Experimental Study on Performance Parameters of Power Cable Conduits of Chlorinated Polyvinyl Chloride

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Abstract. Chlorinated polyvinyl chloride (CPVC) pipes are used more and more widely as protective conduits in the field of power cables. According to the application characteristics in the field of cables, there are special requirements for the performance parameters of CPVC pipes. In this paper, several key performance parameters such as CPVC pipe size inspection, ring stiffness, longitudinal retraction rate, vicat softening temperature, density and flattening test are selected, and the theoretical research of the test method is carried out. On the basis of theoretical research, the difference between the dimensional inspection, the ring stiffness, the longitudinal retraction rate, the density and the vicat softening temperature parameters of the unqualified sample and the qualified sample are compared. It is found that the unqualified samples of the flattening test have relatively poor compressive performance, and the longitudinal plasticity stability under the influence of the heat source is also relatively poor. Moreover, when the sample size is unqualified, it directly affects the compressive performance of the sample. Through the research results, it provides the necessary reference for the application of CPVC pipes in the field of power cables.

1. Introduction
With the acceleration of the pace of urbanization in the country, the diversification of urban functions, the increase in electricity consumption, and the continuous transformation of urban power cables into the ground, the power cable lines of various voltage levels have been rapidly increasing every year[1]. The high-voltage power cable conduit has been widely used in the laying of power cable lines because of its high temperature resistance, aging resistance, high mechanical strength and excellent electrical and flame-retardant properties [2]-[3].

At present, there are many types of conduits for power cables, including: cable conduits of chlorinated polyvinyl chloride (CPVC) and unplasticized polyvinyl chloride (PVC), double wall corrugated cable conduits of chlorinated polyvinyl chloride and unplasticized polyvinyl chloride, cable conduits of fiber cement, cable conduits of fiberglass reinforced plastics, cable conduits of socket type precast concrete and cable conduits of modified polypropylene (MPP)[4]. Among them, CPVC is a modified product obtained by further chlorination of PVC, which has the advantages of corrosion resistance, aging resistance, flame retardance, smoke resistance, dielectric properties and mechanical properties. And with the price advantage of other thermoplastic engineering plastics, the application of power cable lines is also more and more extensive [5]-[6].

However, the quality level of cable chlorinated polyvinyl chloride (CPVC) pipes is uneven, and the quality of a considerable number of pipes is not stable. The material has the disadvantages of poor tensile strength, low bending strength, low softening point of micro-card, and poor processing.
performance [7]. It poses certain safety hazards for its application in power cables. To this end, it is necessary to study the cable chlorinated polyvinyl chloride conduit performance test method to effectively evaluate the performance and quality of the protection tube.

Chlorinated polyvinyl chloride pipes are used as power cable protection conduits. According to the characteristics of laying underground power cables, CPVC pipes are required to have high mechanical strength and heat resistance, as well as good corrosion resistance, pressure resistance, electrical insulation and sealing. In this paper, the performance parameters such as size inspection, ring stiffness, longitudinal retraction rate, Vicat softening temperature, flattening test and density of CPVC pipe were selected, and the detection methods were studied.

2. The appearance and size inspection
The visual inspection of the CPVC conduit is carried out by visual inspection and hand contact. The inner and outer walls of the conduit are not allowed to have bubbles, cracks and obvious cracks, depressions, impurities, discoloration and color defects. The inner wall of the catheter should be smooth and flat. The end face of the pipe should be cut flat and perpendicular to the axis. The outer wall of the socket end should be chamfered when it is processed. The drafting angle of no more than 1° is allowed during the processing of the socket end, and there is no deflection phenomenon.

The nominal length of the conduit is expressed in terms of effective length, the distance from the end of the socket to the bottom of the socket. The nominal length deviation is the effective length (0 ~ 0.5%). The nominal inner diameter of the conduit, the inner diameter of the socket, and the nominal wall thickness are measured by tools such as steel rulers and wall thickness micrometers. The allowable deviation should meet the standard size requirements [4].

3. The physical property test
3.1. The ring stiffness test
Ring stiffness is an important indicator of CPVC ducting and characterizes the ability of CPVC ducts to withstand external pressure loads. The test preparation and test methods are as follows.

A straight line is drawn along the axial direction of the outer surface of the pipe to be tested as a mark, and then three samples a, b, and C are respectively taken, and both ends of the sample should be vertically cut. The average inner diameters $d_{ia}$, $d_{ib}$, $d_{ic}$ of the three samples a, b and c were measured, and the average value $d_i$ of the three values was calculated [8]:

$$d_i = \frac{d_{ia} + d_{ib} + d_{ic}}{3}$$  \hspace{1cm} (1)

First, place three samples in an (80±2) °C oven for 1 hour, and then take them out. Place the sample a in the ring stiffness tester so that the marking line is in contact with the upper plate, and the other two samples b, c are placed at a position rotated by 120° and 240° with respect to the sample a. Lower the plate until it touches the upper part of the sample, apply a load including the mass of the plate, and compress the sample at a constant rate until a deformation of at least 3% $d_i$ is reached. Then, the loop stiffness of the conduit is expressed as follows:

$$S = \left(0.0186 + 0.025 \frac{y}{d} \right) \frac{F}{Ly} \times 10^6$$  \hspace{1cm} (2)

In the above formula, $F$ is the load when the deformation is 3% with respect to the pipe, and the unit is kN. $L$ is the length of the sample, the unit is mm. $y$ is the amount of deformation when deformed relative to 3% of the pipe, and the unit is mm. which is $\frac{y}{d} = 0.03$. $S$ is the ring stiffness of the sample, and the unit is kN/mm².
3.2. The longitudinal retraction rate test

Longitudinal retraction rate is an important indicator for the mechanical properties of CPVC ducts. This paper chooses to use the oven for longitudinal retraction rate test. Take three samples from a marked pipe and place them at ambient temperature (23±2) °C for not less than 2 hours, and measure the line spacing at this temperature as $L_0$. Adjust the oven temperature to 150±2°C, place the sample on a flat plate with talcum powder, and then take it out in the oven for a specified period of time [9]. When it is completely cooled to (23±2) °C, measure the maximum or minimum distance between the sample surface along the bus line as $L_1$. The expression of the longitudinal retraction rate of the sample is as shown in the Formula (3).

$$ R_L = \frac{\Delta L}{L_0} \times 100 $$

(3)

$$ \Delta L = |L_0 - L_i| $$

(4)

In the formula, $L_0$ is the distance between two lines of the sample before being placed in the oven, the unit is mm. $L_i$ is the distance between the two marking lines measured along the busbar after taking out the oven, the unit is mm.

Then the longitudinal retraction rate $R_L$ of the catheter can be expressed as:

$$ R_L = \left( R_{L1} + R_{L2} + R_{L3} \right) / 3 $$

(5)

3.3. The Vicat softening temperature test

The Vicat softening temperature is one of the indicators for evaluating the heat resistance of the material and reflecting the physical and mechanical properties of the sample under heat. The higher the Vicat softening temperature of the power cable conduit, the better the dimensional stability of the material when it is heated, that is, the better the heat deformation resistance.

Cut the sample to a prescribed size and pretreat it for 5 minutes at a temperature lower than the Vicat softening temperature of 50°C. Then place the sample concave up and place it horizontally under the pressure pin of the unloaded metal rod. Adjust the temperature of the heating bath to less than 50 °C, and place the sample in a heating bath. After the needle is positioned for 5 minutes, apply a pressure of (50 ± 1) N to the sample, and adjust the dial gauge for measuring the depth of the needle to zero. Heat the heating bath at a constant rate of (50±5) °C per hour. When the needle is pressed into the sample (1± 0.01) mm, record the temperature at this time, which is the Vicat softening temperature of the sample. In general, the standard requires that the Vicat softening temperature of the CPVC pipe should be not less than 93 °C [10].

3.4. The flattening test

The CPVC conduit flattening test is a test method for testing the deformation performance of a catheter to a specified size and showing its defects. After pressing to the specified size, there is no crack or other defect in the deformation of the pipe, which is considered qualified. The test method is as follows. Take pipe length samples of length (300±10) mm from the outside of the pipe socket. Both ends of the sample shall be cut flat and perpendicular to the axis. Place the sample horizontally between the upper and lower plates of the flattening tester, and compress the sample at a speed of (10 ± 2) mm/min. When the amount of deformation in the vertical direction is 30% of the original inner diameter of the sample, remove the load immediately. Observe the sample for cracks or other defects. If there is a defect, judge it that the sample flattening test is unqualified.
3.5. The density test

CPVC conduit density parameters usually reflect changes in the physical structure or composition of the material. There are three methods for measuring density: impregnation, liquid pycnometer, and titration. In this paper, the dipping method was chosen to test the density of CPVC pipes.

First, weigh the quality of the sample suspended by the wire having a diameter of not more than 0.5 mm in the air and record it. The dip is selected from fresh distilled or deionized water at a temperature of (23±2)℃. Then, place the sample suspended with a thin wire in a beaker filled with the immersion liquid. After removing the bubbles adhering to the sample with a fine wire, record the mass of the sample in the immersion liquid. Finally, the density of the sample is calculated according to Formula (6) [11].

\[
\rho = \frac{m_A \times \rho_{IL}}{m_A - m_{IL}}
\]  

In the above formula, \(\rho\) is the density of the sample at 23 ℃, and the unit is g/cm\(^3\). \(m_A\) is the mass of the sample in air, and the unit is g. \(m_{IL}\) is the performance quality of the sample in the immersion liquid, and the unit is g. \(\rho_{IL}\) is the density of the immersion liquid at 23 ℃, and the unit is g/cm\(^3\).

4. Analysis of test results

CPVC ducts are used as power cable protection conduits. According to the characteristics of underground power cables, CPVC ducts are required to have high mechanical strength. Therefore, in this paper, seven samples ruptured after the flattening test and 15 samples qualified after the flattening test were selected for testing. To investigate whether there are significant differences between the two samples in terms of dimensional inspection, ring stiffness, Vicat softening temperature, longitudinal retraction rate, and density. The test results are shown in Table 1 and Table 2.

Table 1. Test results of ruptured samples after flattening test.

| Number | Dimensional inspection | Ring stiffness (kPa) | Vicat softening temperature (℃) | Longitudinal retraction rate (%) | Density (g/cm\(^3\)) | Flattening test |
|--------|------------------------|---------------------|---------------------------------|---------------------------------|-----------------------|-----------------|
| 1      | Unqualified            | 13.0                | 94.0                            | 3.5                             | 1.30                  | Rupture         |
| 2      | Unqualified            | 14.3                | 95.0                            | 2.0                             | 1.30                  | Rupture         |
| 3      | Unqualified            | 14.3                | 94.0                            | 4.0                             | 1.30                  | Rupture         |
| 4      | Unqualified            | 12.4                | 94.9                            | 1.6                             | 1.57                  | Rupture         |
| 5      | Qualified              | 12.4                | 94.2                            | 3.1                             | 1.54                  | Rupture         |
| 6      | Qualified              | 12.4                | 93.6                            | 1                               | 1.51                  | Rupture         |
| 7      | Qualified              | 12.7                | 93.5                            | 1.1                             | 1.54                  | Rupture         |
| Average value | /            | 13.071              | 94.171                          | 2.329                           | 1.437                 | /               |
According to the test results in Table 1, the four performance parameters of ring stiffness, Vicat softening temperature, longitudinal retraction rate and density can meet the standard requirements in the seven samples of ruptured after the flattening test. However, four of the sample size inspections did not meet the standard requirements. This indicates that about 57.1% of the sample size of the flattened test rupture sample does not meet the requirements. When the sample size does not meet the requirements, it can directly affect the compressive performance of the sample.

It can be seen by comparing the test results of Table 2 and Table 1. The average value of the sample ring stiffness parameters of the flattened test rupture is 4.5% lower than the qualified sample after the flattening test. The average value of the Vicat softening temperature parameter of the sample ruptured by the flattening test is 0.1% higher than that of the qualified sample after the flattening test. The average value of the longitudinal retraction rate of the sample ruptured by the flattening test is 15.3% higher than that of the qualified sample after the flattening test. The average value of the sample density parameters of the flattened test rupture is 0.6% higher than the qualified sample after the flattening test. Therefore, the following conclusions can be drawn. Compared with the qualified sample, the difference between the average values of ring stiffness, Vicat softening temperature and density of the fractured sample after flattening test is less than 5%. It can be considered that there is no significant difference between the two parameters in terms of these three parameters. However, there are significant differences between the longitudinal retraction rate parameters. The average longitudinal retraction rate of the flattened test rupture sample is significantly higher than that of the qualified samples. It is indicated that the longitudinal plasticity stability of the flattened test rupture sample under the influence of heat source is worse and it is easily deformed by heat.

### Table 2. Test results of qualified samples after flattening test.

| Number | Dimensional inspection | Ring stiffness (kPa) | Vicat softening temperature (℃) | Longitudinal retraction rate (%) | Density (g/cm³) | Flattening test |
|--------|------------------------|---------------------|---------------------------------|---------------------------------|-----------------|----------------|
| 1      | Qualified              | 16.0                | 94.0                            | 3.5                             | 1.50            | Qualified      |
| 2      | Qualified              | 14.0                | 97.0                            | 3.5                             | 1.10            | Qualified      |
| 3      | Qualified              | 14.0                | 97.0                            | 3.5                             | 1.20            | Qualified      |
| 4      | Qualified              | 12.5                | 94.1                            | 2.1                             | 1.56            | Qualified      |
| 5      | Qualified              | 13.5                | 93.5                            | 1.4                             | 1.46            | Qualified      |
| 6      | Qualified              | 14.0                | 93.5                            | 2.1                             | 1.50            | Qualified      |
| 7      | Qualified              | 13.0                | 94.2                            | 1.0                             | 1.47            | Qualified      |
| 8      | Qualified              | 13.1                | 93.6                            | 1.9                             | 1.48            | Qualified      |
| 9      | Qualified              | 13.9                | 93.2                            | 1.8                             | 1.43            | Qualified      |
| 10     | Qualified              | 13.6                | 93.1                            | 1.6                             | 1.43            | Qualified      |
| 11     | Qualified              | 13.5                | 94.1                            | 0.8                             | 1.53            | Qualified      |
| 12     | Qualified              | 13.9                | 94.1                            | 1.1                             | 1.44            | Qualified      |
| 13     | Qualified              | 13.4                | 93.1                            | 1.7                             | 1.43            | Qualified      |
| 14     | Qualified              | 13.1                | 93.5                            | 1.9                             | 1.47            | Qualified      |
| 15     | Qualified              | 13.4                | 93.1                            | 1.7                             | 1.43            | Qualified      |
|        | Average value          | /                   | 13.660                          | 94.073                          | 1.973           | 1.428          |
5. Conclusion

Based on the theoretical study of CPVC conduit size inspection, ring stiffness, longitudinal retraction rate, Vicat softening temperature, flattening test, density and other performance parameters, this paper conducts specific experimental analysis. By comparing the difference between the size inspection, the ring stiffness, the longitudinal retraction rate, the Vicat softening temperature and the density performance parameters of the ruptured sample and the qualified sample after the flattening test, the following conclusions were drawn:

(1) If the CPVC pipe fails to pass the dimensional inspection, it can directly affect the compressive performance of the pipe and must be paid enough attention.

(2) The longitudinal retraction rate of the rupture test sample is higher than that of the qualified sample, and its longitudinal plasticity stability under the influence of the heat source is worse and it is easily deformed by heat.

(3) The flattened test rupture samples did not differ significantly from the qualified samples in terms of ring stiffness, Vicat softening temperature, and density parameters.

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