the surface convex structure and size have undergone significant changes, that is, the stronger the polishing, the convex The number remains the same or decreases. The gap between the raised structures becomes longer and wider while maintaining the branch structure. The polished material surface still meets the gap conditions required by the mechanical lock theory, and the changes brought about by the polishing are sufficient The next experiment provides reference control. The surface of the polished material is difficult to observe the convex structure and structure gap under a microscope at 400 times, and it is reserved as a blank control group for the experiment.

(2) Analysis of wax adhesion on material slices

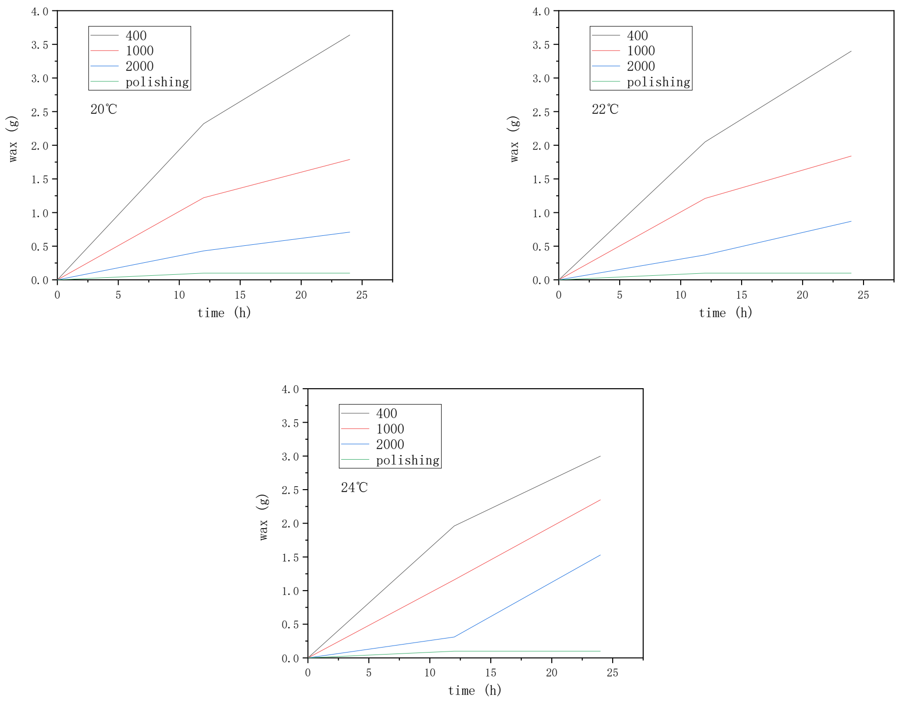

Figure 5 Trend graph of wax deposition at different temperatures

According to the chart, it can be seen that in the 12-hour period, the wax adhesion weight increase trend at each temperature is the same, that is, at the same temperature, the higher the roughness of the sample, the more wax is attached, which shows that in the early stage of wax deposition At this stage, the smoothness of the interface is an important influencing factor, that is, the mechanism of mechanical locking. With the increase of time, from 12 hours to 24 hours, although the overall wax adhesion amount is increasing, it can be clearly seen that the growth rate has changed greatly. The sample polished by 400 grit sandpaper is compared with the previous period. Compared with the slight decrease, the samples polished with 1000 mesh and 2000 mesh sandpaper will rise compared with the previous period. This article believes that this situation is because the surface of the material is completely covered by the wax layer, and the wax molecules behind It is caused by further deposition on the wax layer instead of deposition on the glass fiber reinforced plastic sample, and its surface roughness can no longer be reflected. And with the passage of time, the three lines indicating the increase of wax deposition on different samples have a tendency to gradually develop horizontally. This article believes that this is caused by the change in the chemical properties of the interface after the wax layer completely covers the surface, namely The root cause of the change is the mechanism of chemical bonding. For the sample group after polishing treatment for the blank control, although the deposition amount is very small, there is still deposition. This article believes that this phenomenon is caused by the chemical bonding mechanism. To sum up, in the process of wax deposition on the surface of FRP, mechanical locking theory and chemical bonding theory work together on the wax-FRP interface, and mechanical locking theory is dominant.

(3) Analysis of the adhesion of the wax layer

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Table 1 The failure strength of the wax layer with different roughness

Breaking strength（MPa）				
Roughness / Numbers	400 grit sandpaper	1000 grit sandpaper	2000 grit sandpaper	polishing
1	0.026111	0.026556	0.026778	0.025778
2	0.026778	0.025778	0.026222	0.026333
3	0.026667	0.025667	0.026444	0.026
4	0.025889	0.026333	0.026333	0.025667
5	0.026444	0.026889	0.025889	0.026111
6	0.026	0.026	0.025889	0.025889
average	0.026333	0.026333	0.026222	0.026

According to the test results, at room temperature, the average value of force and shear strength required for the wax block of the experimental sample size to be pulled apart vertically is 23.6N and 0.026MPa, and it hardly changes with the surface roughness. The change, with the increase of roughness, only has a very small increase. This article believes that the reason for the very small change is the existence of type 2 gullies on the surface of the sheet. This confirms the previous conjecture that the chemical bond bonding mechanism and the mechanical locking mechanism work together for the vertical wax-glass fiber reinforced plastic surface damage, but the mechanical locking mechanism has very little influence and can be ignored. It is caused by the chemical bond. The combination mechanism is dominant.

4. Shear direction wax layer peeling experiment

4.1. Experimental sample preparation

In order to shorten the experiment period, the wax layer of the sample used in this experiment is obtained by melting and reshaping the paraffin, that is, the inner surface of a certain roughness material sample to be prepared is placed in parallel with the outer surface of the unpolished material sample. The sizes are 1~4 mm. After the paraffin is formed, the slices can be cut into the required size with a cutter as needed.

The experimental materials used in the experiment in this section, including oil medium, section paraffin, and other experimental tools and reagents are the same as those in the previous section. In order to restore the internal conditions of the pipe as much as possible in the shear peeling experiment, the peeling sample used in this section is changed from the glass steel plate slice to the DN50 pipe slice, and the length and width of the slice are 120mm X 30mm.

4.2. Experimental method

Refer to "ISO 4587-2003 The method for determination of strength properties of adhesive in shear by tension loading", according to the standard requirements, the number of samples per batch is 5, when the situation mentioned in the international standard ISO 10365:1992 At that time, it was considered that damage had occurred. The result of shear strength σ_2 (unit MPa) is calculated according to the following formula: F_2 ——Failure load, N; A_2 ——Shear area, mm^2.

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$$\sigma_2 = \frac{F_2}{A_2} \tag{5-1}$$

4.3. Experimental results and analysis

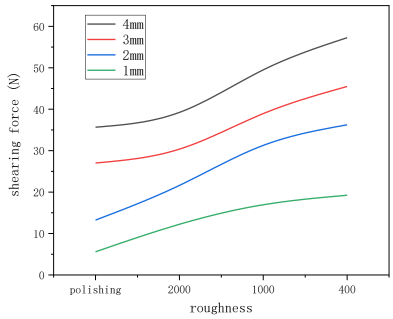

Figure 6: Wax block shearing force vs. roughness

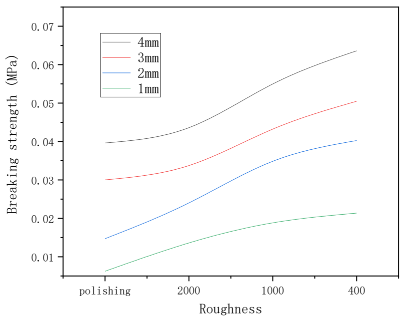

Figure 7 Wax block shearing strength vs. roughness

According to the chart, as the roughness increases, the shear strength of wax blocks of different thicknesses also gradually increases. In the polishing section to 2000 mesh roughness, the relationship of the growth rate is 2mm sample>1mm sample>3mm sample≈4mm sample. Polishing 2000 mesh to 1000 mesh roughness section, the relationship of the growth rate is 2mm sample>3mm sample≈4mm sample >1mm sample. After 1000 mesh polishing to 400 mesh roughness section, the relationship of the growth rate is 4mm sample>3mm sample>2mm sample >1mm sample. The growth rate of shear strength changes with the roughness, indicating that the rougher the surface of the FRP, the greater the impact on the shear strength. The overall experimental results confirmed that the mechanical locking theory dominates the failure of the wax-glass reinforced plastic interface in the shear direction.

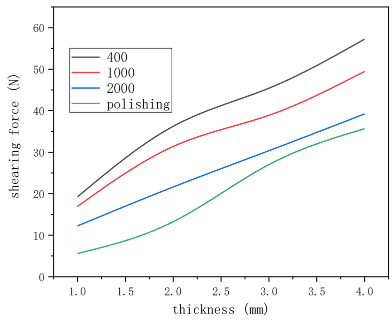

Figure 8: Wax block shearing force vs. thickness.

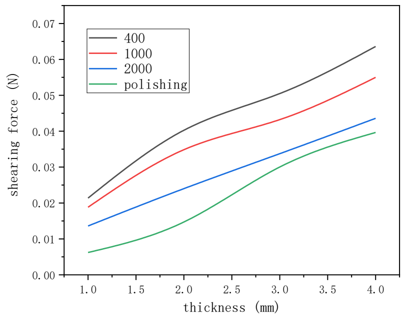

Figure 9 Wax block shearing strength vs. thickness.

According to the chart, as the roughness increases, the shear strength of wax blocks of different roughness also gradually increases. In each thickness section, the relationship of the growth rate is 4mm sample>3mm sample>2mm sample>1mm sample. This article believes that this is due to the thickening of the wax layer, which causes the wax particles to enter the surface of the FRP surface gully deeper under the action of gravity, which increases the resistance provided by the mechanical interlocking mechanism.

5. Conclusion

(1) Through the analysis of the generation conditions of the mechanism theory, it is concluded that the mechanism theory that may exist at the wax-FRP interface is the mechanical locking mechanism and the chemical bonding mechanism.

(2) Through the cold finger experiment of FRP pipe slices with different roughness, it can be seen that the rougher the FRP surface, the more surface protrusions and grooves provided for locking, and the more deposits. At the same time, the almost smooth FRP surface is still There is a small amount of wax deposition, indicating that both the mechanical locking theory and the chemical bonding theory are applicable to the formation of the wax-glass reinforced plastic interface, and the mechanical locking theory plays a leading role.

(3) Regarding the vertical wax-glass fiber reinforced plastic interface failure, it can be seen from the vertical pull and adhesion experiment that the tensile force required for samples with different roughness does not increase with the increase of the roughness of the sample, indicating that The peeling of wax-glass reinforced plastic deposits in the vertical direction has little effect on mechanical locking theory and can be ignored.

(4) Regarding the destruction of the wax-glass reinforced plastic interface in the shear direction, the shear peel force experiment found that the greater the roughness of the sample, the greater the peel force, indicating that the mechanism of mechanical locking has an effect.

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