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MECHANICAL BEHAVIOR OF COMPOSITIONS OF GLASS-FIBER REINFORCED PLASTIC MORTAR PIPES BASED ON THEIR FUNCTIONING

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ABSTRACT

The experimental investigation on the mechanical parameters compositions of glass-fiber reinforced plastic mortar (GRPM) pipe is the basis of simulating and analyzing the mechanical characteristics of the complete structure of GRPM pipe. Due to the anisotropic material properties of GRPM pipe, the compressive property test is carried out, and the results show that the circumferential compressive strength(CCS) is 49.93 MPa, the axial compressive strength(ACS) is 40.79 MPa, the circumferential elastic modulus(CEM) is 4.84 GPa, and the axial elastic modulus(AEM) is 4.04 GPa. The difference between the CCS and ACS and EM is about 20%, as well as the CCS and EM are greater than the ACS and modulus of elasticity. Conclusions drawn from the tests provide an important basis for checking whether the materials meet the design requirements.

KEYWORDS

GRPM pipe culvert, Mechanical behavior, Elastic modulus, Compressive strength

INTRODUCTION

Glass-fiber reinforced plastic mortar (GRPM) pipe has been developed and applied in many industries, and its excellent properties such as high strength and stiffness, high corrosion resistance and smooth internal surface et al. are widely considered as the most suitable pipe material in culvert engineering [1]. As a buried GRPM pipe in highway engineering, in addition to good drainage performance, it also needs to bear the impact of external load and surrounding earth pressure on the pipe itself. Therefore, before studying the stress characteristics of the whole structure of GRPM pipe, it is necessary to test and study the basic mechanical parameters of GRPM pipe. In 2015, Rafiee et al. [2] and others investigated the failure mechanism of glass fiber reinforced pipes, and established a failure assessment model including stress analysis, failure assessment and material function degradation. The effects on the failure pressure for four different fiber volume fractions: 52.5%, 55%, 57.5% and 60%, and three different winding angles: 52.5%, 57.5% and 60.19% were studied. The results show that the failure pressure of function and the first ply decrease with the increase of fiber volume fraction, while an increase in winding angle (measured from the axial axis) increases the failure pressure. Melo et al. [3] presented experimental and numerical result of filament-wound E-glass/polyester pipes with nominal inside diameter of 300 mm and wall thickness of 5.7 mm, which were produced with the incorporation of quartz sand as filler and tested to failure under internal pressure. According to the results presented, both failure criteria predicted values which are within one standard deviation of the measured mean response. The average experimental leakage pressure (4.55 MPa) was about 2% below the ficco-ply-failure numerical prediction, using the failure criterion of Hoffman (4.66 MPa) and 4% below the prediction adopting the failure theory of Tsai–Hill (4.75 MPa). Schrock [4] studied the design method of GRPM pipe and pointed out that according to the structural characteristics and bearing requirements of GRPM pipe, it is necessary to calculate the maximum load, bending strength, shear strength and bearing capacity of each layer of the pipe in detail.

In this paper, the production technology, compressive strength and elastic modulus of GRPM pipes are studied. The mechanical performance of such structural components, which are normally subjected to external parallel load, depends on the manufacturing process and includes aspects such as microstructure and volume fractions of the constituents, as well as distribution, sizes and shapes of the reinforcing phases, voids and cracks [5]. These aspects as well as the mechanical behavior of the pipes, are discussed in this study. The experimental analysis and calculation results provide basic data for the evaluation of the mechanical properties and numerical simulation of the GRPM pipe.

DESCRIPTION OF GRPM PIPE

The production process of GRPM pipe mainly includes filament winding and centrifugal casting [6]. The GRPM pipe selected in this paper is GRPM pipe of filament winding type, and as the highway buried pipe culvert, the performance of the winding pipe culvert is more suitable [7].

The wall structure of GRPM pipe can be generally divided into five layers, from the inside to the outside are interior liner, inner structure layer, core, outer structure layer and exterior surface. Figure 1 shows a GRPM pipe wall construction demonstrating laminated structure.

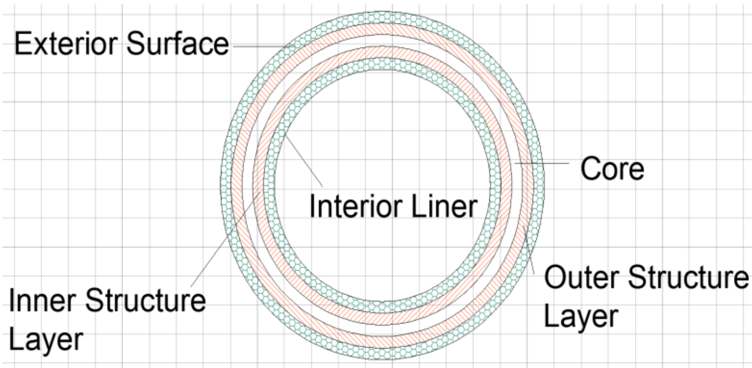

Fig.1 - GRPM pipe wall construction

Interior liner

The inner liner directly contacts with the fluid conveyed in the pipeline, which should meet the requirements of the conveyed fluid in the pipe, and has the functions of anti-seepage, wear-resistant, corrosion-resistant, etc. The interior liner should be particularly smooth, without defects, cracks or stratification. In order to obtain a smooth and dense inner surface, the process of first gluing and then wrapping felt is adopted, and the secondary inner layer is directly formed by spray method. It is usually produced on a cylindrical metallic mold composed of stitched glass fiber mat (450 g/m^2), surface mat (30 g/m^2) shown in Figure 2 and unsaturated polyester resin with the approximate thickness of 1.5 mm..

Inner structural layer

The inner structural layer, also known as the inner reinforcement layer, is mainly composed of the tensile and compressive stresses caused by the internal pressure load and the axial bending load on the circumferential and spiral fibers. The fiber consumption, resin composition, winding thickness and wire arrangement of the layer are determined by the design and calculation of the internal and external pressure load requirements of the pipeline.

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Core layer

The core layer, also known as resin mortar layer, is composed of structural resin and quartz sand. Its thickness is determined according to the buried depth of the pipeline and the rigidity design required by the ground load. The main function is to enhance the rigidity of the pipeline.

Outer structural layer

The outer structural layer, also known as the outer reinforcement layer, has the same circular layer and spiral layer as the inner winding layer, which is the outer skin with sand layer structure. Its thickness and layout design depend on internal pressure, external pressure and bending load. In this way, the pipe wall of sandwich structure is composed of inner and outer structural layers and core layers.

Exterior surface

The exterior surface, also known as anti-aging layer, is composed of anti-corrosion resin, weather resistant resin and other auxiliary materials. Unsaturated polyester resin is one of the most commonly used thermosetting resins. It is a linear polymer formed by condensation of saturated dicarboxylic acid, unsaturated dicarboxylic acid and diol. It is a resin solution with certain viscosity diluted by cross linking monomer or active solvent, which is called up for short. It can resist the erosion of natural environment factors such as atmospheric aging, sunlight and water immersion. In addition, its hardness is generally high, which can improve the anti-collision ability of pipeline.

(a)Glass fiber roving *(b)Surface mat* *(c)Chopped mat*

Fig.2 - Glass fiber

According to the analysis of the cross section structure of GRPM pipe wall as shown in Figure 1, it is not difficult to discover that GRPM pipe is a reasonable pipe wall structure with clear structure level and clear function division.

In the discontinuous winding process, first, the lining is made on the lining machine, and then the winding and sanding operation is carried out on the basis of the completion of the anti-seepage lining layer according to the structural design requirements of the pipe wall. The continuous fiber is used in turn to move back and forth along the axis of the rotating core mold through the dip groove. The placement of the fiber relative to the mandrel axis and the winding angle are controlled by the ratio of the moving speed of the glue bath and the rotation speed of the mandrel. The inner winding layer, the sand layer, the outer winding layer and the outer protective layer are completed respectively. The whole process is controlled by the computer. The wrapped pipe is placed on the curing machine and rotated, heated by far-infrared electric heating plate, heated and solidified while rotating until the curing process is completed. After curing, it shall be lifted to the correction machine for bearing and socket turning, and then it shall be lifted to the demoulding machine for oil pressure demoulding. The production procedure is shown in Figure 3.

(a) Lining fabrication *(b) Filament winding* *(c) Sand winding*

(d) Solidification *(e) Demoulding*

Fig.3 - Fabrication process of the filament-wound pipe

EXPERIMENTAL PROCEDURE

Materials and test specimens

The specimens for test of compressive strength and modulus of elasticity of the GRPM pipe composite was fabricated according to the Standard ANSI/AWWA C950-01[8]. The length of pipe is 6 m with 1.5 m diameter and 0.05 m wall thickness.The thickness of test specimen wall is taken as the section with length a=50 mm, width b=47 mm, and the height of the specimen is taken as h =150 mm. The fabrication and size of specimens are shown in Figure 4.

The compressive strength and elastic modulus of GRPM pipe can be tested in two directions: circumferential direction and axial direction. A vernier callipers with an accuracy of 0.02 mm was used to measure the specific dimensions of each specimen. The length, width and height of each specimen are respectively three different positions of the specimens. The detailed dimension data of specimens are shown in Table1.

Where HY1-5 are representative of No.1-5 specimens in hoop direction, and ZY1-5 stand for No.1-5 specimen in axial direction. The following three requirements should be met for sample preparation:

(1) The samples should be prepared by machining method, and the positions without bubble and crack defects should be selected for sampling, and the number of test pieces should not be less than 5 effective test pieces;

(2) The upper and lower, left and right, front and rear of the sample should be parallel to each other;

(3) The error of length, width and height of the sample is within 5mm.

Tab.1 - Size of specimens

	Hoop specimen	Unit: mm			Axial specimen	Unit: mm	
No.	Length a	Width b	Height h	No.	Length a	Width b	Height h
HY1	50.60	46.78	150.20	ZY1	51.62	47.02	151.80
	50.66	47.06	149.92		51.58	47.26	151.74
	50.78	47.08	149.80		51.72	47.06	151.60
M-value	50.68	46.97	149.97	M-value	51.64	47.11	151.71
HY2	51.10	47.18	145.66	ZY2	51.48	47.58	151.80
	50.72	47.10	145.30		51.22	47.42	151.40
	50.72	46.92	145.20		50.60	47.08	151.38
M-value	50.84	47.06	145.38	M-value	51.10	47.36	151.52
HY3	51.38	47.10	148.92	ZY3	51.60	47.10	151.40
	51.18	46.78	148.78		51.98	47.28	151.38
	51.36	47.30	149.10		52.20	47.48	151.36
M-value	51.30	47.06	148.93	M-value	51.92	47.28	151.38
HY4	51.20	47.10	147.46	ZY4	52.10	47.10	150.98
	51.48	47.08	147.80		51.60	47.12	151.10
	51.12	47.14	147.10		51.36	47.20	151.18
M-value	51.26	47.11	147.45	M-value	51.68	47.14	151.08
HY5	50.78	47.10	148.44	ZY5	52.02	47.26	151.42
	50.98	47.38	148.34		51.60	47.22	151.16
	50.80	47.76	148.04		51.50	47.24	151.30
M-value	50.85	47.21	148.27	M-value	51.37	47.24	151.29

In this test, the samples are taken from the hoop and axial direction of GRPM pipe. Each type includes two mechanical indexes of compressive strength and elastic modulus with 5 specimens respectively.

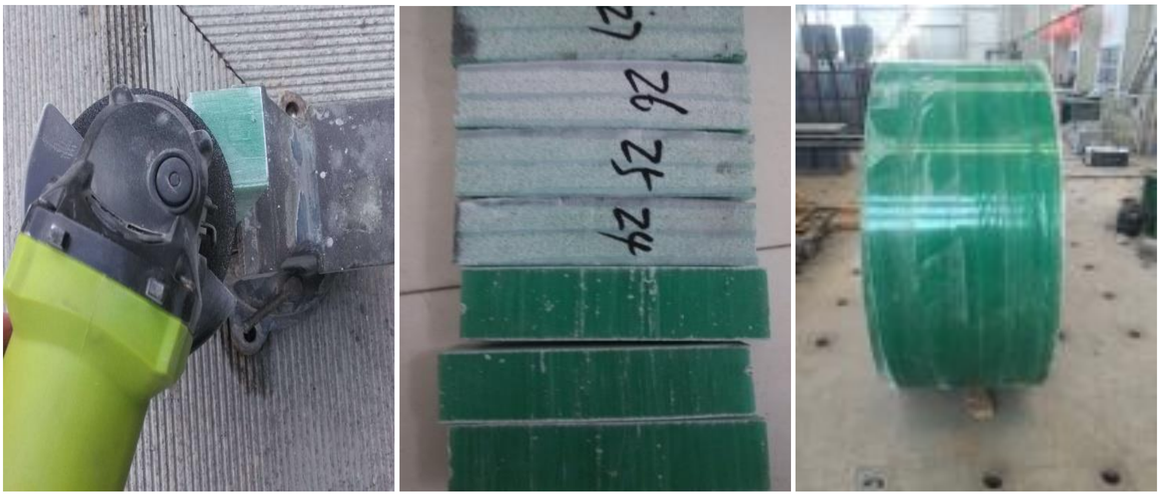
Fig.4 - Pipe specimens

Test equipment

In this test, the dual space system of WAW-1000 universal testing machine controlled by computer, which can be seen in Figure 5, is adopted. The test system is composed of main engine, hydraulic power unit, dscc-5000 multi-channel electro-hydraulic servo closed-loop control system and computer data processing system. It adopts the electro-hydraulic servo control technology, which can meet the three closed-loop control requirements of load, deformation and displacement. It has three control modes of load, deformation and displacement, and can realize smooth switching according to the set control mode, and achieve constant speed Rate load control, constant rate deformation control, constant rate displacement control and other programs to meet the requirements of various material tests. The equipment can be used for tensile test and compression test of bar, plate and other samples. Bending and shearing tests can be carried out with bending and shearing clamps.


Fig. 5 - WAW-1000 universal testing machine

Experimental procedures

The test was conducted at (23 ± 2) ℃ and relative humidity with (50 ± 10)%. Before the test, the sample shall be placed under the standard environmental conditions of the laboratory for at least 24 hours. The basic procedures were carried out according to the Standard [8].

(1) Prepare the sample according to the requirements of the test standard, then number the sample and measure the size of any three places and fill in the table;

(2) The loading head of the testing machine should be smooth and free of sundries. The parallelism of the upper and lower pressboards should be adjusted before testing;

(3) Adjust the position of the lower crossbeam of the testing machine, install and place the test piece, make the center line of the test piece align with the center of the upper and lower pressing plates of the testing machine, and put it in the state of load to be applied;

(4) Load according to the set test loading speed. When the compressive strength is tested, the loading speed is 3 mm/min, and the uniform and continuous load is applied to the specimen until the specimen is damaged. The tester automatically records the maximum load and fills the value in the corresponding table;

(5) The loading speed is 2 mm/min for the elastic modulus testing. The dial indicator is placed, the initial load is applied, and the test piece and the dial indicator are checked and adjusted, so that the whole system is in normal working state and the compression deformation of both sides of the test piece is consistent. Then the load is applied at a certain loading speed, divided into six levels of loading, the applied load should not exceed 50% of the maximum load, and the repeated loading is three. The deformation size of each test piece is recorded and the average value is taken. The test load application procedure is shown in Figure 6.

Fig.6 - Specimen loading

The compressive strength σ_c of GRPM pipe is calculated by the following equation.

$$\sigma_c = \frac{P}{a \times b} \tag{1}$$

where σ_c is compressive strength, kN/cm^2;

P is the load at failure, kN;

$a \times b$ is the loading section area, cm^2;

The applied load of testing the elastic modulus of GRPM pipe should not exceed half of the failure load, and then calculate the elastic modulus according to Equation 2.

$$E_c = \frac{L \cdot \Delta P}{a \cdot b \cdot \Delta L} \tag{2}$$

where, E_c is elastic modulus;

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ΔP is the increment of applied load, kN,

ΔL is the increment of deformation corresponding to ΔP, mm;

RESULTS AND DISCUSSION

The typical curve of the compressive strength test results of DN1500 spiral wound GRPM pipe material is shown in Figure 7. Figure 7 shows the failure mode of the samples. In Figure 6, the vertical axis is the test load (kN), and the horizontal axis is the deformation (mm). According to the test results, one can determine the compressive strength of the material and its corresponding failure displacement, determine the maximum load according to the first peak of the test result curve, take the maximum load as the ultimate compressive load to calculate the compressive strength, and determine the final result according to the average strength of the five samples.

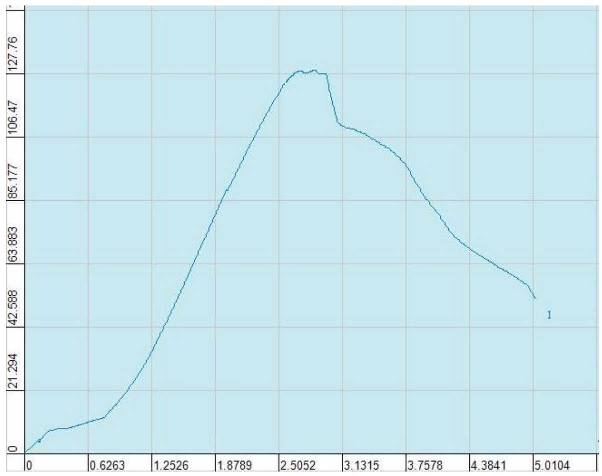

Fig.7 - Compressive strength curve

Fig.8 - Failure modes of specimens

As shown in Fig.8, under the continuous loading, there will be small cracks between the sand layer and the numerical layer. As the load increases continuously, the cracks increase, and develop in longitudinal direction. Finally, the cracks connect with each other, and the sample fails. Under the continuous loading of the circumferential sample, at first, there will be inclined small cracks with an angle of about 45^{o} with the horizontal in the sand layer. With the continuous increase of the load, the inclined cracks will increase. Finally, the cracks will penetrate into each other and form the main cracks with an angle of about 45^{o} with the horizontal. The sample fails.

Based on the classical laminated plate theory, the stress-strain relationship of the middle layer in the principal direction coordinate is expressed as follows by the stiffness component:

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix}_0 = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix}_0 \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} \tag{3}$$

Where $Q_{11} = \frac{E_1}{1-v_{12}v_{21}}, Q_{22} = \frac{E_2}{1-v_{12}v_{21}}, Q_{66} = G_{12}, Q_{12} = v_{12}Q_{22} = v_{21}Q_{11}$

According to the coordinate transformation relationship, the stress-strain relationship of filament winding layer in off-axis coordinate system is:

$$\begin{Bmatrix} \sigma_x^{(k)} \\ \sigma_y^{(k)} \\ \tau_{xy}^{(k)} \end{Bmatrix}_k = \begin{bmatrix} \overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}} \\ & \overline{Q_{22}} & \overline{Q_{26}} \\ sym. & & \overline{Q_{66}} \end{bmatrix}_k \left\{ \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{bmatrix} + z_k \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix} \right\} \tag{4}$$

Where, Q_{ij} is the stiffness modulus component in the off-axis coordinate system. Similarly, for the core inclusion layer, first assume that its stress-strain formula in the off-axis coordinate system is

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} Q_{11,m} & Q_{12,m} & Q_{16,m} \\ Q_{12,m} & Q_{22,m} & Q_{26,m} \\ Q_{16,m} & Q_{26,m} & Q_{66,m} \end{bmatrix}_k \left\{ \begin{bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \end{bmatrix} + z \begin{bmatrix} k_x \\ k_y \\ k_{xy} \end{bmatrix} \right\} \tag{5}$$

Where, $Q_{ij,m}$ is the stiffness coefficient of sand inclusion layer.

The core layer of GRPM pipe can be regarded as isotropic material, and its stress-strain can be expressed as

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} 1 & & sym. \\ v & 1 & 0 \\ 0 & 0 & \frac{1-v}{2} \end{bmatrix}_0 \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} \tag{6}$$

The stiffness coefficient of sand layer of FRP sand pipe is

$$Q_{11,m} = Q_{22,m} = \frac{E}{1-v^2}, Q_{12,m} = E\frac{v}{1-v^2}, Q_{66,m} = \frac{E}{2(1+v)}, Q_{16,m} = Q_{26,m} = 0$$

Then, the stress of filament winding layer and sand inclusion layer is integrated in the direction of pipe wall thickness

$$\begin{pmatrix} N \\ M \end{pmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{pmatrix} \varepsilon_0 \\ k \end{pmatrix} \tag{7}$$

Where

$$\begin{cases} A_{ij}=\sum_{k=1}^{n_f}(\overline{Q_{ij,f}})_k(h_k-h_{k-1})+\sum_{l=1}^{n_m}(Q_{ij,m})_l(h_l-h_{l-1}), i,j=1,2,6 \\ B_{ij}=\frac{1}{2}\left[\sum_{k=1}^{n_f}(\overline{Q_{ij,f}})_k(h_k^2-h_{k-1}^2)+\sum_{l=1}^{n_m}(Q_{ij,m})_l(h_l^2-h_{l-1}^2)\right], i,j=1,2,6 \\ D_{ij}=\frac{1}{2}\left[\sum_{k=1}^{n_f}(\overline{Q_{ij,f}})_k(h_k^3-h_{k-1}^3)+\sum_{l=1}^{n_m}(Q_{ij,m})_l(h_l^3-h_{l-1}^3)\right], i,j=1,2,6 \end{cases} \quad (8)$$

According to the test results, sort out the test data of the annular and axial specimens of the GRPM pipe, and get the average value of the compressive strength, as shown in Table 2 and 3.

Tab. 2 - Hoop compressive strength

Specimen	Length a （mm）	Width b （mm）	Height h （mm）	Ultimate load (kN)	Compressive strength Σ(MPa)	Failure displacement (mm)
HY1	50.68	46.97	149.97	120.98	50.82	3.06
HY2	50.84	47.06	145.38	121.94	50.97	2.96
HY3	51.30	47.06	148.93	118.65	49.14	3.08
HY4	51.26	47.11	147.45	119.18	49.35	3.00
HY5	50.85	47.21	148.27	118.54	49.38	3.04
Average value	50.99	47.08	148.00	119.86	49.93	3.13
Dispersion coefficient	0.54	0.19	1.17	1.47	1.77	3.96

Tab. 3 - Axial compressive strength

Specimen	Length a （mm）	Width b （mm）	Height h （mm）	Ultimate load (kN)	Compressive strength σ(MPa）	Failure displacement （mm）
ZY1	51.64	47.11	151.71	100.71	41.10	3.01
ZY2	51.10	47.36	151.52	98.23	40.59	3.00
ZY3	51.92	47.28	151.38	98.37	40.07	3.09
ZY4	51.68	47.14	151.08	99.02	40.64	2.92
ZY5	51.37	47.24	151.29	100.15	41.27	3.08
Average value	51.54	47.23	151.40	99.30	40.79	3.02
Dispersion coefficient	0.61	0.21	0.16	1.10	1.33	2.28

As shown in Table 3, the average hoop compressive strength and the average axial compressive strength of GRPM pipe are 49.93 MPa and 40.79 MPa respectively. The circumferential compressive strength is slightly higher than the axial compressive strength.

The ultimate compressive load of GRPM pipe material determined above, then the elastic modulus test should be carried out. The maximum loading amount of the elastic modulus test is 50% of the ultimate compressive load. For the same sample, one need repeat loading for three cycles, record the corresponding deformation and load, determine the elastic modulus according to the load, deformation and sample size, and take the average value of three loading and unloading cycle tests as the elastic modulus of each sample modulus.

The elastic modulus in the direction of hoop and axial are shown in Table 4 and 5.

Table 4 - Hoop modulus of elasticity

Specimen	Experimental data								Modulus of elasticity E (GPa)
HY1	Load (kN)	5	10	15	20	25	30	35	4.39
	Deformation (mm)	0.095	0.171	0.244	0.314	0.385	0.450	0.532	
HY2	Load (kN)	5	10	15	20	25	30	35	5.96
	Deformation (mm)	0.112	0.162	0.245	0.306	0.369	0.436	0.491	
HY3	Load (kN)	5	10	15	20	25	30	35	4.64
	Deformation (mm)	0.110	0.172	0.244	0.309	0.380	0.444	0.504	
HY4	Load (kN)	5	10	15	20	25	30	35	4.50
	Deformation (mm)	0.120	0.196	0.271	0.340	0.400	0.468	0.529	
HY5	Load (kN)	5	10	15	20	25	30	35	4.70
	Deformation (mm)	0.083	0.151	0.217	0.279	0.350	0.415	0.476	
	Average (GPa)		4.84		Dispersion coefficient			13.20	

As shown in Table 4, the average hoop modulus of elasticity measure from five specimens was 4.84 GPa, with dispersion coefficient of 13.20. It can also be seen in Table 4, the stiffness modulus at different degree of loads are much different in values, the comparative analysis can't be made directly using the stiffness modulus. In order to further explain the change rule between load and displacement, linear regression analysis is carried out for the data in the table, and the results are shown in the Figure 9.

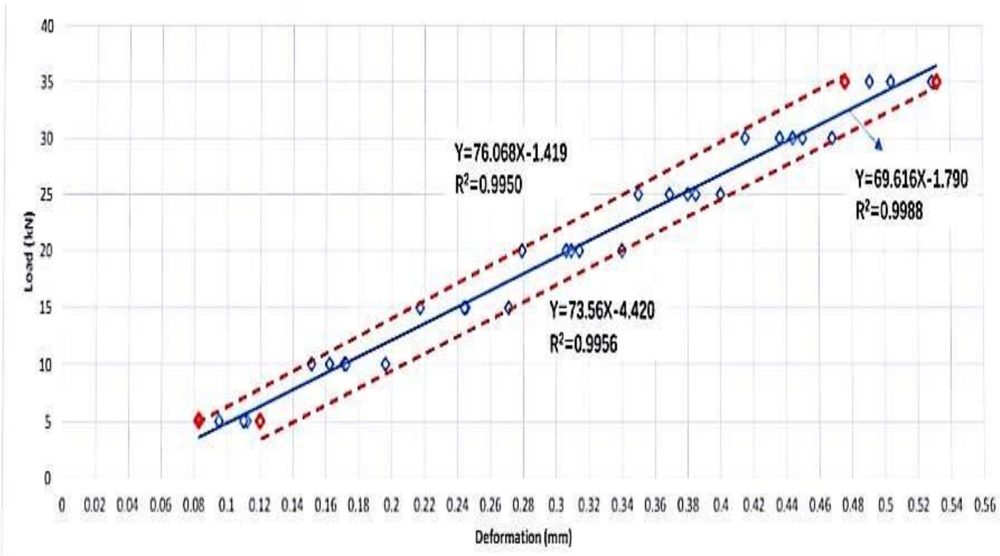

Fig.9 - Hoop elastic modulus

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Tab. 5 - Axial modulus of elasticity

Specimen	Experimental data								Modulus of elasticity E (GPa)
ZY1	Load (kN)	5	10	15	20	25	30	35	3.74
	Deformation（mm）	0.130	0.251	0.356	0.468	0.570	0.697	0.823	
ZY2	Load (kN)	5	10	15	20	25	30	35	4.14
	Deformation（mm）	0.157	0.279	0.381	0.472	0.571	0.670	0.763	
ZY3	Load (kN)	5	10	15	20	25	30	35	4.04
	Deformation（mm）	0.117	0.220	0.320	0.415	0.510	0.626	0.730	
ZY4	Load (kN)	5	10	15	20	25	30	35	4.05
	Deformation（mm）	0.123	0.211	0.306	0.406	0.511	0.622	0.728	
ZY5	Load (kN)	5	10	15	20	25	30	35	4.24
	Deformation (mm)	0.106	0.194	0.279	0.375	0.473	0.571	0.684	
	Average (GPa)		4.04		Dispersion coefficient				6.16

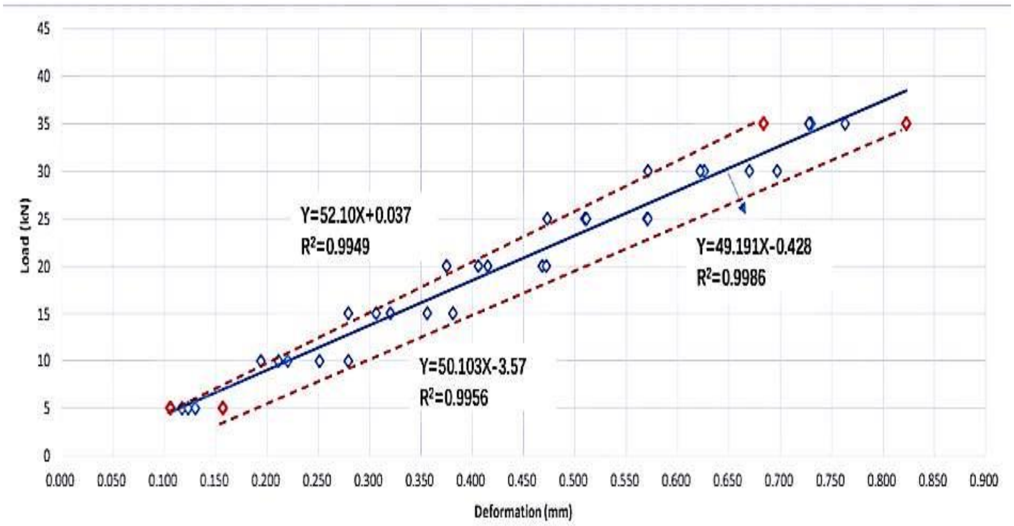

Fig.10 - Axial elastic modulus

As shown in Figure 9 and Figure 10, the optimal relation curve after fitting is drawn as a solid line. The hoop and axial deformation of specimen is changed linearly with loading, this trend agrees with the results obtained by R. Rafiee et al. [9].The hoop deformation-load curve slope of GRPM pipe is greater than of axial ,as the hoop elastic modulus are bigger than axial elastic modulus.

According to the above experimental results and analysis, it can be obtained that the hoop compressive strength of GRPM pipe is 42.66 MPa, the failure deformation is 3.59 mm, and the elastic modulus is 3.21 GPa; the axial compressive strength of GRPM pipe is 43.51 MPa, the failure deformation is 4.01mm, and the elastic modulus is 3.83 GPa; the hoop compressive strength of GRP fiber is 149.84 MPa, the failure deformation is 3.91mm, and the elastic modulus is 10.76 GPa; the glass fiber The compressive strength of glass fiber is 72.67 MPa, the failure deformation is 3.76 mm, and the elastic modulus is 4.82 GPa; the compressive strength of sand layer is 38.13 MPa, the failure deformation is 5.74 mm, and the elastic modulus is 1.79 GPa.

For the spiral wound GRPM pipe, the difference between the hoop and axial compressive strength and elastic modulus is not significant; the hoop compressive strength and elastic modulus of fiberglass are much larger than that of the axial; and the compressive strength and elastic modulus of the sand layer are relatively small.

CONCLUSION

GRPM pipe is a new composite material, the pipe wall is composed of layers in the thickness direction. According to this characteristic, the influence of each layer of GRPM pipe on the overall properties of the composite pipe is studied, and the compression tests of single material layer and composite material layer are carried out respectively. The conclusions are as follows:

For the spiral wound GRPM pipe, the values of circumferential and axial compressive strength are similar, but the circumferential elastic modulus is slightly larger than the axial elastic modulus. Due to the manual operation in the winding process, the uniformity of the material itself is poor, so the dispersion coefficient of the compressive strength results is slightly larger. Because the extensometer and displacement sensor of the test equipment cannot be used, the dial indicator used in the elastic modulus test is installed manually to level the sample for testing. Each sample is greatly affected by the human environment factors, and the instrument error leads to a large discrete coefficient of elastic modulus measurement but increasing the number of tests to take the average value can reduce the error of the test results.

From the failure state of the sample, it can be seen that the circumferential failure of the sample of the wound GRPM pipe is basically along the interface between layers, that is, the weak surface of the material of the wound GRPM pipe is generally the interface between layers, while the axial failure of the sample is more similar to the failure of the concrete sample, that is, along a certain sliding crack surface.

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