Development of Insulated Wire and Cable Using Recycled PVC

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ABSTRACT Most of polyvinyl chloride (PVC) used for sheathing distribution wires and cables have seldom been reused for wire sheathing when they are retrieved, so that they are usually applied in other uses or disposed of as industrial waste. By investigating the sorting retrieval and the recycling methods of the sheath material as well as its applications, the authors have been successful in developing insulated wire and cable that use recycled sheath material out of retrieved wire and cable, together with a recycling system that permits obtaining recycled material comparable to unused material in terms of cost. All the sheath material investigated in this study are retrieved from used wires for power distribution owned by Tokyo Electric Power Co. (TEPCO), and will be used again in the recycled wire and cable to be delivered to the same company.

1. INTRODUCTION

Currently various sheath materials are used depending on the objectives in power distribution wires and cables for TEPCO, including mainly polyvinyl chloride (hereafter called PVC), polyethylene (PE), and cross-linked polyethylene (XLPE). Whereas valuable conductors of electric wire and cable have been recycled conventionally, sheath materials have been directed, without being reused in electric wire and cable, to other uses with less performance requirements in addition to thermal recycling and disposal as industrial waste. Thus, due to the increased awareness of environmental issues together with the standpoints of global resource preservation and industrial waste reduction over the last several years, it has been required to establish a closed recycling system for reusing the sheath materials of electric wire and cable, so that we proceeded to develop such a system as shown in Figure 1.

In this study, PVC of electric wire sheath was investigated for recycling. With respect to sorting and retrieval which is an important issue for recycling in the first instance, a retrieval method with a sorting level equivalent to that of the current level was studied first. Then a recycling system based on this retrieval method was investigated in an effort to make this system using recycled material capable of achieving a cost level comparable to that of using unused material.

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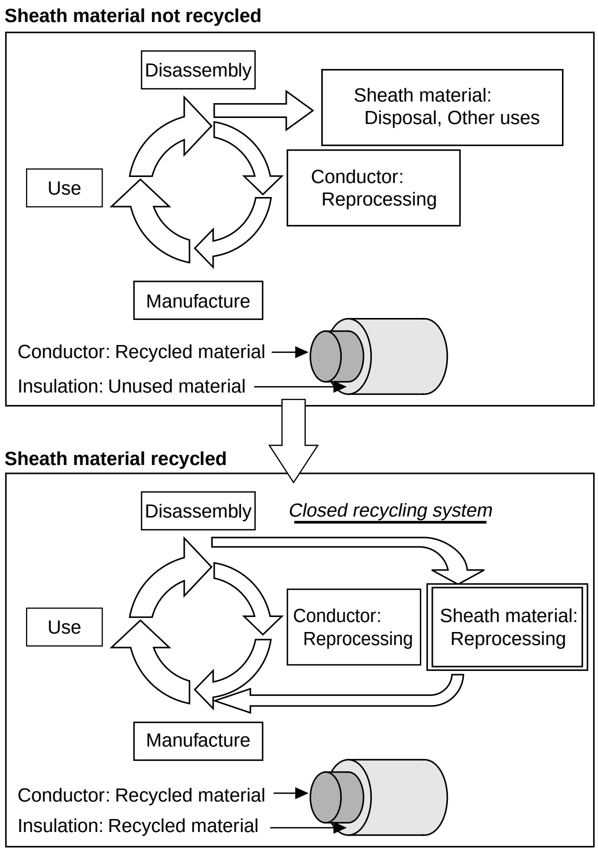

Figure 1 Conceptual image for recycling of insulated wire and cable.

2. DEVELOPMENT OF INSULATED WIRE AND CABLE USING RECYCLED PVC

PVC is most extensively used as a general sheath material for low-voltage electrical wires, so that its retrieved quantity is the greatest. This makes it possible to some degree to select the application areas that match the properties of recycled material. In this study we used samples as shown in Photos 1 and 2, which were obtained through a process where the wire and cable were finely shredded followed by separating the conductor and sheath by vibration, etc. Although the retrieved wire undergoes sorting before shredding by classifying such PVC-based wires and cables as OW, DV, IV, SV, etc. to obtain sorted PVC material, it is difficult to carry out perfect sorting, so that the retrieved material contains some amount of other types of wires including tapes such as F-CO tape. Since a target was set at implementing a cost-viable recycling system in this study, the retrieved material out of the practical sorting level mentioned above was evaluated to see if recycling was feasible or not. Retrieval experiments in different periods were also carried out several times to evaluate the property fluctuation of retrieved material.

Specific procedures for the study are as follows.

1) Understanding of the properties of retrieved PVC sheath material.
2) Evaluation of the properties of recycled PVC material.
3) Investigation of application areas for the recycled material with improved properties.
4) Manufacture and evaluation of electrical wire and cable using recycled PVC.

Photo 1 Retrieved PVC jacket material.

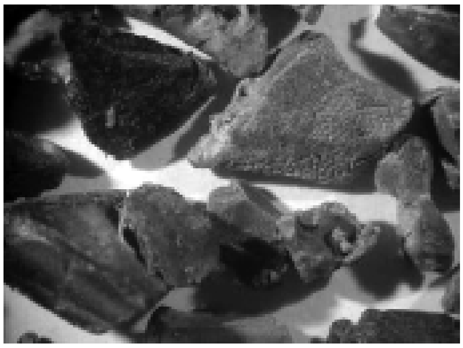

Photo 2 Retrieved PVC jacket material. (Enlarged photograph)

2.1 Understanding the Properties of Retrieved PVC Sheath Material

Sheet samples were prepared by roll processing the retrieved PVC sheath material shown in Figure 1, and the samples were evaluated for their properties. Photo 2 and Table 1 show the macrophotograph of retrieved PVC sheath material and the properties of sheet samples, respectively.

Photo 2 confirms that the retrieved PVC sheath material include some deteriorated samples which have cracks on their surface.

Table 1 shows the results of property evaluation of rolled sheet samples, from which the following properties of retrieved PVC sheath material can be confirmed.

- The surface of the rolled sheet is somewhat granular, i.e., the surface is roughened.
- Volume resistivity does not meet the standard.
- Embrittlement property tends to be deteriorated, insufficiently satisfying the standard in some cases when deviation is considered.
- Except for volume resistivity and embrittlement, no problems of practical importance were found.
- No property fluctuations were appreciable among the results of four evaluation tests.

2.2 Properties of Recycled PVC Material

We have prepared compounds of recycled PVC material taking into consideration the problems described in Clause 2.1, and the properties of the recycled PVC material are shown in Table 2. In the compound preparation, plasticisers and such were added to improve embrittlement property, and the compounds were filtered through a mesh strainer with an objective of removing dust and foreign particles. Evaluation was carried out based on extruded samples so as to check the appearance of recycled material.

Table 1 Properties of retrieved PVC sample sheet.

	Volume resistivity (Ω·cm)	Embrittlement (°C)	Room temp. tensile strength (MPa)	Room temp. elongation (%)	Heated tensile strength (Residual in %)	Heated elongation (Residual in %)	Oil resistance & others
JIS K 6723	≥ 5.0E+13	≤ -15	≥ 10	≥ 200	≥ 90	≥ 80	——
Unused material	1.1E+14	-24	17	300	99	105	Passed
Retrieved material A1	1.2E+13	-14	20.3	260	101	94	Passed
Retrieved material A2	1.2E+13	-19	20.4	278	101	88	Passed
Retrieved material A3	1.2E+13	-18	19.9	262	103	97	Passed
Retrieved material A4	1.4E+13	-20	20.3	284	102	90	Passed

Table 2 Properties of recycled PVC sample jacket after extrusion.

	Appearance of extruded surface	Volume resistivity (Ω·cm)	Embrittlement (°C)	Room temp. tensile strength (MPa)	Room temp. elongation (%)	Heated tensile strength (Residual in %)	Heated elongation (Residual in %)	Oil resistance & others
JIS K 6723	——	≥ 5.0E+13	≤ -15	≥ 10	≥ 200	≥ 90	≥ 80	——
Unused material	Good	1.1E+14	-24	17	300	99	105	Passed
Sample No. 1	Somewhat granular	9.6E+12	-23	18.6	306	103	96	Passed
Sample No. 2		9.8E+12	-21	19.0	328	105	90	Passed
Sample No. 3		1.2E+13	-23	18.9	324	101	86	Passed
Sample No. 4		1.1E+13	-21	19.6	318	98	91	Passed

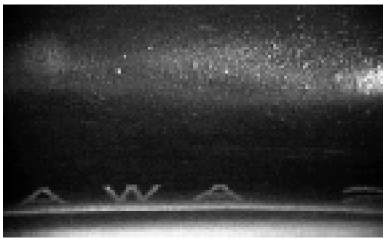

Photo 3 Surface of recycled PVC jacket after extrusion.

1) Appearance of recycled material

Photo 3 shows an appearance of recycled PVC material after extrusion. The material shows a partly degraded surface with somewhat granular appearance due to unavoidable entry of small amounts of foreign particles. However, as can be seen from Table 2, the degree of deterioration was not so serious as to give significant influences on mechanical properties such as tensile strength and elongation.

2) Results of improving embrittlement property

The embrittlement property has been improved by the addition of plasticisers. It was shown that an improved level could be secured that was slightly inferior to that of unused material but not below the standard.

3) Results of improving volume resistivity

It was confirmed from the results in Table 2 that the volume resistivity of recycled PVC material was little improved by foreign particle elimination at the time of compound preparation based on filtering using a mesh strainer. We then examined whether or not the retrieved PVC sheath material improves in volume resistivity by blending unused material. Table 3 shows the results of evaluation when an unused material is blended with ratios of 1/3 and 2/3 over the retrieved PVC sheath material.

It is seen from Table 3 that blending unused material improves the properties only to a level not exceeding the standard, thus demonstrating that the volume resistivity is difficult to be improved.

4) Long-term weather resistance

As shown in Sub-clause "2) Results of improving embrittlement property" above, the initial value of embrittlement property of the recycled PVC material proved to be improvable. Accordingly accelerated aging tests were conducted using a sunshine weatherometer to determine the long-term weather resistance property. Because long-term weather resistance strongly depends on the color of samples, comparisons were made with black and blue unused materials in use for TEPCO's DV wire.

Table 3 Volume resistivity of retrieved PVC jacket material blended with unused material.

Sample No.	Blending ratio: Retrieved material	Blending ratio: Unused material	Volume resistivity (MΩ·cm)
No.1	100 %	——	7.0×10^{12}
No.2	2/3	1/3	7.7×10^{12}
No.3	1/3	2/3	3.3×10^{13}
No.4	——	100 %	1.1×10^{14}
Standard (JIS K 6723)			5.0×10^{13}

Table 4 Weather resistance properties represented by embrittlement temperature.

	Unused material (Black)	Unused material (Blue)	Recycled material
0 h	-26°C	-25°C	-17°C
1000 h	-15°C	-13°C	-14°C
2000 h	-13°C	-5°C	-9°C

It has thus been confirmed, as shown in Table 4, that whereas the recycled material is slightly inferior to black and blue unused materials in terms of the initial value, it is superior to the blue unused material with respect to the long-term performance because its color is nearly black.

2.3 Study on the Application Methods of Recycled Material

From the results in Clause 2.2, features of the recycled material may be summarized as follows.

- It is equivalent to unused material in terms of mechanical properties such as tensile strength and elongation.
- In terms of embrittlement property, although the material has inferior initial properties compared with unused material, its long-term properties are superior to those of some unused material --e.g., blue-colored-- because of its natural color which is nearly black.
- Volume resistivity is deteriorated when compared with

unused material.

- The extruded surface is somewhat granular, but this presents no practical problems.

Given the features mentioned above, potential applications of recycled material have been proposed as follows.

Proposal 1: Although its electrical properties are rather poor, the material has excellent weather resistance, so that application to cable jacket is proposed. However, the color should be black in principle.

Proposal 2: A double-skin structure is proposed where an unused material is used for outer layer for identification, while a recycled material is used for inner layer. In this case, the issues of color and appearance will solve themselves but a decline in insulation resistance is expected.

2.4 Manufacture and Evaluation of Electrical Wire and Cable Using Recycled PVC Material

A prototype of SV cable (3 × 8 mm^2) has been manufactured as a typical electrical wire based on recycled material. Table 5 shows the results of tests equivalent to TEPCO's type tests.

The results of manufacture and evaluation of prototype cable demonstrated that the cable passed every type test items satisfactorily, thereby confirming that there is no problem in using the recycled material for the inner insulation layer and the jacket. With respect to the insulation resistance at room and elevated temperatures a considerable decline was seen compared with the average value of unused material, as could be expected from the declined volume resistivity manifested by the sheet sample evaluation. But it was also confirmed that the use of unused material for the identification layer ensured the insulation resistance of the product.

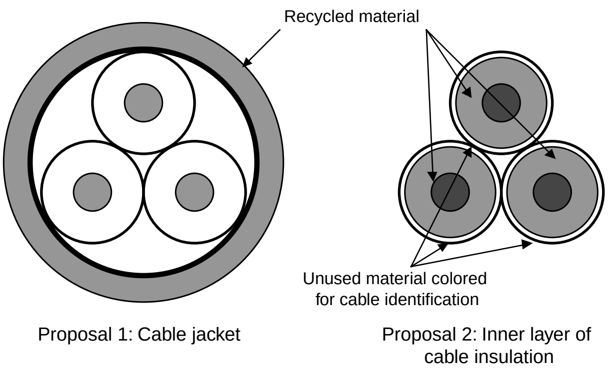

Figure 2 Applications of recycled PVC material.

2.5 Specifications for Applications of Recycled PVC Material

Both Proposals 1 and 2 were confirmed to be feasible for application through the results of prototype wire manufacture followed by evaluation, making Proposal 2 applicable without modification to insulation wires such as DV, IV, and OW. In cases where Proposal 1 is applicable, on the other hand, consideration must be given to the fact that the jacket is going to be black in color. In the case of SV cable for TEPCO, the jacket color is specified to be gray. In consideration of efficiency improvement due to color identification at the time of cable retrieval and sorting work, it was decided to adopt Proposal 2 for SV cable, i.e., an unused material in gray is used for the outer jacket and a recycled material for the insulated inner core.

Table 5 Characteristics of prototype cable using recycled PVC.

		Standard	Black phase	White phase	Red phase	Sheath*4
Appearance, Structure, Flame-retardance test		——	Good	Good	Good	Good
Withstand voltage (in air, in water)		——	Good	Good	Good	——
Conductor resistance (Ω/km)		2.36	2.23	2.24	2.24	——
Room temp.	Tensile strength (MPa)	10	20.3	20.4	19.9	20.3
	Elongation (%)	120	260	278	262	284
Residual in elevated temp. (100°C x 48 h)	Tensile strength (MPa)	90	101	101	103	102
	Elongation (%)	70	94	88	97	90
Residual after oil test (70°C x 4 h)	Tensile strength (MPa)	85	94	97	99	98
	Elongation (%)	75	84	84	93	84
Room temp. insulation resistance (MΩ·km)*1		50	170	110	160	——
High temp. insulation resistance (MΩ·km)*2		0.15	0.40	0.40	0.39	——
Windability (Low temp. and high temp.)		——	Good	Good	Good	Good
Low temp. resistance (°C)*3		-15	-24	-23	-24	-22
Heated deformation test (%)		50	9.5	8.6	7.2	6.8

Notes: *1) Room temp. insulation resistance: 900~1300 MΩ is typical with Furukawa's unused material conventionally used.
*2) 4 MΩ is typical with Furukawa's unused material conventionally used.
*3) Identical to unused material due to the skin layer of unused material for identification.
*4) In this study the sheath was also made of recycled material.

3. IN CONCLUSION

Recycling of PVC sheath of wires and cables retrieved from the installed fields of TEPCO was studied, and the authors have been successful in demonstrating that a closed recycling system is applicable to recycle this material to be reused in the sheath of electrical wire and cable. In terms of cost which often raises problems, a cost level that compares favorably with unused material has been realized through the examination of sorting retrieval method as well as the operation of recycling system.

The recycled PVC electrical wire developed in this study has passed the type tests of TEPCO for their inventory items and is scheduled for delivery in due time. A study program for recycling PE and XLPE is planned to follow this study on PVC.