Experimental Study on Ring Stiffness of Cable Conduit

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Abstract. Ring stiffness is an important factor in the construction and design of buried cable conduit, which determines whether the pipe can resist external forces for a long time. This paper focuses on the experimental study of the ring stiffness of cable conduit. The ring stiffness tests of chlorinated polyvinyl chloride (CPVC) and modified polypropylene (MPP) under different conditions are carried out to verify the influence of thickness and temperature on the ring stiffness of pipe. The test results show that both thickness and temperature have a significant effect on the ring stiffness of pipe. At the same time, the influence of temperature on the ring stiffness of different materials is different, and the possible reasons are analyzed. The conclusion of the experiment has guiding significance for the quality inspection and practical application of cable conduit.

1. Introduction
With the rapid growth of power load and the requirements of urban planning, power supply by overhead lines alone cannot meet the demand of power supply [1]. At the beginning of this century, the country made a major plan for urban development, and buried all the power and communication lines over the city, such as cobweb, underground [2], which led to the requirement of power cable to the ground [3].

In traffic, road and bridge engineering, urban street lamp and other cable laying, cable protection pipes are usually used. The cable conduit has good safety and reliability, which plays a good role in protecting the cable. It can greatly reduce the cable failure caused by external force damage and extend the service life of the cable. At the same time, the construction area is small, and the construction period is short, so it is convenient and simple. It can also be embedded in advance to solve the problem of multiple construction and road breaking [4].

Buried cable conduit has the comprehensive properties of high strength, high temperature resistance, high flame retardant and high insulation, aging resistance and corrosion resistance. At present, chlorinated polyvinyl chloride (CPVC) and modified polypropylene (MPP) thermoplastic conduit are commonly used at home and abroad.

The buried cable conduit shall bear the weight of soil and the static load generated by the ground, as well as the dynamic load generated when the transport vehicle passes. An important index is the resistance to external pressure load capacity, which is usually expressed by the ring stiffness in the world. In practical engineering application, once the ring stiffness index of plastic pipe is unqualified, it will directly affect the engineering quality and service life [5].

The ring stiffness of cable conduit refers to the ability of cable conduit to resist deformation under load, which is the key parameter to reflect the mechanical properties of cable conduit. At present, the research on the ring stiffness of plastic conduit mainly focuses on how to select the appropriate ring
stiffness in engineering design [6], and the influence of pipe material on the ring stiffness [7], and the influence of line load on the ring stiffness [8], and the requirements for the ring stiffness under different environmental conditions [9], and the technical key points in trenchless laying construction [10-11], etc. In these studies, the ring stiffness is used as a variable parameter to meet different needs, there is no research on whether the ring stiffness itself will change, and how to change. When XLPE insulated cable (10kV) works normally, the allowable operating temperature is 90 ℃ [1], and the cable conduit around it is bound to be affected. The Vicat softening temperature of CPVC conduit is 93 ℃ and that of MPP conduit is 150 ℃. So when the ambient temperature is high, whether the ring stiffness of cable conduit will be affected and whether it still has good load resistance is a problem worthy of discussion.

In this paper, CPVC and MPP cable conduit are systematically tested, and the influence of different sizes and temperatures on the ring stiffness is analyzed. The test conclusion is of guiding significance for the detection and application of the ring stiffness of cable conduit of these two materials.

2. Definition and measurement of ring stiffness

In order to obtain, check and guarantee pipe parameters (external pressure resistance load) easily in practical production and application, a numerical index named "ring stiffness" is introduced internationally.

2.1. Definition of ring stiffness

The international standard ISO defines the ring stiffness S as follows (see iso9967):

\[ S = \frac{EI}{D^3} \]  

Where \( E \) is the elastic modulus of the material, and \( I \) is the moment of inertia. \( D \) is the average diameter of the pipe, and the unit of ring stiffness \( S \) is kN/m².

Theoretically, these three values must be known before the design and calculation of buried plastic conduit. In principle, if the design is based on these three values, the pipes provided by the manufacturer should guarantee these three values. However, these three values are not easy to obtain in practice. First of all, the elastic modulus of pipes is not easy to measure, and the elastic modulus of raw materials with different brands and proportions will vary greatly. In addition, the moment of inertia of the longitudinal section of the pipeline is difficult to calculate, and the change of the structure size (such as thickness) will cause the obvious change of the moment of inertia. Moreover, after the design is determined, it is unrealistic for the manufacturer to ensure that all three values remain the same.

2.2. Measurement of ring stiffness

The value of ring stiffness \( S \) in production can be obtained by the actual measurement of the pipe. The method has been standardized, which is the international standard ISO 9969. China's national standard GB/T 9647 "Thermoplastics pipes—Determination of ring stiffness" is equivalent to ISO 9969.

The national standard GB/T 9647 is simple to measure the ring stiffness. According to the required method, compress a section of pipe between two parallel plates, and measure the force \( F \) when the pipe diameter deformation reaches 3%, then the ring stiffness of pipe can be calculated according to the following formula:

\[ S = \left( 0.0186 + 0.025Y / d \right) \frac{F}{LY} \]  

\[ Y = 0.03d \]  

Where, \( F \) is the force value (kN) relative to 3% deformation of the pipe, and \( L \) is the length of the sample (m). \( Y \) is the deformation amount (m), and \( d \) is the inner diameter (m). It is a typical material mechanics problem to compress the pipe section between two parallel plates. It can be proved by the
analysis method of material mechanics that the deformation, force and the parameter of pipe ring stiffness have a clear relationship expressed by the above formula.

At present, the ring stiffness index is widely used in the world to express the external pressure resistance capacity of plastic buried pipe. With this index, it is not necessary to know the exact values of elastic modulus $E$, moment of inertia $I$ and pipe radius $r$, but only to know the value of ring stiffness $S$, which can be obtained through the actual measurement of pipes.

3. Experiment

3.1. Experiment preparation
The first is the selection of test objects. In this experiment, three specifications of MPP and two specifications of CPVC are selected based on the production practice of Shandong power grid, which basically covers the common models of Shandong power grid. Among them, the inner diameters of three kinds of MPP pipes are 100mm, 175mm and 200mm respectively, and the thicknesses are 8mm, 14mm and 16mm respectively. The inner diameters of two kinds of CPVC pipes are 50mm and 100mm respectively, and the thicknesses are 4mm and 5mm respectively.

Then, the test equipment includes electronic tensile machine, air aging box, extensometer, vernier caliper, etc., and all of them have passed the measurement verification. Finally, before the test, the samples were prepared according to the standard method and stored at room temperature ($20^\circ C$) for more than 24 hours.

3.2. Influence of thickness on ring stiffness
Some manufacturers do not strictly control the thickness in the production process of conduit, which leads to the difference of conduit thickness with the same inner diameter specification. In order to study the influence of thickness on ring stiffness, two sets of tests are set up in this section. In the first group of tests, the other parameters of the pipe were kept unchanged, only the thickness of the pipe was changed, and the change of the ring stiffness was measured. In order to be representative, the most commonly used MPPΦ175 pipe is selected here. The test results are shown in Table 1.

It can be seen that when the inner diameter is constant, the pipe ring stiffness increases significantly with the increase of thickness, and the relationship between the ring stiffness and thickness is nearly linear, as shown in Figure 1.

| Internal diameter(mm) | Thickness(mm) | Ring stiffness(kPa) |
|----------------------|--------------|--------------------|
| 175                  | 13.8         | 41.7               |
| 175                  | 14.0         | 43.4               |
| 175                  | 14.5         | 47.2               |
| 175                  | 15.4         | 58.6               |
In the second group of tests, it was noted that the ratio of the inner diameter to the thickness of three different specifications of MPP pipes was the same (100/8 = 175/14 = 200/16), that is, with the increase of the inner diameter, the thickness of the pipes increased equally. All three types of MPP pipes are selected for comparison, and the changes of ring stiffness are measured when the thickness ratio of inner diameter is constant. The results are shown in Table 2.

Table 2. The change of ring stiffness of three kinds of MPP pipes

| Specifications | Internal diameter(mm) | Thickness(mm) | Ring stiffness(kPa) |
|----------------|-----------------------|---------------|--------------------|
| MPP Φ100       | 100                   | 8             | 44.8               |
| MPP Φ175       | 175                   | 14            | 46.2               |
| MPP Φ200       | 200                   | 16            | 50.5               |

It can be seen that for MPPΦ100, MPPΦ175 and MPPΦ200 pipes, when the ratio of the inner diameter to the thickness is constant, with the increase of thickness, the ring stiffness only slightly increases, basically remains unchanged. For CPVC pipes, due to the different ratio of inner diameter to thickness, it is impossible to do comparative experiments.

3.3. Effect of temperature on ring stiffness

According to operation and use experience, the maximum allowable working temperature of XLPE insulated cable for a long time is 90 ℃ for 10kV and below and 80 ℃ for 20kV and above. The maximum allowable temperature for a short time (lasting for 5S) is 250 ℃. The cable conduit is generally made of thermoplastic material, which will soften under high temperature. The Vicat softening temperatures of CPVC and MPP pipes are 93 ℃ and 150 ℃, respectively.

In order to study the influence of cable heating on the "ring stiffness" of conduit during normal operation, this section selects all two specifications of CPVC pipes and three specifications of MPP pipes to conduct ring stiffness tests at 20 ℃, 50 ℃ and 80 ℃ respectively, with a total of five groups of comparative tests. Each group of tests were repeated three times to measure the average value of the ring stiffness and calculate the ratio of the ring stiffness at 50 ℃ and 80 ℃ to the ring stiffness at room temperature (20 ℃). The test results of the five groups are shown in Table 3, Table 4, Table 5, Table 6 and Table 7 respectively.

Table 3. Relationship between ring stiffness and temperature of CPVCΦ50 conduit

| Temperature(℃) | Ring stiffness(kPa) | Proportion |
|----------------|--------------------|-----------|
| 20             | 106.76             | 100%      |
| 50             | 90.50              | 84.77%    |
| 80             | 60.69              | 56.85%    |
Table 4. Relationship between ring stiffness and temperature of CPVCφ100 conduit

| Temperature(℃) | Ring stiffness(kPa) | Proportion |
|----------------|--------------------|------------|
| 20             | 37.70              | 100%       |
| 50             | 29.21              | 77.48%     |
| 80             | 14.62              | 38.78%     |

Table 5. Relationship between ring stiffness and temperature of MPPφ100 conduit

| Temperature(℃) | Ring stiffness(kPa) | Proportion |
|----------------|--------------------|------------|
| 20             | 45.55              | 100%       |
| 50             | 31.96              | 70.16%     |
| 80             | 21.62              | 47.46%     |

Table 6. Relationship between ring stiffness and temperature of MPPφ175 conduit

| Temperature(℃) | Ring stiffness(kPa) | Proportion |
|----------------|--------------------|------------|
| 20             | 41.70              | 100%       |
| 50             | 31.65              | 75.90%     |
| 80             | 18.47              | 44.29%     |

Table 7. Relationship between ring stiffness and temperature of MPPφ200 conduit

| Temperature(℃) | Ring stiffness(kPa) | Proportion |
|----------------|--------------------|------------|
| 20             | 56.76              | 100%       |
| 50             | 36.17              | 63.72%     |
| 80             | 33.55              | 59.11%     |

It can be seen from the above table that temperature has a great influence on the ring stiffness of CPVC pipe and MPP pipe. Compared with room temperature, for CPVCφ50, the ring stiffness decreases to 84.77% at 50 ℃, 56.85% at 80 ℃; for CPVCφ100, the ring stiffness decreases to 77.48% at 50 ℃, 38.78% at 80 ℃; for MPPφ100, the ring stiffness decreases to 70.16% at 50 ℃, 47.46% at 80 ℃; for MPPφ175, 75.90% at 50 ℃, 44.29% at 80 ℃; for MPPφ200, the ring stiffness decreases to 63.72% at 50 ℃ and 59.11% at 80 ℃. See Fig. 2 for the reduction of ring stiffness of all five specifications of pipes affected by temperature.
Figure 2. Reduction of ring stiffness of all five specifications of pipes affected by temperature

It can be seen from Fig. 2 that with the increase of temperature, the ring stiffness of the five specifications of pipes decreases significantly, especially when the temperature is close to the normal working temperature (90 ℃), the ring stiffness will drop to about half of the value at room temperature. Among them, the ring stiffness of CPVC φ 100 decreased the most, only 38% of the original.

Comparing CPVC and MPP, it can be seen that compared with MPP pipe, the ring stiffness of CPVC pipe does not decrease significantly at 50 ℃ (the ring stiffness of CPVC pipe is about 80% of the original, while that of MPP pipe is about 70%), but it decreases significantly at 80 ℃ (CPVC is about 40%, while MPP is about 50%). It is speculated that this is because the Vicat softening temperature of CPVC is lower than that of MPP (93 ℃ and 150 ℃, respectively). When the temperature is close to the Vicat softening temperature of CPVC, the CPVC pipe softens rapidly, resulting in a significant decrease in the ring stiffness.

In addition, comparing Table 4 and Table 5, it can be seen that the ring stiffness of MPP is higher than that of CPVC for pipes of two materials with the same inner diameter, whether at normal or high temperature, which indicates that MPP can bear greater external load and is more suitable for underground use.

4. Conclusion

In this paper, the ring stiffness tests of CPVC and MPP cable conduit with different thickness and temperature are carried out to verify the influence of thickness and temperature on the ring stiffness of cable conduit with different materials. The following conclusions can be drawn from the experiment, for the thermoplastic cable conduit:

- If the inner diameter is constant, the greater the thickness is, the greater the ring stiffness is; if the ratio of the inner diameter to the thickness is constant, the greater the inner diameter is, the ring stiffness is basically unchanged;

- With the increase of temperature, the ring stiffness of CPVC pipe and MPP pipe will decrease obviously; because the Vicat softening temperature of MPP pipe is higher than that of CPVC pipe, the temperature has more influence on the ring stiffness of CPVC pipe in the process of rising from normal temperature to cable operating temperature;

- For CPVC pipes, when the temperature is close to Vicat softening temperature, the ring stiffness will be significantly reduced. So CPVC can't bear the situation of overheating for a long time;

- For two kinds of pipes with the same inner diameter, the ring stiffness of MPP pipe is higher than that of CPVC pipe at room temperature or high temperature, so MPP pipe is more suitable for deep buried areas.

The experimental results are of great significance to the measurement of the ring stiffness of the two kinds of cable conduits and the application of the two kinds of pipes in the production.
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