Performance Parameter Analysis of Power Cable Modified Polypropylene (MPP) Conduit

Weiwei Zhang*, Ying Lin, Yuhui Liu, Haochen Wang and Chenrui Guo
State Grid Shandong Electric Power Research Institute, Jinan250002, China

*E-mail address: weiwei.1302@163.com

Abstract. Modified polypropylene (MPP) conduits are increasingly used as protection conduits for trenchless power cables. In order to ensure the performance and quality of MPP conduits used in the field of power cables, this article has carried out research on its performance parameters and test methods. First of all, in view of the problem of excessive deviation of the MPP conduits appearance and size inspection, the relationship between the conduits wall thickness and the mechanical performance ring stiffness parameter was studied. Then, through the MPP conduits density, ring stiffness, Vicat softening temperature, and flattening test results, the correlation between the three parameters of density, ring stiffness, and Vicat softening temperature is analyzed. It also concluded that the ring stiffness and Vicat softening temperature have a moderate positive correlation. Finally, the article compares some similarities and differences between the MPP conduit and the CPVC conduit for two power cable protection conduits in terms of performance parameter test items.

1. Introduction
In recent years, the urban electrification process in our country has been accelerating, and the transmission of urban electric energy has been changed from an overhead open line to an underground pipeline. This has caused many problems for the protection of power cables in the city. First, municipal pipelines such as urban water supply and drainage pipelines, communication pipelines, thermal pipelines, and gas pipelines are intricate. Such a complex underground environment requires that the cable protection duct should not only be resistant to corrosion, high temperature, and high pressure, but also have reliable connection performance, impact resistance, and aging resistance. Secondly, when power cables pass through various types of buildings, traffic roads, urban downtown areas and other places that are not suitable for excavation, in order to reduce the damage to the surrounding environment and the impact on people’s daily lives. The laying and repair of power cables should not try to dig the ground. Finally, in order to ensure the reliability of urban power supply in response to various conditions of urban stratum changes and ground vibrations, cable protection conduits should have good resistance to ground settlement and earthquake resistance. The above problems all put forward more stringent requirements on the selection and performance of power cable conduits [1-6].

In order to ensure the effective transmission of urban electric energy, various protective conduits are used for power cables, mainly including modified polypropylene (MPP) plastic conduits, carbon corrugated pipes, chlorinated polyvinyl chloride (CPVC) and hard polyvinyl chloride (PVC) plastic pipes, plastic-coated steel pipes, fiber cement pipes, etc. Among them, the modified polypropylene (MPP) plastic cable conduit has many advantages compared with other cable protection conduits.
These advantages include no need for excavation construction, hot-melt welded joints with high strength, good toughness, over-length high-traction towing pipe, good anti-settlement and seismic performance, good tensile and compressive resistance, and high and low temperature resistance, etc. These advantages effectively solve the above problems of high-voltage power cable laying. Modified polypropylene conduit makes the promotion of trenchless laying of power cables possible. It does not affect the urban environment, reduces repeated excavation of the urban ground, and can withstand high temperatures, pressure shocks, and corrosion, ensuring the safety and reliability of power cable engineering [7].

Due to the wide application of MPP conduit trenchless power cable laying, this puts forward higher requirements on the performance parameters of modified polypropylene conduit. For this reason, it is necessary to study the performance parameter detection test of the MPP conduit of the power cable to effectively evaluate the performance and quality of the conduit. This article analyzes the performance parameters of cable MPP conduits such as appearance size, density, Vicat softening temperature, and ring stiffness, and studies the difference between MPP conduits and CPVC conduits in performance testing and parameters.

2. Appearance and size inspection
The visual inspection and dimensional measurement of the MPP conduits should be tested in accordance with the requirements of the standard. Check whether the inner and outer walls of the conduits have cracks, depressions and other defects that affect the use, and whether the inner diameter and wall thickness of the conduits meet the requirements[8]. In addition, it is also necessary to measure the maximum and minimum outer diameters of the same cross section of the conduits to calculate whether the out-of-roundness meets the requirements.

At present, the quality of power cable MPP conduits is not stable, and dimensional inspection projects often have problems with excessive deviations in inner diameter and wall thickness. Select 40 catheters with unqualified size inspection. After statistical analysis, it was found that the deviation of the wall thickness and inner diameter of 70% of the samples exceeded the standard value. Among them, 97.5% of the samples had too thin wall thickness, 47.5% of the catheter had too large inner diameter, and 25% of the catheter had too small inner diameter. Therefore, in the MPP catheter size inspection, the wall thickness is too thin is a relatively common problem. Therefore, in the MPP catheter size inspection, the wall thickness is too thin is a more prominent problem.

When the thickness of the conduit wall is too thin, it will inevitably affect the mechanical properties of the conduit. Taking the ring stiffness parameter of the MPP catheter as an example, 36 qualified samples with wall thickness and 36 unqualified samples with too thin wall thickness were selected. The ring stiffness test results of the two types of samples are shown in Figure 1.

![Figure 1. The ring stiffness test results.](image-url)
According to the ring stiffness test results, the average value of the ring stiffness parameter of the qualified wall thickness sample is about 59.7 kPa, and the average value of the ring stiffness parameter of the unqualified sample whose wall thickness is too thin is about 46.5 kPa. This shows that when the thickness of the conduit wall is too thin, it will lead to a decrease in the stiffness index of the catheter ring, which directly affects the ability of the conduit to resist the external pressure load. If the ring stiffness is too small, the conduit may undergo excessive deformation or buckling. This will directly threaten the safety and reliability of the power cable for MPP conduits applied in trenchless power cable protection. Therefore, in the inspection of the appearance and size of MPP conduits, the measurement of wall thickness is very important and should be paid enough attention.

3. Physical performance test

The physical performance tests of MPP conduits mainly include inspection items such as density, Vicat softening temperature, ring stiffness, flattening test, and drop weight impact. The density test can reflect to a certain extent whether the chemical composition of the conduit meets the requirements. Vicat softening temperature measurement can reflect the physical properties of the conduit under heating conditions. The power cable conduit needs to be heated for a long time. The higher the Vicat softening temperature, the better the heat-resistant deformation ability of the conduit. The ring stiffness, flattening test and drop weight impact test mainly reflect the physical properties of the conduit against external pressure, deformation and external force impact. These parameters are very important indicators for trenchless cable protection conduits buried in the ground for a long time and squeezed by external forces.

In order to study the MPP conduit physical performance parameter test and the correlation between various parameters, the MPP conduit was tested and analyzed. In this paper, 33 MPP conduit samples were selected, and the samples were tested for density, Vicat softening temperature, ring stiffness and flattening. The test results are shown in Table 1:

| Number | Density(g/cm³) | Ring stiffness (kPa) | Vicat softening temperature(℃) | Flattening test |
|--------|---------------|----------------------|-------------------------------|----------------|
| 1      | 0.90          | 54                   | 151.5                         | Qualified      |
| 2      | 0.90          | 67                   | 152.5                         | Qualified      |
| 3      | 0.91          | 60                   | 150.5                         | Qualified      |
| 4      | 0.90          | 66                   | 150.5                         | Qualified      |
| 5      | 0.92          | 47                   | 150.4                         | Qualified      |
| 6      | 0.91          | 63                   | 151.1                         | Qualified      |
| ...    | ...           | ...                  | ...                           | ...            |
| 30     | 0.91          | 72                   | 156.0                         | Qualified      |
| 31     | 0.90          | 63                   | 150.9                         | Qualified      |
| 32     | 0.89          | 45                   | 150.0                         | Qualified      |
| 33     | 0.90          | 64                   | 155.0                         | Qualified      |

In order to analyze the relationship between the MPP sample density, Vicat softening temperature, and ring stiffness, whether there is a certain correlation between the parameters, a correlation coefficient is used for analysis. The calculation formula is:

\[ \delta(x, y) = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} \]  
(1)
In the formula, $x$ is the parameter 1 sample value, $y$ is the parameter 2 sample value, $\bar{x}$ is the average value of parameter 1 sample, and $\bar{y}$ is the average value of parameter 2 sample.

The range of $\delta(x, y)$ is between -1 and 1. The closer $|\delta(x, y)|$ is to 0, the smaller the correlation between $x$ and $y$, and the closer $|\delta(x, y)|$ is to 1, the greater the correlation between $x$ and $y$.

3.1. Density and ring stiffness

Bring the density and ring stiffness parameters of the MPP samples as $x$ and $y$ into the formula (1). The correlation coefficient of the two is $\delta_1 = 0.094$. $\delta_1$ is close to 0. It can be seen that the density of the MPP conduit has little correlation with the ring stiffness, and it can be considered that the size of the sample density is not related to the ring stiffness.

3.2. Density and Vicat softening temperature

Bring the density and the Vicat softening temperature parameters of the MPP sample as $x$ and $y$ into the formula (1). The correlation coefficient of the two is $\delta_2 = -0.262$. The density of the MPP conduit is negatively correlated with the Vicat softening temperature, that is, the greater the density, the lower the Vicat softening temperature. But $\delta_2 < 0.3$, the relationship between the two parameters can be considered as weak correlation.

3.3. Ring stiffness and Vicat softening temperature

Bring the ring stiffness and the Vicat softening temperature parameters of the MPP sample as $x$ and $y$ into the formula (1). The correlation coefficient of the two is $\delta_3 = 0.368$. The ring stiffness of the MPP conduit is positively correlated with the Vicat softening temperature, that is, the greater the ring stiffness, the greater the Vicat softening temperature. $0.3 \leq \delta_3 \leq 0.7$. The two parameters have a medium positive correlation. Plot the scatter diagram of the ring stiffness and Vicat softening temperature parameters of the sample as shown in Figure 2. It can be seen from Figure 2 and the correlation coefficient $\delta_3$ that the ring stiffness of the MPP catheter has a certain positive correlation with the Vicat softening temperature, but the correlation is not strong.

![Figure 2. Scatter plot of ring stiffness and Vicat softening temperature.](image)

4. Comparison of performance test between MPP conduit and CPVC conduit

CPVC is a modified variety obtained by further chlorination of PVC. With its excellent corrosion resistance, aging resistance, good dielectric strength and good mechanical properties, its application in
Conduits for power cable protection also occupy an important position. Unlike cable modified polypropylene conduits, cable CPVC conduits are mainly used under roads, across highways, railways and buildings, substation entry and exit sections, and bridge supports. Although both are used as protective conduits for power cables, the difference in performance parameters between the two results in different applications, and of course there are differences in performance test methods [9] [10].

### Table 2. MPP conduit and CPVC conduit comparison table.

| Number | Test item                        | CPVC                          | MPP                                    |
|--------|----------------------------------|-------------------------------|----------------------------------------|
| 1      | Appearance and size inspection   | Should meet the requirements of the standard[5]. | Should meet the requirements of the standard[5]. |
| 2      | Density                          | ≤1.60 g/cm³                   | (0.90~0.94) g/cm³                      |
| 3      | Ring stiffness (3%)              | Test at 80 °C                 | Test at (23±2)°C                       |
| 4      | Flattening test                  | Apply load until the vertical deformation of the sample is 30% of the original inner diameter. | Apply load until the vertical deformation of the sample is 50% of the original inner diameter |
| 5      | Vicat softening temperature      | ≥93°C                         | ≥150°C                                 |
| 6      | Longitudinal retraction rate     | ≤5%                           | NO                                     |
| 7      | Drop weight impact test          | Impact test at room temperature | The sample shall be kept at (-5 ± 1) °C for at least 8h, and the impact test shall be completed within 30s after taking out. |
| 8      | Coefficient of sliding friction  | NO                            | ≤0.35                                  |
| 9      | Tensile strength, elongation at break, bending strength | NO                            | YES                                   |

By comparing the performance test methods of MPP conduit and CPVC conduit in Table 2, we can see that there are similarities and differences between the two in terms of performance testing.

#### 4.1. The similarities

Both of these cable protection conduits need to be tested for appearance and size, density, ring stiffness, flattening test, Vicat softening temperature, drop weight impact, etc. The appearance size inspection and density test methods are basically the same, but the test methods of other test items are somewhat different.

#### 4.2. The differences

In terms of ring stiffness, CPVC conduits need to put the sample in an oven at (80±2)°C for one hour, and then take the sample out of the oven for 2 minutes to complete the test. The ring stiffness grades are usually SN8, SN12, SN16 [8]. However, the ring stiffness test of the MPP conduit needs to be performed under the condition of (23±2)°C. The ring stiffness grades are usually SN24, SN32, and SN40 [11].

In the Vicat softening temperature test, the CPVC conduit requires that the temperature of the heating bath be adjusted to 50°C lower than the softening temperature of the sample to maintain a constant temperature. At this time, the sample is placed in it, and the total pressure of the needle on the sample is (50±1)N [12]. MPP conduit sample requires that when the heating bath temperature is (20~23)°C, put the sample into it, the total pressure of the pressure needle on the sample is (10±0.2)N [13].
In terms of the drop weight impact test, the CPVC conduit requires an impact test at room temperature. However, before the impact test of the MPP conduit, the sample needs to be placed in a low-temperature test box (-5±1)°C for at least 8 hours, and the impact test should be completed within 30 seconds after the sample is taken out [9].

In terms of test items, CPVC conduits require longitudinal shrinkage test, while MPP conduits add test items for tensile strength, elongation at break, bending strength, and sliding friction coefficient.

5. Conclusion
This article studies the relationship between the performance parameters of cable MPP conduit size, density, Vicat softening temperature, ring stiffness, etc. The similarities and differences between MPP conduits and CPVC conduits in performance testing and parameters are analyzed. Finally, the following conclusions are drawn:

(1) In the dimension measurement project, it is found that when the wall thickness of the MPP conduit is too thin, it will cause the ring stiffness index of the conduit to decrease, which directly affects the conduit's ability to resist external pressure load.

(2) In the physical property parameter test of the MPP conduit, it was found that the density parameter of the MPP conduit has little correlation with the ring stiffness and Vicat softening temperature. The ring stiffness and Vicat softening temperature parameters have a medium positive correlation, but the correlation is not strong.

(3) MPP conduits and CPVC conduits have certain similarities in the test items. However, the two have obvious differences in the test methods of the ring stiffness, Vicat softening temperature, and drop weight impact test items, and it is necessary to pay attention to the distinction during the test.

References
[1] Zhenghua Zhang, Aidi Cai, Hua Chen. Modified polypropylene pipe for high-voltage power cable protection. Metallurgy and materials. 2019, 39(6):129-132.
[2] Guofeng Tian, Ao Fu, Zhentian Yang, Likun Tian. Preventing the External Force Damage of Urban Power Cable. Shandong Electric Power. 2014, 41(04):66-68.
[3] Bin Chen, Shuai Li, Ziyang Li. Laying Modes and the Effect on Safe Operation of High Voltage Cable Line with Large Size Conductor. Shandong Electric Power. 2015, 42(03):39-42.
[4] Pifan Qiao, Yu Zhang, Huaming Cao, Fenglu Li, Likun Wei. Research on the Installation Defects of 10kV Cable Joint. Shandong Electric Power. 2019, 46(07):33-37+65.
[5] Ping Zhang, Feng Chen, Daoxing Dai, Mingqing Zhong. Preparation and Property of modified polypropylene composites in trenchless pipe. New Building Materials. 2012, 39(06):77-81.
[6] Huiqiang Deng, Zifan Liu, Youbang Liang. Application progress of plastic pipes for trenchless laying. Shandong Chemical Industry. 2016, 45(18):47+49.
[7] Haiyong Sun, Zhe Wang, Dong Liu, Baqun Chen. Standard comparison analysis of trenchless modified polypropylene (MPP) cable sheath tube. China Standardization. 2019, (18):255-256.
[8] China. Technical requirements for electric cable conduits Part 1: General. DL/T 802.1-2007.
[9] China. Technical requirements for electric cable conduits Part7: trenchless cable conduits of modified polypropylene. DL/T 802.7-2010.
[10] China. Technical requirements for electric cable conduits Part3: Cable conduits of chlorinated polyvinyl chloride and unplasticized polyvinyl chloride. DL/T 802.3-2007.
[11] China. Thermoplastics pipes-Determination of ring stiffness. GB/T 9647-2015.
[12] China. Thermoplastics pipes and fitting-Determination of vicat softening temperature. GB/T8802-2001.
[13] China. Plastic-Thermoplastic materials-Determination of Vicat softening temperature(VST) . GB/T1633-2000.