Return to Session

Development of Pre-Molded Joint for 230kV XLPE Power Cable

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Abstract : Traditionally, Various cable joints including TMJ(Tape Molded Joint), TJ(Tape Wrapped Joint) and PJ(Prefabricated Joint) have been developed and used for XLPE cable. But Pre-molded joints that have significant advantages as less skill, less jointing time and quality control have been widely used lately. We already developed pre-molded joint for 154kV-class in 2004. Under the experience and technology, we succeeded development of pre-molded joint using silicone rubber for 230kV class and passed IEC type test in accordance with IEC standard 62067. All the tests were carried out successfully and proved that the new PMJ has quite high reliability for 230kV class XLPE cable.

Keyword : Silicone Rubber, 230kV, EHV XLPE cable, Pre-molded Joint

1. Introduction

Because of the growing of popularity in worldwide market of straight through joints for EHV XLPE cables in a wide range of voltage class recently, we have developed pre-molded joints up to 230kV voltage class with research on electrical and mechanical properties of material.

Pre-molded joints which are prefabricated and tested electrically in the manufacturing site have high quality reliability. For electrical test on the pre-molded rubber unit, we also have developed electrical test facilities. We have carried out routine test on the pre-molded joints at 2.5Uo/30min for AC withstand voltage and 1.5Uo for PD test.[4]

Silicone rubber has several advantages in mechanical and electrical properties in comparison with Ethylene-Propylene Rubber(EPR) as lower elasticity, lower permanent set and so on. And most manufactures of EHV cable joints are using silicone rubber for the pre-molded unit. So we adopted silicone rubber as insulation and electrode materials and studied mechanical and electrical properties of silicone rubber to apply it to our design prototype of pre-molded rubber unit.

We researched rubber injection process and curing process for silicone rubber with injection and curing analysis computer module. In this process, we found out expected defects like air gap, excoriation and so on in the pre-molded rubber unit and then revised the injection process and the curing condition to resolve the expected defects.

We studied the installation process for easier installation and shorter installation time and research inner mechanical stress and inner strains during installation with mechanical stress analysis module. When the rubber unit is installed on the cable, the interfacial pressure between rubber unit and cable insulation is very important parameter to guarantee electrical performance, so we studied the interfacial pressure properties using interfacial pressure analysis units developed by ourselves. The interfacial pressure analysis units consist of steel pipe to simulate outer diameter of the cable insulation, embedded pressure gauges and pressure analysis PC module.[3] As the result of mechanical analysis, we found that one pre-molded rubber unit is applicable to various cable sizes. (from 115% to 145% in expansion rate)

The electrical properties of the pre-molded joint are satisfied our target test voltage. We carried out AC withstand test, AC breakdown test and lightning Impulse withstand test and lightning impulse breakdown test several times. And we established the electrical design standard of silicone rubber unit.

This paper reports on the electrical and mechanical properties of silicone rubber unit, electrical characteristics of the pre-molded joint and type test result in accordance with IEC 62067.

2. Mechanical test on silicone rubber

Now, EPR and silicone rubber are mainly applied to pre-molded joints for the EHV underground cable. We adopted silicone rubber as insulation and electrode materials because silicone rubber was known to have several advantages in mechanical and electrical properties.

We studied the mechanical characteristics of insulation silicone rubber and semi-conductive silicone rubber, the research item consists of tensile strength, tear strength, permanent set and so on.

The result shows excellent mechanical properties of permanent set and elongation in comparison with EPR. See table 1.

Table 1. Material properties of silicone rubber

Item	insulation	conductive
Tensile strength [N/㎟]	4.0	6.0
Stiffness [Shore A]	40	40
Elongation at break [%]	500	650
Tear strength [N/㎜]	25	12

During insertion of pre-molded unit onto the cable, there are possibilities of occurrence of excoriation at the interface between insulation and conductive electrode. It could affect the degradation electrically. So we tested the adhesive property of silicone rubber that we adopted. The result is that the adhesive property between insulation and conductive material has excellent adhesive property. All ten test samples were torn at the insulation portion, not the interface. See figure 1.

Return to Session

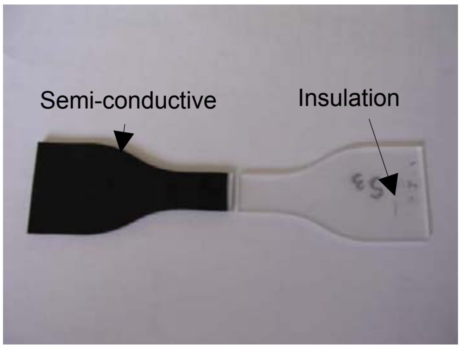


Figure 1. Test sample after adhesive property test

3. Design of Interfacial pressure.

Pre-molded joint is a kind of cable joint that keep the insulation property just by self elasticity of pre-molded rubber unit. So it is very important point to design interfacial pressure between pre-molded rubber unit and cable insulation preferentially.
In order to withstand electrical strength between pre-molded rubber unit and cable insulation, the interfacial pressure must keep sufficient pressure range.
The interfacial pressure consists of initial interfacial pressure and final interfacial pressure. Initial interfacial pressure means the pressure as soon as installation of pre-molded rubber unit onto cable and final interfacial pressure is the pressure after operation period of thirty years or forty years. It is known that in order to insure the electrical performance of PMJ, interfacial pressure must maintain more than 0.5 kg/mm^2.[2] Silicone rubber has excellent permanent set property, so if our pre-molded rubber blocks are designed 1kg/mm^2 in initial interfacial pressure, those could satisfy final interfacial pressure.
We tested an interrelation between interfacial pressure and breakdown voltage several times and then we established the interfacial pressure design standard.
Figure 2 shows the calculated interfacial pressure by means of a computer between pre-molded rubber unit and cable insulation along the whole length of pre-molded rubber unit.

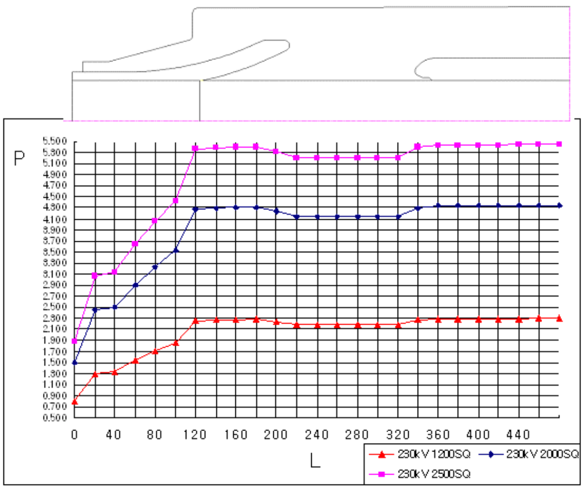


Figure 2. Interfacial pressure distribution

As a result of research on the discrepancy between calculated interfacial pressure and real interfacial pressure, we found some different points, however most of calculated interfacial pressure accord with real interfacial pressure.
Figure 3 shows the unit for checking the interfacial pressure.

Figure 3. Interfacial Pressure analysis unit

4. Electrical Design

In order to carry out electrical design of pre-molded joint, it is necessary to establish the target test voltage. The calculation procedure of target voltage is shown below.

1) AC Withstand Voltage

$V_{AC} = Um/\sqrt{3} \times K_1 \times K_2 \times K_3 = 245kV/\sqrt{3} \times 1.1 \times 2.83 \times 1.1$
$= 530kV$

Where, Um : Highest Voltage for equipment [kV],
K_1 : Thermal factor for AC,
K_2 : Aging factor
K_3 : Uncertainty factor or Safety factor

K_2 is calculated using the V-t curve characteristic for the material. The formula is below.

$K_2 = (30years \times 365days \times 24hours/test\ hours(1hr))^{1/n} = 2.83$

Assuming the life exponent(n) is 12.

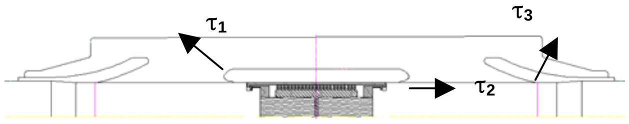
2) Impulse Withstand Voltage

$V_{imp.} = BIL \times K_1 \times K_2 \times K_3 = 1050kV \times 1.1 \times 1.1 \times 1.1$
$= 1{,}400kV$

Where, BIL : Base Impulse Level [kV],
K_1 : Thermal factor for Impulse,
K_2 : Degradation factor by repetition of impulse
K_3 : Uncertainty factor or Safety factor

In term of electric field distribution, it is optimized by means of adjust the shape of conductive electrode that is molded integrally with the insulation silicone rubber with a computer electric field analysis module. The designing features of pre-molded rubber units are limited to three key positions ($\tau_1 \sim \tau_3$).[1] See figure 4.
Figure 5. shows the result of electric field analysis by means of a computer program.

Return to Session



τ_1 : Tip of electrode
τ_2 : Interface between rubber unit and cable insulation
τ_3 : Edge of deflector

Figure 4. Electric field analysis model

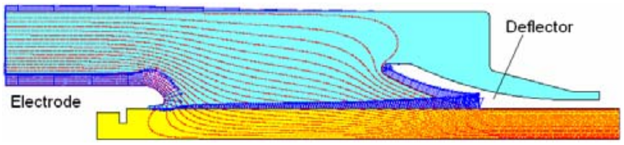


Figure 5. Result of electric field analysis

We could take expected breakdown voltage from the electric field analysis. Table 2 shows the result of calculation of expected breakdown voltage.

Table 2. Expected breakdown voltage of 230kV PMJ

Item	AC withstand voltage	Imp. withstand voltage
τ_1	705kV	-1520kV
τ_2	675kV	-1490kV
τ_3	720kV	-1540kV

5. Study on installation of pre-molded joint

There are several installation methods for pre-molded joint. We have studied all available installation methods and adopted and have used two kinds of installation. One is slip on method that rubber unit is slid on cable directly and another is using an expansion pipe which is split four pieces. We have selected one method according to cable construction or cable size and the condition of each construction site. See figure 6 and 7.

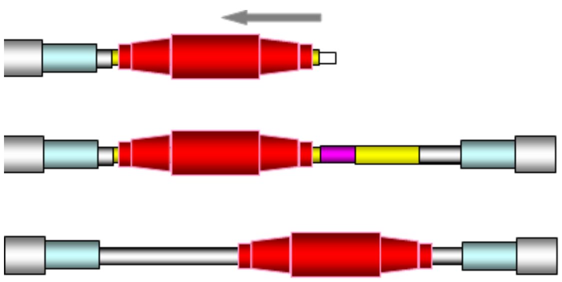


Figure 6. Schematics of slip-on installation method

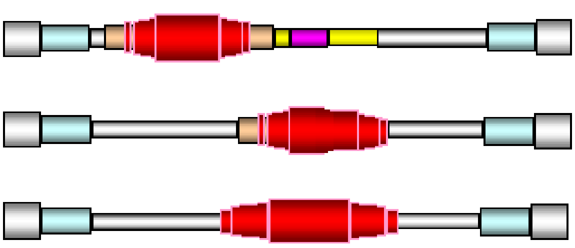


Figure 7. Schematics of expansion pipe method

6. Research on injection and molding process

To estimate and revise the injection quantity, pressure and position of compound inlet or ventilation point, we analyze injection properties and a mold shape by means of a computer simulation program. It is very important to prevent generations of air traps in the rubber unit, so it is necessary to decide proper position of ventilation and sufficient injection pressure. As the result, we decided to make three ventilation points to avoid expected air traps.
Curing time and temperature affect gel time and insulating properties of rubber unit, so it is very important to find and settle the ultimate curing time and temperature.
Figure 8, 9 and 10 show results of injection and curing analysis of rubber unit for 230kV XLPE cable.

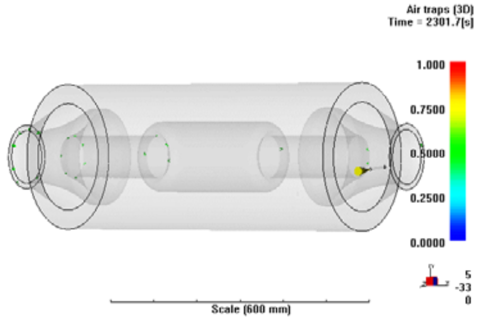


Figure 8. Expected positions of air traps

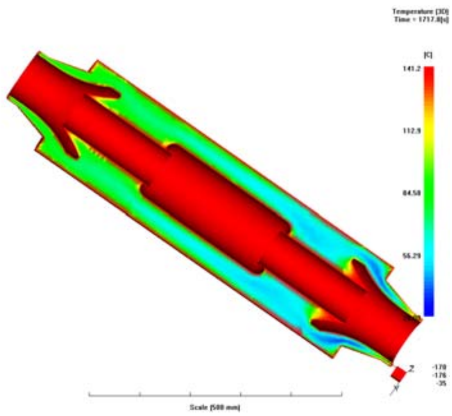


Figure 9. Temperature distribution during curing

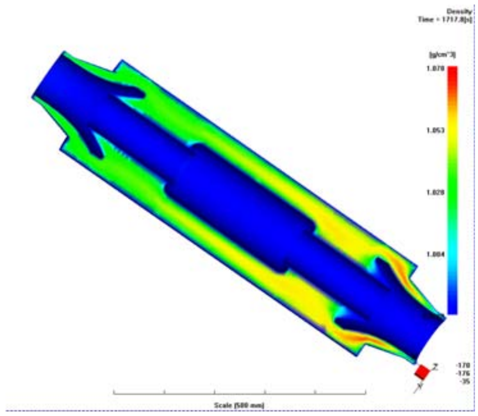


Figure 10. Density distribution during pressurizing

7. Development test of 230kV-class PMJ

We have developed 154kV-class PMJ and completed KEPCO type test in accordance with KEPCO standard in 2004. And we finished development test and IEC type test for 132kV-class PMJ with various cable sizes (300mm^2 ~1600mm^2). Under this background of technologies, we developed 230kV-class PMJ successfully without any serious problems.

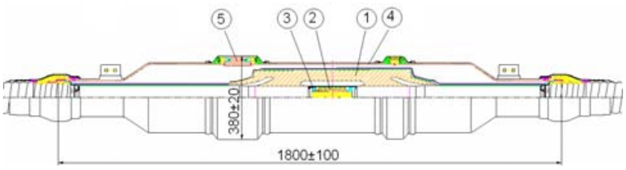
We carried out electrical tests for 230kV-class PMJ in accordance with the target withstand voltage which above-mentioned and then we acquired the electrical properties of 230kV PMJ. We found that the PMJ met all electrical performance required of IEC 62067.

The test conditions and the result of breakdown tests are shown in table 4.

Table 4. The result of development test

	AC voltage	Imp. voltage
Start voltage	430kV/1hr	±1050kV/10 times
Target voltage	530kV/1hr	±1400kV/10 times
Temperature	Ambient Temp.	Ambient Temp.
Set-up step	30kV/30min	±30kV/10 times
Breakdown voltage	620kV~670kV	1530kV ~ 1570kV

The structure and dimensions of 230kV-class PMJ are shown in figure 10.



1	Rubber Unit	4	Protecting tube
2	Conductor Sleeve	5	Insulating Flange
3	Corona Shield		

Figure 11. Schematic of PMJ for 230kV XLPE cable

8. Type test

After fulfilling development tests successfully, we completed IEC type test in accordance with IEC 62067 in the presence of KEMA in 2006. The test circuit consists of 230kV XLPE 1CX2500mm^2(23mm in thickness of insulation) cable, two outdoor terminations, two SF6 gas immersed sealing ends and two PMJ that one of two was equipped with a insulating flange. The test results are shown in table 5.

Table 5. Type Test results for 230kV XLPE cable & joint

Item	Test condition	Result
PD Test	190kV/5pC↓(Amb. Temp.)	Pass
Heat Cycle Test	254kV/20 Heat Cycles	Pass
PD Test	190kV/5pC↓ (Hot & Amb. Temperature)	Pass
Impulse withstand Test	±1050kV/10 times (Hot Temperature)	Pass
AC Voltage Test	254kV/15 minutes	Pass

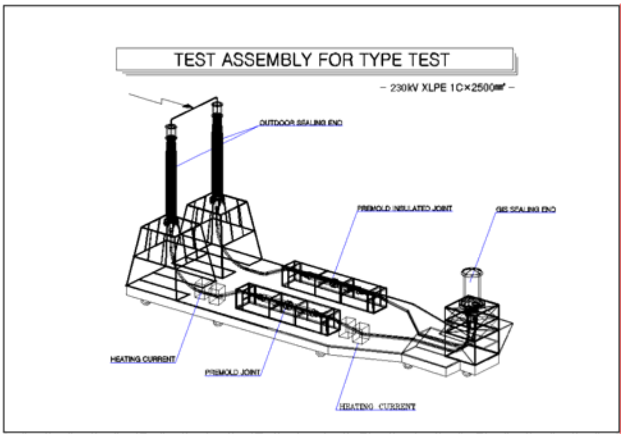


Figure 12. Schematic circuit for IEC type test

Along with electrical tests, we conducted the outer protection test in accordance with Annex D in IEC 62067 and completed the test without encountering any problems. See table 6.

Table 6. Test result of outer protection for buried joints

Item	Test Condition	Result
Heat Cycling	3 Cycles	-
Water immersion & Heat Cycling	20cycles/20℃↑ ~ 75℃↓	-
DC voltage test	20kV/1min.	Pass
Impulse Voltage Test(part to Earth)	±47.5kV/10 times	Pass
Impulse voltage Test(between parts)	±95kV/10 times	Pass

Figure 13. Test facility for outer protection test

9. IEC P.Q test

We started IEC P.Q test(Prequalification Test) in presence of KEMA on October, 2006. The test will complete this year. The test circuit consists of two lines of 230kV XLPE 1CX2500mm^2 cables which one line is buried directly and another is laid in the simulated power tunnel. The view of test circuit is shown in figure 14.

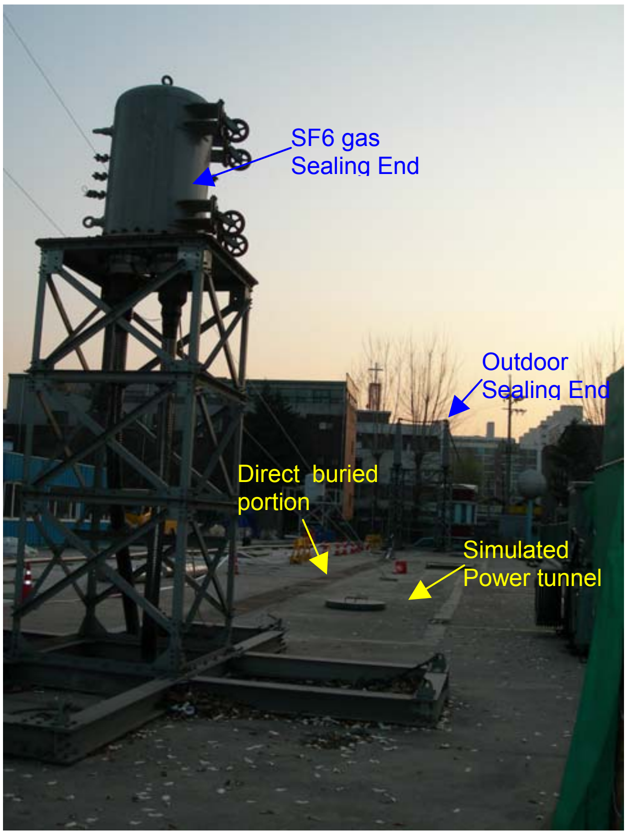


Figure 14. View of test circuit for PQ TEST

10. Conclusion

In conclusion, we have developed PMJ 230kV-class XLPE cable and prepared to supply PMJ to worldwide cable market. The electrical and mechanical performance verification test showed excellent results. We have already installed test lines and started IEC PQ test for 230kV-class XLPE cable. And we have completed IEC TYPE TEST for 400kV-class XLPE cable recently and now we are preparing to start IEC PQ test.

Using the advantage of less skill, short installation time, high performance reliability and cost reduction, we have dominated PMJ market up to 170kV-class gradually.

11. References

[1] Shozo Kobayashi et al; Jicable'03

[2] Hiroaki Susuki et al ; p.109, vol.20, Furukawa Review (2000)

[3] Akitoshi Watanabe et al ; p.60, Fujikura Technical Review(2001)

[4] IEC 62067, Edition 1.1[2006.03]

12. Glossary

PMJ : Pre-Molded Joint