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Study on the Lateral Impact Behavior of FRP-concrete-steel Tube Composite Structure

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Abstract: *In this test, a 74mm diameter split type get-a-purkinson test device was used to impact the specimen. The relationship between the peak stress and the number of impacts, the air pressure and the thickness of FRP tube was studied by using the control variable method.The test results show that:Under the same air pressure, the elastic modulus of the specimen increases first and then decreases, and the peak stress decreases after the first impact, and then stays stable.The peak value of stress increases with the increase of air pressure. The increase of air pressure has a linear relationship with the peak value of stress.With the increase of FRP pipe thickness, the stress peak value will change greatly, and the stress peak value will increase more and more quickly with the increase of FRP pipe thickness.*

Keywords: *SHPB test system, Strain. Peak stress, FRP tube thickness, Pressure*

Fiber reinforced composites (FRP) are composites formed by winding, molding or pultrusion of reinforced fiber materials and matrix materials.

Scholars at home and abroad have done a lot of research on the mechanical characteristics and failure mechanism of FRP materials, and made a great breakthrough. Teng Jinguang [1] proposed a new composite column structure, which is a new material filled with concrete between steel pipe and FRP, namely FRP concrete steel pipe composite column.This material has many advantages, which is in line with the development direction of light weight, high strength and durability; We can learn from each other, give better play to the advantages of materials and avoid their own shortcomings; Reduce the use of concrete and reduce the self-weight of the composite structure; It is easy to manufacture, simplifies the construction process, and can be mass produced on a large scale. After the proposal, this material has attracted great attention.

Liang Lei [2] impacted the FRP confined concrete test block for many times and found that the impact times had little effect on the peak stress, indicating that the stability of FRP confined concrete test block was relatively good. Mingxue Liu [3] tested three specimens and studied the flexural properties of FRP concrete steel double-layer tubular members (dstms). The theoretical calculation formula of bending strength of dstms is proposed. The simplified formula of bending strength of dstms is obtained by test, simulation and theoretical analysis, and the three line moment curvature model is expressed as a function of bending stiffness of dstms section. Zou Miao [4] established the FRP concrete steel tube composite beam model by using the finite element software ABAQUS, and found that the void ratio has a great impact on the anti-riot performance of the composite beam. When the void ratio is 0.7, the impact mechanical performance of the composite beam is the best. Huo Jingsi [5] conducted a drop weight impact test to compare the failure mode and shear strength of non web reinforced reinforced concrete beams and FRP reinforced non web reinforced concrete beams. After FRP reinforced beams, the bearing capacity of each stage is improved. Liu Ye [6] used the finite element software ABAQUS and the orthogonal analysis method to study the effects of seven factors such as impact height and section size on the peak impact force and impact force platform value of the specimen.

In this paper, the control variable method is used to control the thickness and impact pressure of FRP pipe, and the impact tensile test is carried out on the specimen with a separated Hopkinson test device with a diameter of 74 mm. The stress-strain relationship under multiple impact tension, the relationship between peak stress and impact pressure, and the effect of FRP pipe wall thickness on peak stress were studied

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1. SHPB Test Theory and Specimen Fabrication

1.1. SHPB Test Device

A 74mm diameter split Hopkinson compression bar device was used in the test. A 74mm diameter split Hopkinson compression bar device was used in the test.

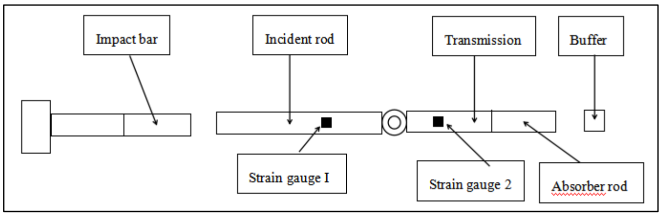

Figure 1: System diagram of SHPB test device

1.2. Experimental Theory

The SHPB compression bar experiment and the analysis of experimental results are based on two basic assumptions, which are as follows: (1) one dimensional stress wave hypothesis, that is, the strain waveform is known not only at the measuring point where the strain gauge is located, but also at other points on the bar. (2) Uniformity hypothesis, that is, the stress field and strain field in the specimen are uniform along the length of the specimen.

From the actual test experience, it is found that the assumption of uniform deformation is not completely correct under rapid loading. There are three kinds of materials used in the specimen, namely FRP pipe, concrete and steel pipe. In the splitting tensile test, the specimens are not uniform and the same material, and their elastic modulus and mechanical properties are different, so it is more difficult to realize the uniform deformation of the specimens. In order to reduce the influence of non-uniform stress, the average stress on the two interfaces is used to calculate the stress in the specimen. The experimental data are processed by three wave method [7]:

$$\dot{\varepsilon}(t) = \frac{C_0}{L_S}\left[\varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t)\right] \tag{1}$$

$$\varepsilon(t) = \frac{C_0}{L_S}\int_0^t \left[\varepsilon_i(t) - \varepsilon_r(t) - \varepsilon_t(t)\right] dt \tag{2}$$

$$\sigma(t) = \frac{EA}{2A_S}\left[\varepsilon_i(t) + \varepsilon_r(t) + \varepsilon_t(t)\right] \tag{3}$$

Where: A and as are the cross-sectional areas of compression bar and test piece; E. C0 is the elastic modulus and longitudinal wave velocity of compression bar material respectively; LS is the length of the test piece; ε i(t), ε r(t), ε T (T) is the incident strain, reflection strain and transmission strain of t at a certain time, and t is the duration of stress wave.

In order to reduce the impact of adverse factors on the test and obtain more accurate data. Adjust the height and angle of the incident rod and the transmission rod so that the axes of the impact rod, the incident rod and the transmission rod are on the same horizontal line. The end face of the contact between the impact rod and the incident rod is added with brass sheet flexible material to reduce the vibration, so as to reduce the dispersion effect [8, 9]. The contact surface between the test piece and the compression rod is coated with vaseline and other lubricants, which can greatly reduce the energy consumed by friction [10, 11].

1.3. Specimen Fabrication

Select the raw materials for making the test piece according to the design scheme. The inner diameter of the steel pipe is 30mm, the outer diameter is 32mm and 34mm respectively, and the height is 38mm. The outer diameter of FRP pipe is 74mm, and the inner diameters are 70mm, 68mm, 66mm and 64mm respectively. The height is 38mm. River sand with particle size of 0.3mm ~ 1.25mm shall be selected. The tap water from the laboratory of Anhui University of technology is selected. P0.42.5

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conch brand ordinary portland cement is selected. The designed mass ratio of concrete is cement: Sand: water = 1:1:0.4. And prepare relevant auxiliary equipment and equipment.

Make the test piece in strict accordance with the manufacturing process and relevant standards. Part of the test piece is shown in Figure 2.

Figure 2: Pictures of some test pieces

2. Results and Analysis

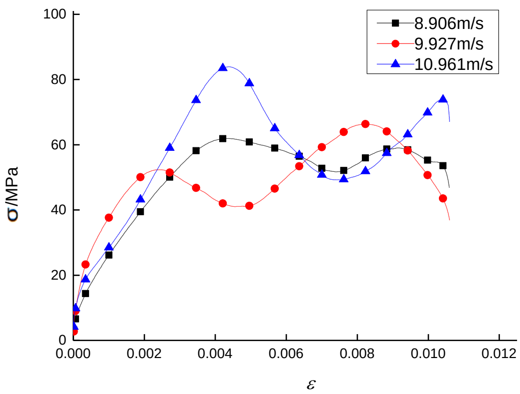
The basic parameters and test results of the test piece are shown in Table 1.

Table 1: Basic parameters and test results

NO	D/mm	ID/mm	H/mm	FRP Tube T/mm	Pa/MPa	V/m/s	σ /MPa
1	74.14	29.66	39.89	2	0.6	8.906	60.34
2	74.26	29.09	39.66	2	0.7	9.927	72.92
3	74.34	29.95	39.33	2	0.8	10.961	83.91
4	74.22	29.64	39.04	3	0.6	8.870	64.85
5	74.25	29.72	39.12	3	0.7	9.235	77.30
6	74.11	29.93	39.63	3	0.8	10.695	89.26
7	74.37	29.58	39.15	4	0.6	8.881	88.89
8	74.03	29.64	39.34	4	0.7	9.657	90.69
9	74.30	29.81	39.07	4	0.8	10.731	95.51
10	74.04	29.31	39.45	5	0.6	8.863	91.25
11	74.01	29.68	39.34	5	0.7	9.255	96.01

2.1. Typical Stress-Strain Curve

Under different test conditions, the stress-strain curve of the specimen is shown in Figure 3.



(1) Stress strain of FRP pipe with thickness of 2mm

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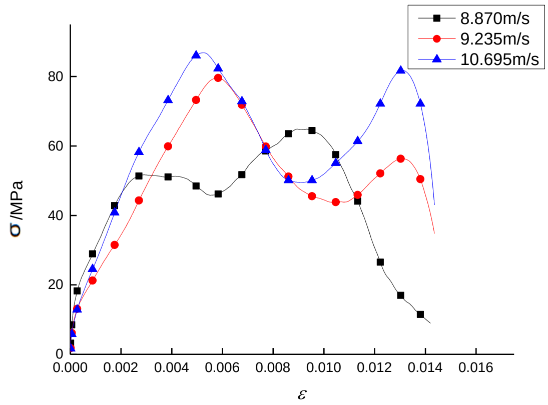
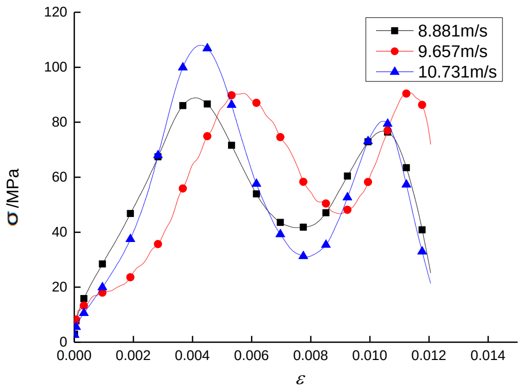
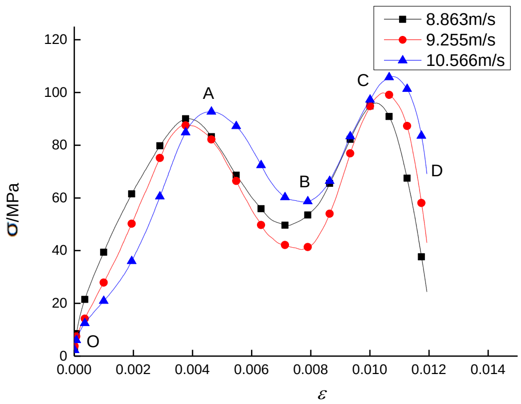


(2) Stress strain of FRP pipe with thickness of 3mm



(3) Stress strain of FRP pipe with thickness of 4mm



(4) Stress strain of FRP pipe with thickness of 5mm

Figure 3: Stress-strain curves at different speeds

It can be seen from the figure that the stress-strain curve images obtained by impact with different speeds and the stress-strain curve images obtained by impact with different FRP pipe thicknesses with the same air pressure show an "m" shape.

Select No. 12 specimen and mark the letters corresponding to the image of stress-strain curve. The stress process is divided into four sections. The analysis process is as follows:

(1) In the first stage of OA section, under the action of SHPB device, the specimen is extruded, the concrete is compacted, and FRP pipe, concrete and steel pipe work together. The specimen is further extruded under the action of incident rod and transmission rod, and the stress reaches the first wave peak, that is, point a.

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(2) In the second stage, in section AB, the concrete produces cracks and massive damage. Due to the damage of concrete, the FRP pipe and steel pipe are deformed, and the stress of the specimen decreases with the increase of temperature.

(3) In the third stage, in section BC, after falling to point B, the stress of the specimen is redistributed, and the stress of the specimen after re compaction rises again to point C of the second wave peak.

(4) In the fourth stage, after the CD segment reaches the peak value, due to the interaction of force, the rod and the specimen gradually disengage, and the stress also decreases in the process of disengagement.

It can be seen from Figure 3 that the change process of stress-strain curve at different speeds tends to be stable with the increase of FRP pipe thickness. This indicates that the impact velocity is not sensitive to the effect of thicker FRP pipes.

2.2. Velocity and Peak Stress

Fit the curve between the impact air pressure and the peak stress of the test piece, as shown in Figure 5.

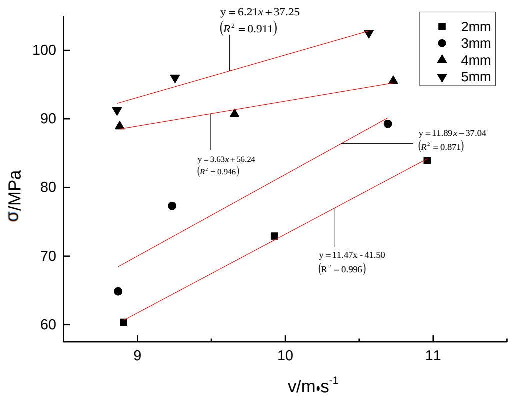

Figure 4: Relationship between peak stress and velocity

It can be seen from Figure 4 that the peak stress of the specimen increases with the increase of impact velocity, and there is a linear relationship between them. The increase of velocity makes the impact rod obtain greater velocity. Under the same conditions, the incident rod transmits more energy to the specimen, releases more

Energy in a short time and produces greater stress.

2.3. Stress and Wall Thickness

When the same air pressure impacts the specimens with different FRP pipe thickness, compare them between different air pressures, take the impact stress, and fit the curve between the thickness of the specimen and the impact stress. The fitting results are shown in Fig. 6.

It can be seen from the fitting curve in Figure 5 that the peak stress increases linearly with the increase of FRP pipe thickness. When the air pressure increases by 0.1MPa, the stress slows down with the increase of FRP pipe thickness.

From the mechanical analysis, FRP pipe has strong binding force. The increase of FRP pipe thickness enhances the binding ability of the specimen, the confining pressure increases, and the peak stress of the material increases with the increase of confining pressure [12, 16]. From microscopic analysis, voids are caused by uneven and insufficient mixing in the process of concrete production. From the nature of the material itself, the cementitious material of FRP pipe makes the distance between molecules closer than. When impacted, the buffer distance between molecules is relatively close, which will increase the stress. Therefore, the increase of FRP pipe thickness will increase the peak stress.

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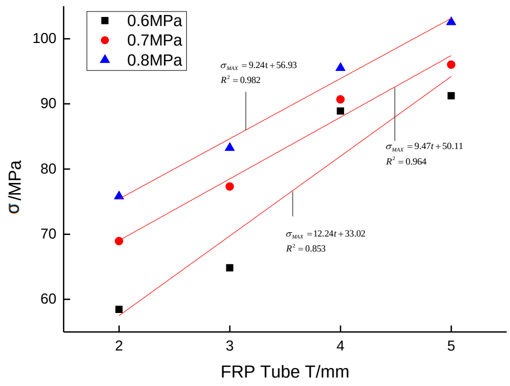


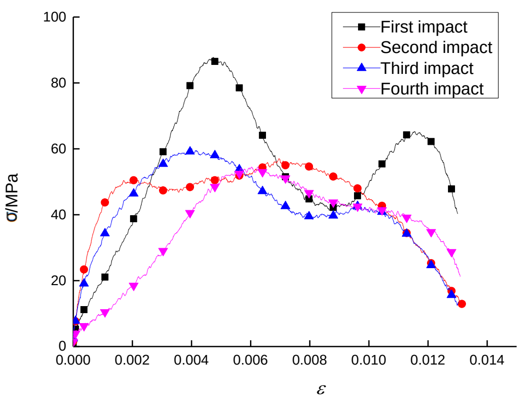
Figure 5: Curve relationship between FRP pipe thickness and stress

2.4. Stress-strain of Multiple Impact

The impact splitting test is carried out under the same conditions. The test pieces with wall thickness of 2mm, 3mm, 4mm and 5mm are used respectively. The test pieces are impacted four times with the same air pressure of 0.8MPa. The data obtained are processed. The test results of multiple impacts are shown in Table 2. The obtained stress-strain curve is shown in the figure below. For test piece 15, the third impact data is lost due to instrument reasons.

Table 2: Basic number of multiple shocks

NO	Impact times	FRP Tube T/mm	V/m/s	P/MPa
13	1	2	10.431	87.80
	2	2	10.213	57.05
	3	2	10.314	60.12
	4	2	10.326	54.57
14	1	3	10.695	100.65
	2	3	10.213	108.97
	3	3	10.096	83.74
	4	3	10.082	
15	1	4	10.731	95.77
	2	4	10.082	89.77
	3	4	10.773	103.82
	4	4	10.757	123.43
16	1	5	10.566	105.41
	2	5	10.832	94.56
	3	5	10.142	115.63
	4	5	10.199	114.44



(a) Stress-strain curve of FRP pipe with thickness of 2mm under multiple impact

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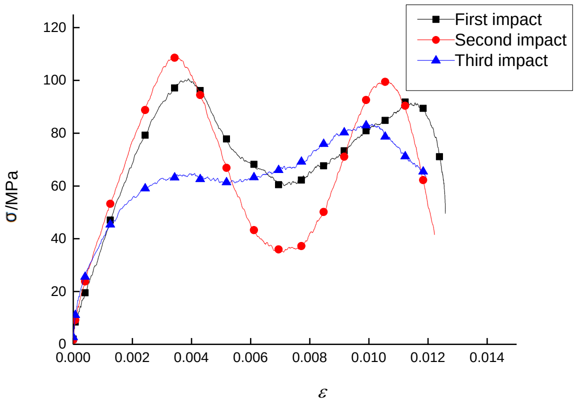
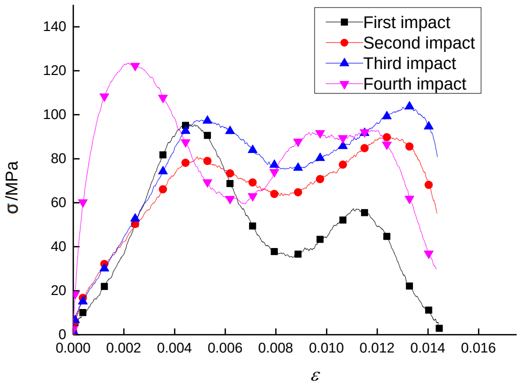
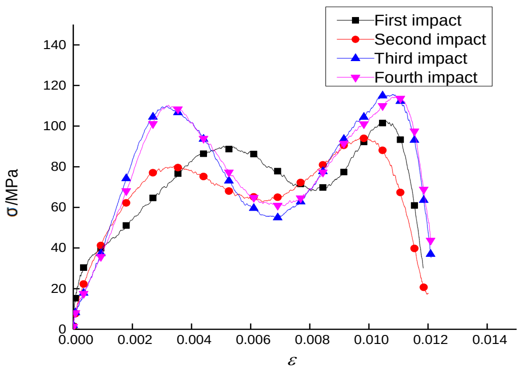


(b) Stress-strain curve of FRP pipe with thickness of 3mm under multiple impact



(c) Stress-strain curve of FRP pipe with thickness of 4mm under multiple impact



(d) Stress-strain curve of FRP pipe with thickness of 5mm under multiple impact

Figure 6: Stress-strain curve under multiple impact

It can be seen from Figure 7 that after the first impact on the specimen, the stress of the specimen is significantly reduced, and the stress of the specimen remains basically unchanged after the second, third and fourth impact. This is because after the specimen is impacted by 0.8MPa air pressure, the steel pipe and FRP pipe deform and the concrete cracks occur; After impact, the specimen reaches a stable state, so the stress will not decrease.

It can be seen from Fig. 7 ~ 10 that with the increase of the thickness of FRP pipe, the ability of the specimen to bear impact load is gradually strengthened. After four impacts, the stress of the specimen with relatively thick FRP pipe changes little, and the stress-strain curve is in the shape of "m". This shows that the thicker the FRP pipe is, the less sensitive it is to the impact times, and the FRP pipe has strong stability.

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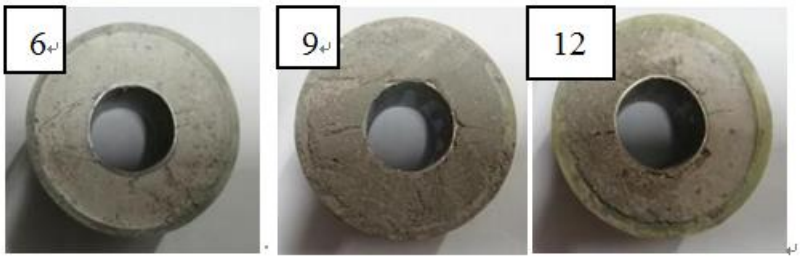
2.5. Crushing Form

For the previously impacted test blocks, select No. 1, No. 2 and No. 3 test blocks to impact with 0.6MPa, 0.7MPa and 0.8MPa air pressure respectively, and observe the failure mode under different air pressure. No. 3, No. 6, No. 9 and No. 12 specimens were impacted with 0.8MPa air pressure, and the failure modes under different FRP pipe wall thicknesses were observed. The crushing form is shown in Figure 7.

(1) Crushing morphology at 0.6MPa
(2) Crushing morphology at 0.7Mpa
(3) Crushing morphology at 0.8Mpa



(6) FRP pipe wall thickness 3mm, broken shape
(9) FRP pipe wall thickness 4mm, broken shape
(12) FRP pipe wall thickness 5mm, broken shape

Figure 7: Crushing form of test piece

As can be seen from Fig. 11, the increase of air pressure increases the cracks and broken block objects of the test block. Under the impact of high pressure, the concrete in the test block produces more cracks and fragments. Combined with the stress-strain curve under multiple impacts, the concrete is damaged after the first impact and is in triaxial compression under the constraints of FRP pipe and steel pipe [17-19], and the specimen still has relatively high resistance and is in a stable state. With the increase of FRP pipe thickness, the damage degree of concrete in the specimen decreases gradually, which indicates that FRP pipe has strong ability to resist impact load damage. FRP pipe restraint has a good protective effect on concrete [17].

3. Conclusion

(1) The peak stress increases with the increase of impact pressure and FRP pipe thickness, and there is a strong linear relationship between them.

(2) The confining pressure increases with the increase of FRP pipe thickness, and the stress increases with the thickness of FRP pipe. When the air pressure increases by 0.1MPa, the stress decreases with the increase of FRP pipe thickness.

(3) The bearing capacity of FRP concrete steel tube specimen is not completely lost after four impacts, and it still has high bearing capacity. With the increase of FRP pipe thickness, the bearing capacity of the specimen is improved. The specimen with FRP pipe thickness of 5mm experiences multiple impacts, and the change of stress and strain is small. FRP pipe has strong stability.

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