Development of Waterproof Jacket Materials for Power Cables

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Abstract - This paper describes various characteristics of the new compounds for cable jackets and model cables advanced in waterproof performance in order to essentially solve the problems of underground (URD) distribution class power cable failures.

Several compounds were manufactured by the inclusion of additives to base resins available in Korea and tested for basic property, mechanical and electrical characteristics. Two model cables were created by using the compounds determined in the test as being the most appropriate for new structured model cable jacket material. The waterproof performance and mechanical strength of the new cable jackets were verified by applicable tests.

As a result, MDPE and LLDPE compounds were superior as cable jackets in both mechanical and electrical characteristic aspects when compared with conventional PVC. In addition, the model cables composed of the new compounds based on MDPE showed good quality results in the water permeability test.

Keywords: cable jacket, waterproof performance, mechanical and electrical characteristics

1. Introduction

Nowadays, CNCV-W type power cable is generally employed in 22.9[kV] class underground distribution lines. The research into URD power cables has been primarily focused on improving the insulating characteristics of main insulation (XLPE) and the ageing diagnosis so far [1-4]. While the performance of power cables has been advanced by previous research, the failure of URD power cables has never been reduced [5]. This is considered due to the fact that there can be other failure factors besides defects in main insulation. As a result of the failure analysis of power cables it was confirmed that water permeance through the power cables and irregular interface between the insulation and the semiconductive layer lead to a concentration in electric field, which causes frequent failure of the power cable. Out of the two failure factors the latter can be solved by better quality control during the manufacturing process however, the former needs more basic consideration for cable jacket materials.

The power cable jackets protect the insulation from water content and ionic impurities entering in from the outside. They also prevent external damage when laying the power cables underground and put a stop to corrosion of the neutral wires, by which the URD power cables can last up to their whole expected life. Considering the domestic environment in laying and operating work, it is clear that the water permeance through the cable jacket acts negatively on the normal operation. For this reason the power cables employing swelling tapes and waterproof compounds, etc. have been used to prevent water permeance into the URD power cables. However, in spite of the trial there have been continual failure events in waterproof typed power cables without exception and this is considered due to the fact that the water content permeates along the transverse direction (TX) rather than along the machine direction (MD). This hypothesis was born out by the submersion test in which the conventional PVC (polyvinyl chloride) cable jackets were very poor in mechanical strength and waterproof performance [6]. Therefore, new cable jacket materials more advanced in waterproof performance and mechanical strength were sought after to prevent the permeance of water content through the cable jacket.

In this study the most appropriate compounds for cable jackets were developed by some tests and applied to the two new structures advanced in waterproof performance. Countermeasures against water permeance through the cable jackets and the mechanical damage likely to result in burying and handling processes were ultimately devised.

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2. Test Arrangements and Procedures

2.1 Preparation of Base Resin Specimens

A total of six different types of commercially available

Table 1 Properties of base resins for cable jacket

physical property	test method	units	LLDPE		LDPE		MDPE	HDPE
			1	2	1	2		
melt index @ 190[℃], 2.16[kg]	ASTM D1238	g/10[min]	1.1	2.3	0.3	0.33	0.23	0.21
density @ 23[℃]	ASTM D1505	g/cm^3	0.921	0.921	0.923	0.92	0.935	0.942
tensile strength	ASTM D638	Mpa	20.0	20.7	18.9	18.4	34.5	34.8
tensile elongation	ASTM D638	%	836	872	593	684	860	865
DSC melting pt(annealed)		℃	125	126	114	112	128	131
flexural modulus	ASTM D790	Mpa	472.3	450.8	254.8	266.2	787	882
heat deformation @ 130±3[℃], 1[kgf]		%	13.5	12.7	-	-	9	8.5
Shore D hardness	ASTM D2240		49	48	48	49	56	60

polyethylene were selected as base resins to develop the compounds substitutive for the conventional PVC jacket. Some properties of the compounds tested are listed in Table 1.

2.2 Water Vapor Transmission (WVT) Test

In order to evaluate the waterproof characteristics of the base resins, the WVT test was carried out according to ASTM E96 [7]. The WVT rate indicates the continuous flow of water content through unit area of materials normally not over 32[mm] in thickness for unit time under specified temperature and humidity.

Two basic methods, the desiccant method and the water method, are provided for the measurement of permeance. In this study, the former is used because the water content permeates into the insulating layer through the cable jacket. In the case of the desiccant method the test vessel is placed under constant environmental conditions after the inlet of the test vessel enclosing the desiccant is sealed by each specimen. The degree of permeance of the water vapor, which travels to the desiccant through the specimen, is then determined by periodically measuring and comparing the weight of the test vessel.

A test vessel was specially made of aluminum lest erosion should occur. Fig. 1 shows the vessel for the WVT test.

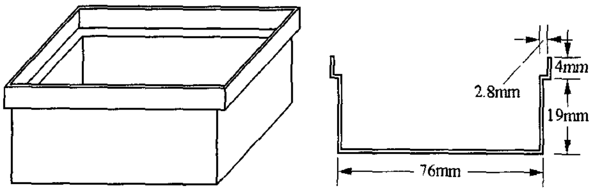


Fig. 1 Vessel for WVT test

As shown in Fig. 1, the test vessel was a square with a side of 76[mm] and the valid area of the test vessel thus became approx. 5,700[mm^2]. A height of the test vessel wall enclosing the desiccant was 19[mm]. For the facile sticking work and the distortion of the specimen, a ledge of 2.8[mm] and a rim of 4[mm] were taken into account on the top of the side wall, by which the water permeation through the interface between the test vessel and sticking of the specimen could be entirely prevented.

After granular $CaCl_2$ of 2~3[mm] in diameter was put in the test vessel as a desiccant, the specimen was stuck on the inlet of the vessel by way of sealant. Prior to placing the test vessel in a thermohygrostat its gross weight measurement was taken. According to the required standards, the temperature and the relative humidity in the thermohygrostat were set to 32± 0.6[℃] and 50± 2[%], respectively. The changes in temperature and humidity were automatically recorded and the atmosphere in the thermohygrostat was continuously convected. The gravimetry with testing time was periodically carried out by an electron balance that can weigh with an accuracy of 10^{-4}[g], and eight to ten data were acquired to calculate the WVT rate.

Pellet type raw materials were compressed at 180[℃] for 10[min] with a hot press, thus the specimens of 0.8[mm] in thickness were prepared.

The slope of the line consisting of gravimetric values was calculated and the WVT rate was calculated in accordance with Equation (1) below:

$$\text{WVT rate}[g/h*m^2] = G/tA = (G/t)/A \quad (1)$$

where, G means the gravimetric change on the line[g], t the testing time[h], G/t the slope of the line[g/h], A the area of test vessel inlet[m^2].

2.3 Abrasion and Cut-through Resistance Test

The distribution class power cable may be mechanically damaged during work. The degree of damage depends on the hardness of the cable jacket. For this reason abrasion and cut-through resistance tests are required. The weight loss due to abrasion of the base resins for the cable jacket was measured according to ASTM D3389-94[8]. Prior to the early weight measurement each specimen of 3 [mm] in thicknesses was sheared in a circular shape of approx. 110

[mm] in diameters and punctured at its center. Each specimen was fixed by a clamp of a holder on a rotary platform, double head (RPDH) abrader and then revolved at the rate of 70[rev/min] under constant pressure with two abrasive wheels also revolving. After 500 revolutions, weight measurement was carried out. Each test was repeated two times and abrasion resistance was calculated by Equation (2).

$$\text{abrasion resistance[mg/rev]} = \frac{w_1 - w_2}{n_r} \qquad (2)$$

where, w_1 means the weight before abrasion test[mg], w_2 the weight after abrasion test[mg], n_r the number of revolutions [rev].

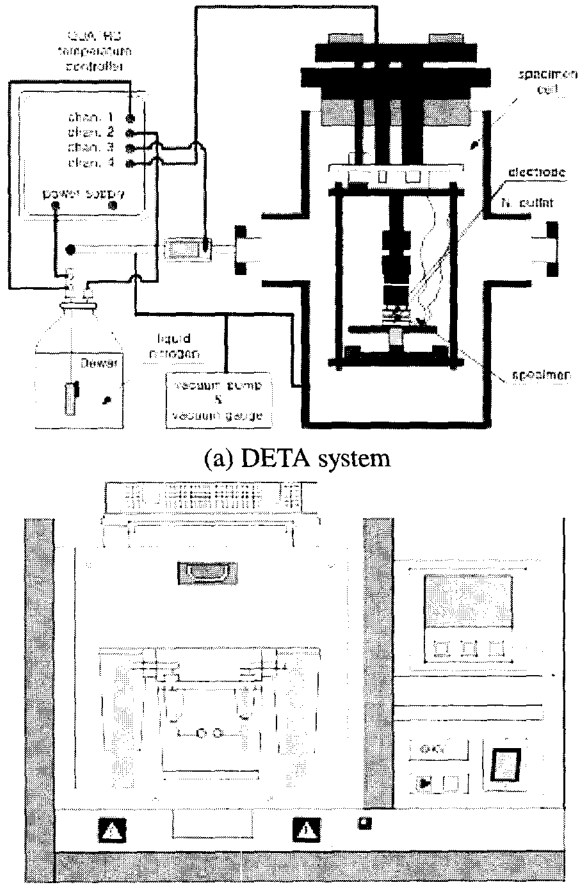
By the way the cut-through resistance means the ability of a material to withstand mechanical pressure without separation. Pressure is usually applied as a sharp edge of the prescribed radius. The standard concerned with the cut-through resistance was not found. Therefore the method applied by Union Carbide Corp. (UCC) was applied. This test compression mode was employed by use of a universal tester. The cut-through resistance is assessed by the maximum force applied at the point that an edge of a wedge-shaped blade pierces a specimen of 1.9[mm] in thickness. The dimension of the blade was 25.4[mm] in width and 0.76[mm] in thickness and it was tipped by 45°. In the test the blade was moved to the specimen at the rate of 10[mm/min].

2.4 Dielectric Characteristics Test

After selecting two types of the specimens that showed excellent properties in mechanical tests, their permittivity and tanδ measurements were conducted. In addition to these tests, dielectric strength measurement was also performed. The equipments for these experiments are shown in Fig. 2.

As shown in Fig. 2, the permittivity and tanδ measurements of the base resins for the cable jacket were made by a DETA system (model: Broadband Dielectric Spectrometer SI 1260, NOVOCONTROL Co.). They were taken at six different frequencies with increasing temperature from -40[℃] to 100[℃] at increments of 2[℃] with error bound of ± 0.5[℃].

For the case of breakdown voltage measurements an AC breakdown voltage tester (model: FOSTERTM OTS 60AF/2, MEGGER Co.) was used. The testing program was performed according to KS standards [9]. The specimens were placed between two spherical electrodes 10[mm] in diameter and ramp voltage of 3[kV] per second was applied. Then ten breakdown voltage measurements were taken and the mean value was calculated using only eight valid data but for maximum and minimum values.



(a) DETA system

(b) breakdown voltage tester

Fig. 2 Experimental apparatus for electrical tests

2.5 Preparation of Compounds for Cable Jacket

As listed in Table 2, based on the testing assessment of base resins, six compounds for cable jackets were produced. In developing the compounds it is very important to determine the optimal mixture ratio of the contents. Generally, some additives such as carbon black, antioxidant and lubricant for facile processing, etc. are added to the compounds for cable jackets.

First of all, the base resin was thoroughly melted in a two-roll mill kept at approximately 125~135[℃] and then it was blended with some additives in the order of; carbon black, antioxidant, etc. During manufacturing, the gap between rolls was properly controlled to disperse the fillers uniformly in the compounds. Out of the cable jacket compounds listed in Table 2, two types of compound that were determined to possess excellent characteristics were used to prepare the model cables with two structures below. In addition a conventional CNCV-W (Concentric Neutral type XLPE insulated Vinyl sheathed Waterproof Power Cable) cable jacket made of PVC was tested in water permeability for comparative assessment and FR CNCO-W (Halogen-free Flame Retardant Concentric Neutral type

Table 2 Components of compounds for cable jacket

		LLDPE-1	LLDPE-2	LDPE-1	LDPE-2	MDPE	HDPE	C / B	antioxidant-1	antioxidant-2	lubricant
materials	T1	○						○	○	○	○
	T2		○					○	○	○	○
	T3			○				○	○	○	○
	T4				○			○	○	○	○
	T5					○		○	○	○	○
	T6						○	○	○	○	○

XLPE insulated Polyolefin sheathed Waterproof Power Cable) was scheduled for substitution of the conventional cable jacket and then also tested in the preliminary examination.

- laminate type made of LLDPE
- laminate type made of MDPE
- encapsulating type made of LLDPE
- encapsulating type made of MDPE
- conventional CNCV-W made of PVC
- flame retardant(FR) CNCO-W

2.6 Additive Added Compounds Test

Six compounds to which different kinds of resins were applied were tested while maintaining a constant composition ratio of the additives in order to evaluate their changing characteristics.

2.7 Water Permeability Test

A portion of the 6 model cables addressed in section 2.5 was cut out and only the cable jackets were used for the test by taking out the contents inside the cable jacket; core, XLPE insulation, neutral wires, swelling tape, semiconductive layer, etc. Each cable jacket was evaluated for waterproof performance. Fig. 3 shows the schematic of the water permeability testing barrel to evaluate waterproof performance of the cable jacket.

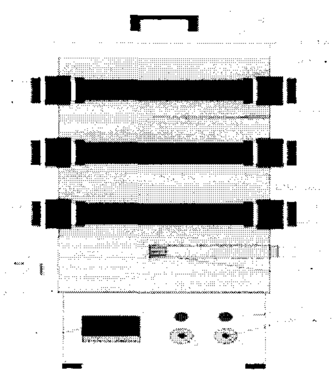


Fig. 3 Schematic of water permeability testing barrel to evaluate waterproof performance of the cable jacket

Six model cables can be simultaneously evaluated at specified temperatures, in the specially constructed water permeability testing barrel shown in Fig. 3. The ASTM method is not appropriate for testing cable type specimens. For this reason the test was executed according to the method that TEPCO applies to 154[kV] class transmission power cables. After the cores of each model cable (approx. 30[cm] in length) were taken out, silica gel of 100[g] in net weight was put in each cable jacket including water interception layers. These cable jackets were submerged under pure water of 60[℃] and then the total weight of each model cable including silica gel were measured at 10 days, 20 days and 30 days. Permeability was calculated by Equation (3);

$$\text{Permeability } [\text{g*cm/cm}^2\text{*day*mmHg}] = \frac{\frac{Q}{l}\times\log\left(\frac{R_2}{R_1}\right)}{2\pi td} \quad (3)$$

where, Q is an amount of permeated water[g], l specimen length[cm], R_1 inner diameter of water interception layer in cable jacket[cm], R_2 outer diameter of cable jacket[cm], d saturated water vapor pressure with testing temperature [mmHg]-149.5[mmHg] @ 60[℃]-, t testing time [day]. The mean value of permeability calculated by the equation must be below 1×10^{-7}[g*cm/cm^2*day*mmHg].

3. Results and Discussion

In order to develop compounds that can substitute for the conventional cable jacket made of PVC, six kinds of resin based on polyethylene and their compounds were manufactured in bulk and then measurements in property, waterproof performance and mechanical strength were taken for each specimen.

3.1 WVT Rate of Base Resins for Cable Jacket

The total weight measurements of the test vessels sealed with six kinds of the base resin previously described in section 2.2 were taken for 360[h]. The WVT rate of each specimen was calculated by using the weight measured with time. The weight change and the calculated WVT rate of the base resin are shown in Fig. 4 and Fig. 5, respectively.

As shown in Fig. 4, the amount of WVT through the base resin increased slightly with testing time. From the slope of the plotted points, the WVT rate of each specimen was calculated and shown in Fig. 5. According to the results, the most superior specimen in waterproof performance was HDPE since the lowest WVT rate appeared for HDPE. From this it was confirmed that the WVT rate was closely related to the density of the material and the effect of the branches of polymer chains.

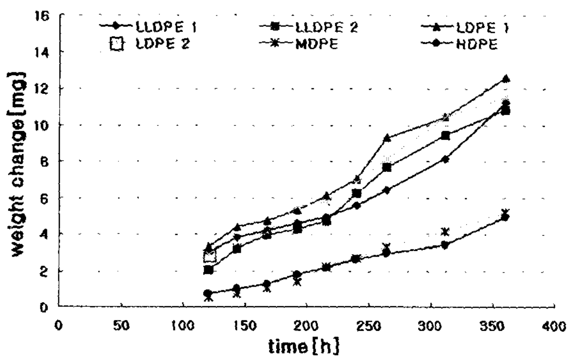


Fig. 4 Amount of WVT through base resins for cable jackets

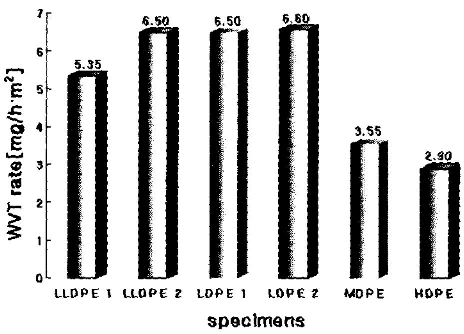


Fig. 5 WVT rate of base resins for cable jackets

3.2 Abrasion and Cut-through Resistance of Base Resins for Cable Jackets

Fig. 6 and Fig. 7 show the weight loss and the cut-through resistance of base resins for cable jackets, respectively.

As illustrated in Fig. 6, LLDPE and MDPE were exceptional, while LDPE performed poorly in relation to abrasion resistance. This is considered due to the fact that LLDPE and MDPE are linear polymers, which makes their properties in tenacity and other mechanical strengths enhanced [10].

Cut-through resistance was the strongest in MDPE, while the difference between LLDPE and LDPE hardly appeared, as shown in Fig. 7.

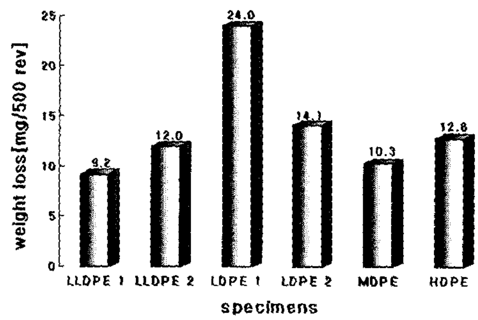


Fig. 6 Weight loss due to abrasion of base resins for cable jackets

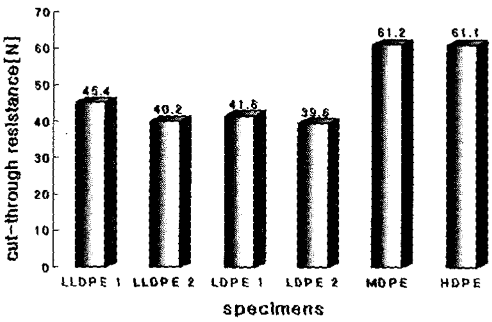


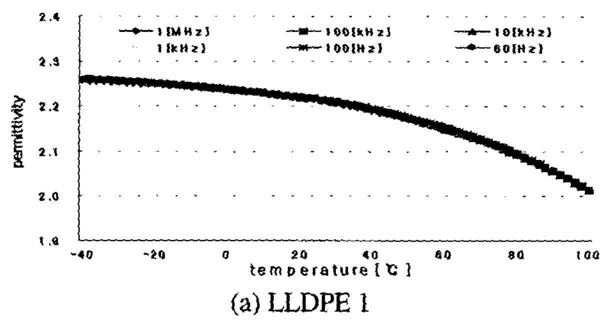
Fig. 7 Cut-through resistance of base resins for cable jackets

3.3 Permittivity and tanδ of Base Resins for Cable Jackets

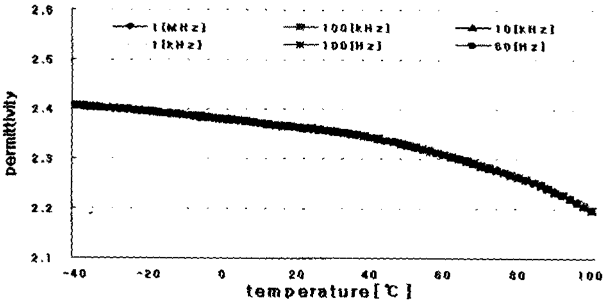
Permittivity and tanδ of LLDPE 1 and MDPE, which demonstrated excellent characteristics in mechanical tests, were measured and the results are shown in Fig. 8 and Fig. 9, respectively.

As shown in Fig. 8, the permittivities of all specimens ranged between 2.0 to 2.3 and they were independent of the change in temperature and frequency. This may be caused because the polar molecules are seldom contained in the base resins. In the test MDPE and LLDPE showed the lowest and the second lowest permittivities, respectively.

All tanδ curves of LLDPE 1 shown in Fig. 9 had a peak not over 10^{-3} and the peak shifted in conjunction with the frequency. In particular, the tanδ curve of commercial frequency displayed a peak around 45[℃]. On the contrary the tanδ of MDPE remained constant over all the temperature ranges tested.

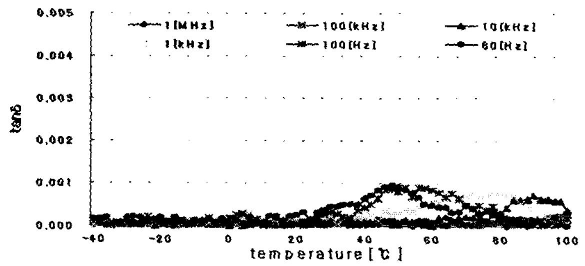


(a) LLDPE 1

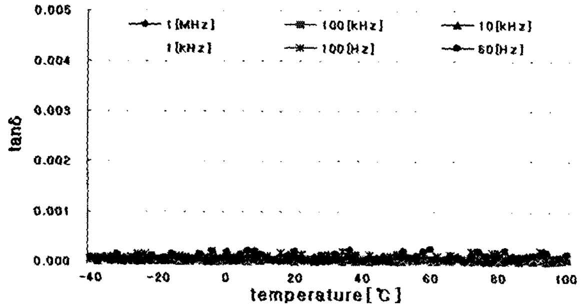


(b) MDPE

Fig. 8 Permittivity of base resins for cable jackets



(a)LLDPE 1



(b) MDPE

Fig. 9 tanδ of base resins for cable jackets

3.4 Dielectric Strength of Base Resins for Cable Jacket

AC breakdown voltage measurements were conducted to calculate the dielectric strength of base resins for cable jackets and the testing results are shown in Fig. 10.

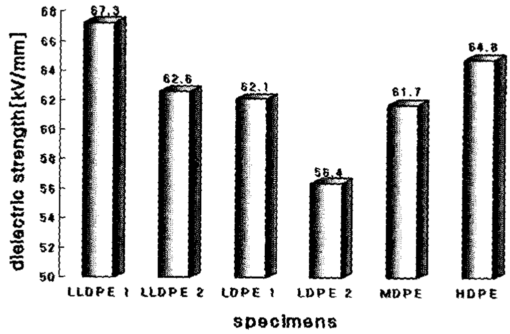


Fig. 10 Dielectric strength of base resins for cable jackets

As shown in Fig. 10, LLDPE 1 and LDPE 2 had the highest and lowest values in dielectric strength, respectively. However, the dielectric strength of the other base resins showed little difference. This may be due to the fact that the difference in dielectric strength is too trivial to cause electrical problems when taking the thickness of the cable jacket into account.

3.5 Properties Tested for Novel Compounds Developed

Table 3 shows various properties of the compounds newly developed for cable jackets. For comparison, those of PVC are also described in Table 3.

As listed in Table 3, the compounds developed in the study showed superiority in most characteristics over the conventional PVC. In particular their WVT resistance, which is an index of waterproof ability, was tens of times higher than PVC. In addition the abrasion and the cut-through resistance concerned with mechanical strength of the cable jacket were sufficient.

A significant difference in property between LLDPE and LDPE appeared and this is thought to be the result of LLDPE having a more linear molecular structure than LDPE. Since LLDPE has a higher melting index than LDPE, greater pressure can be acquired under certain conditions, making its mechanical and thermal characteristics more extraordinary.

Table 3 Some properties of novel compounds for cable jacket

physical property	test method	units	PVC	T1	T2	T3	T4	T5	T6
melt index @ 190[℃], 2.16[kg]	ASTM D1238	g/10min	5.50	1.74	2.47	0.30	0.33	0.20	0.18
density @ 23[℃]	ASTM D1505	g/㎤	1.449	0.929	0.932	0.926	0.928	0.940	0.955
tensile strength	ASTM D638	Mpa	15.6	23.1	26.3	19.9	19.3	40.1	29.5
tensile elongation	ASTM D638	%	292	856	912	577	661	852	717
DSC melting Pt.(annealed)		℃		125	126	114	112	128	131
flexural modulus	ASTM D790	MPa		304.9	327.4	310.3	316.0	327.3	412.0
heat deformation @ 130±3[℃]	KSC C 3004	%	8.2	13.4	12.9	-	-	10.0	9.5
Shore D hardness	ASTM D2240		27	46	45	47	46	54	56

3.6 WVT Rate of Compounds for Cable Jackets

Fig. 11 and Fig. 12 show an amount of WVT through the compounds for cable jackets and WVT rates calculated from the amount, respectively.

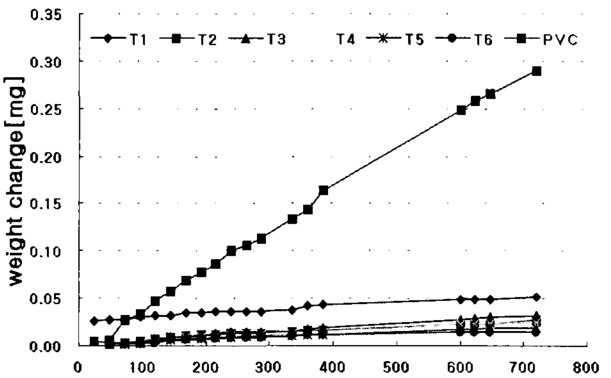


Fig. 11 WVT of additive added compounds for cable jackets

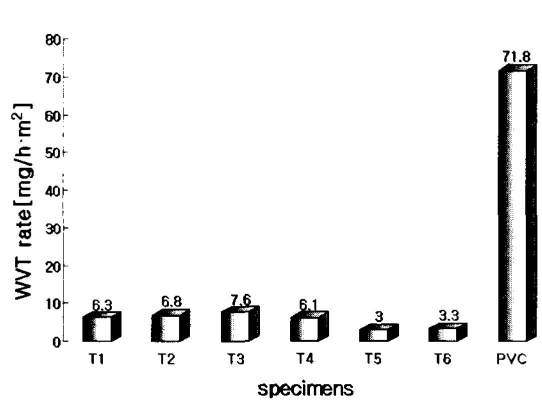


Fig. 12 WVT rate of additive added compounds for cable jackets

As shown in Fig. 11, the weight of the compounds for the cable jackets increased over time, while that of PVC was remarkable. But for PVC, only T1 was higher in weight increase than the other compounds. Considering that the increasing rate in weight of T1 is similar to that of the other compounds, this may be due to the error in initial weight measurement. Incidentally, the WVT rate of PVC was also higher than that of the other compounds, as shown in Fig. 12.

3.7 Abrasion and Cut-through Resistance of Compounds for Cable Jackets

The weight loss due to abrasion and the force loaded at cut-through of the compounds for cable jackets were measured and the testing results are shown in Fig. 13 and Fig. 14, respectively.

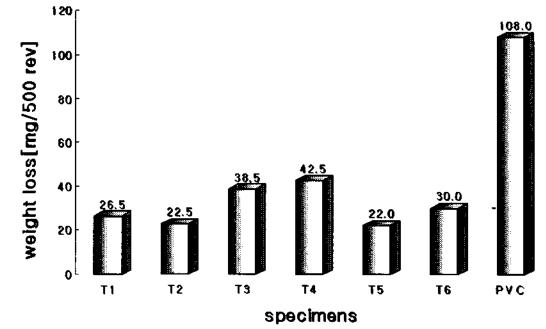


Fig. 13 Weight loss due to abrasion of additive added compounds for cable jackets

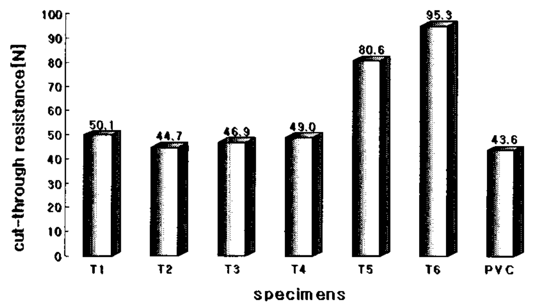


Fig. 14 Cut-through resistance of additive added compound for cable jackets

As shown in Fig. 13, the weight loss due to abrasion of additive added compounds was considerably less than that of PVC. In particular, the amount of weight loss of T1, T2 (base resin: LLDPE) and T5 (base resin: MDPE) was no more than approximately 20[%] when compared with PVC. In addition the cut-through resistance of all additive added compounds was far superior to that of PVC, as shown in Fig. 14.

3.8 Water Permeability of Model Cable Jackets

The conventional CNCV-W, the FR CNCO-W and two types of model cables were tested in water permeability and Fig. 15 shows the testing result.

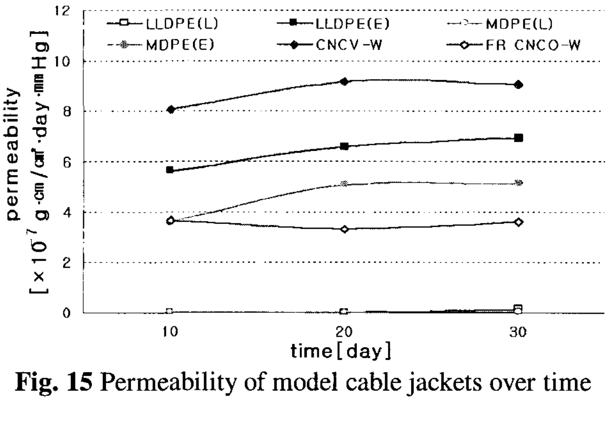


Fig. 15 Permeability of model cable jackets over time

As shown in Fig. 15, the water permeability increased since water content penetrates into the cable jackets with testing time. The rate of increase in permeability with time was highest in 20 days and then it tended to be saturated. Especially, the permeability of CNCV-W was insufficient to pass the criterion specified by TEPCO and this is considered to be due to the fact that the PVC material is polar.

As a side note, the permeability of all specimens except laminate type model cables were a little below the criterion because of the absence of waterproof metal sheath layers employed in transmission class cable. In particular, the permeation of water content hardly appeared in laminate type MDPE cable and this is because of the excellent waterproof performance of MDPE and laminate type metal sheath layers. In this case, considering only the waterproof performance it looks to be the most effective. Water content is however likely to permeate through the splice for joints and the terminal ends upon comparison with the other cases. Since there were no waterproof metal sheath layers in encapsulating type model cables their permeability was below the criterion and the amount of permeated water content was also slightly more than FR CNCO-W. To put it briefly, since the permeance of water content through the cable jackets in encapsulating structures was completely governed by the materials used to construct the cable jackets, it seems difficult to entirely prevent the permeance of water content along the radial direction.

4. Conclusions

In this study cable jacket compounds based on six base resins of polyethylene were developed to substitute for conventional PVC cable jackets. For the base resins, the compounds and the model cables made of the compounds, several tests were performed. The paper concludes as follows;

(1) In the test for WVT of base resins, the WVT rate seemed closely related to the density of the polymer. In a word the higher the molecular density of base resins, the more resistive they were against WVT. This is because of the effect of polymer branching on WVT.

(2) Out of the base resins, LLDPE linear polymer material and MDPE scored very well in abrasion and cut-through resistance.

(3) Out of the compounds developed in this study, MDPE and LLDPE compounds showed excellence in waterproof and mechanical characteristics when compared with conventional PVC. In particular, their WVT rates were also well related to the density of the compounds, as shown in the tests of base resins.

(4) As a result of the water permeability tests of model cables, laminate type cable performed better than encapsulating type cable in regards to waterproofing.

In the event that the new cable jacket compounds tested in this study are applied to the laminate type model cable, exceptional waterproof performance and hardness can be expected. However it is also true that the cable work and handling becomes more difficult since the materials are too solid and the cables have waterproof aluminum sheaths in their structure. These problems were solved by field examination using existing tools such as jacket strippers. It is essential that accelerated aging testing and comparison testing for the cables employing new materials are also carried out in future.

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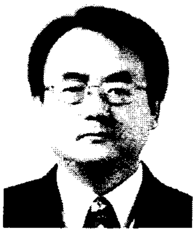

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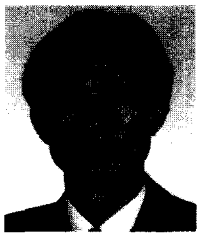

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