論 文
53C-12-3

전력케이블의 반도전 재료에서 불순물 및 물성 측정

Measurement of Impurities and Physical Properties at Semiconductive Shield of a Power Cable

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Abstract - In this paper, we investigated ionic impurities and physical properties by · change of carbon black content, which is asemiconductive material for underground power transmission. Specimens were made into sheet form with three existing resins and nine specimens for measurement. The ionic impurities of the specimens were measured using anICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometer), and the density of specimens was measured by a density meter. Specific heat (Cp) was then measured using aDSC (Differential Scanning Calorimetry). The ranges of measurement temperature were from 0[℃] to 200[℃], and heating temperature was 4[℃/min]. Ionic impurities were measured to be high according to increases in the content of carbon black from this experimental result, and density was also increased according to these properties. In particular, the impurity content values of A1 and A2, and existing resins, were measured at more than 4000[ppm]. Specific heat from the DSC results was lowered according to augmentation in the content of carbon black. The ionic impurities of carbon black containing Fe, Co, Mn, Al and Zn are forms of rapidly passed kinetic energy that increase the number of times breaking occurs during unit time with the near particles according to an increase in the vibration of particles by the applied heat energy.

Key Words : Semiconductive Shield, Ionic Impurities, Density, Specific Heat

1. Introduction

The domestic power cable is composed of aconductor shield, insulation, insulation shield, neutral line and outer skin. Each shield has its own role, and when there is faulting in each shield, the insulation can be damaged, causing the overall fault of the power cable [1, 2].

Research on the electrical phenomenon and characteristics of the power cable up to now have been primarily focused on insulation. In this research, however, the importance of the semiconductive shield of the power cable will be reviewed by thorough analysis to inspire a new understanding of the role and function of the semiconductive shield. First, in order to carry out its proper function as a semiconductive shield, volume resistance, protrusion on the surface, ionic impurities in the materials, etc. must be satisfied.

Currently, the volume resistance and protrusion on the surface have been greatly improved. However, improvement on the ionic impurities in the materials remains inadequate.

If ionic impurities and defects exist between the semiconductive shield and the insulation, the life of the power cable can be seriously threatened. In other words, the ionic impurities can be involved in the oxidation of polymers,promoting deterioration. Also, ionic impurities can promote the development of water trees from the semiconductive shield to the insulation, and cut the branches inside the polymersto introduce an extreme element to surge in a supply of water[3~5].

Thus, in order to extend the life and secure the confidence of the power cable, positive demands should be made on introducing a method to minimize the inflow of impurities from the semiconductive shield to the insulation, and the content of impurities within the semiconductive shield.

First, we have measured the ionic impurities in semiconductive materials used in domestic cables, and in test specimens. As well, we have measured the effects that these impurities have on the density of the semiconductive materials.

Finally, by using the DSC, which is a thermo analyzer, we have measured the specific heat and melting temperature of the semiconductive material. By studying the effects of the ionic impurities exiting the semiconductive

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接受日字 : 2004年 7月 26日
最終完了 : 2004年 9月 14日

shield have on the materials, we emphasize that improving the semiconductive shield can play a significant factor in improving the overall performance of the power cable.

2. Experimental

2.1 Materials

In this paper, EVA (Ethylene Vinyl Acetate), EEA (Ethylene Ethyl Acrylate, ATOFINA) and EBA (Ethylene Buthyl Acrylate, Mitsui Dupont) were used as the basic materials. The composition ratio of these materials is shown in Table 1. As seen in Table 1, the content of conductive carbon black was set as a variable in this paper. The content was 20, 30 and 40[wt%] each.

For convenience purposes, the specimens were represented by the # sign, while the base materials were represented by the figure A. For the sheet, the pallet type specimens went through the primary roll mixing milling for 5 minutes in a 70 ~ 100[℃] roller. Then, the specimens went through the pressing procedure for 20 minutes under 200[kg/cm] of pressure.

표 1. 시편들의 조성

Table 1. Composition of specimens

Unit: wt%

Content	EVA	EEA	EBA	Carbon Black	Additive	Agent	Total
#1	78.2	-	-	20	1.3	0.5	100
#2	68.6	-	-	30	0.6	0.5	100
#3	58.9	-	-	40	0.6	0.5	100
#4	-	78.2	-	20	1.3	0.5	100
#5	-	68.6	-	30	0.6	0.5	100
#6	-	58.9	-	40	0.6	0.5	100
#7	-	-	78.2	20	1.3	0.5	100
#8	-	-	68.6	30	0.6	0.5	100
#9	-	-	58.9	40	0.6	0.5	100
A1	-	-	-	-	-	-	-
A2	-	-	-	-	-	-	-
A3	-	-	-	-	-	-	-

2.2Procedures

To measure the impurities content of the specimens, we have used ICP-AES (Perkin-Elmer Instruments, Optima 3300 DV), which analyzes the mineral elements in ppm levels. Because the specimens used in this test were solid polymers, all processing progress was performed prior to starting the test. The density test was made by using ASTM D 792. The weight of the specimens was measured in air, and then the volume of the specimens was measured by sinking it in an inactive liquid that doesn't chemically react with the specimens.

Finally, to measure the effects that the impurities of carbon black. have upon the specific heat and melting temperatures of the specimens, DSC (TA Instrument, TA 4100) was used. Temperature ranges of DSC were changed from 0[℃] to 200[℃], and the heating rate was 4[℃/min].

3. Results and Discussion

3.1 ICPAES analysis

Table 2 indicates the content of the measured ionic impurities when the carbon black content is changed for each specimen. Because there is no clear limitation level set for the ionic impurities within the underground power cable, the test was based on 22.9[kV] CN/CV-W of the Korea Electric Power Corporation [6].

According to the suggestions of the Korea Electric Power Corporation, the ionic impurities content of the inner semiconductive should be below 500[ppm], while the outershould be below 1500[ppm]. As the carbon black content increased, the impurities content for most specimens in this paper increased to the level between 641.815 and 4316.861[ppm].

표 2. 카본블랙의 함량에 따른 이온성 불순물

Table 2. Ionic impurities according to contents of carbon black

Unit: ppm

Content	#1	#2	#3	#4	#5	#6
Ca	131.308	134.482	163.728	133.181	124.768	101.941
Si	330.720	309.359	1410.105	154.545	221.811	609.002
Cu	-	-	-	-	-	-
Fe	35.766	63.546	41.519	22.272	39.279	50.750
Al	-	2.955	5.875	-	23.105	-
Zn	0.489	0.492	2.350	-	-	-
Mg	27.927	29.064	26.233	22.727	27.726	22.065
Ni	3.919	6.896	4.700	4.545	4.621	4.413
Na	208.231	213.300	689.385	231.818	263.401	150.044
K	80.352	76.847	7.442	72.727	78.558	66.195
Total	818.712	836.941	2351.347	641.815	783.269	1004.410

Content	#7	#8	#9	A1	A2	A3
Ca	110.209	126.023	126.453	160.095	181.367	147.962
Si	461.331	905.368	959.302	356.294	213.082	1920.714
Cu	-	-	-	-	-	-
Fe	17.941	26.387	12.112	19.002	23.786	20.658
Al	-	4.549	-	-	-	22.333
Zn	4.271	4.549	-	593.824	569.871	5.583
Mg	25.630	31.847	29.069	2926.365	2958.374	27.917
Ni	-	-	4.844	4.750	-	-
Na	175.138	195.632	203.488	194.774	213.082	240.089
K	68.346	68.243	67.829	61.757	69.375	94.919
Total	862.876	1362.598	1403.097	4316.861	4228.937	2480.175

-: *Not detected or less than 0.05ppm*

Also, most of the test specimens indicated a value of over 500[ppm], which is the limitation level for the inner semiconductive. However, the test specimens were below the limitation level for the outer semiconductive, except in the case of specimen #3.

The results showed that the impurities content of EEA was lower than other specimens, suggesting that it has outstanding characteristics [7].

A noteworthy fact is seen in the result that all three specimens being used as the current base materials showed values over 1500[ppm], which is the limitation level for the outer semiconductive. Especially, the impurities content in A1 and A2 is over 4000[ppm], indicating that the condition of domestic semiconductive cable is very unstable.

3.2 Density

Table 3 presents the density of each specimen. Generally, density is the basic quality of all polymers, and affects most of the physical properties broadly. Thus, it is a very important test.

As indicated in Table 3, the density of the specimens increases between 1.033 and 1.169[g/cm] as the content of the carbon black increases. Generally, the density is determined by the number of short chain branching among the polymer molecules. When there is more short chain branching, the crystallization level decreases, making the density decrease as well [8, 9].

For this reason, the melting point and tensile strength of high density polyethylene (HDPE) is higher than those of low density polyethylene (LDPE), allowing it to have superior rigidity and hardness.

In this test, however, the density was not measured for the base polymer alone, but was measured following the changes incarbon black content. Thus, the thermal characteristic among the general characteristics revealed conflicting results.

표 3. 카본블랙의 함량에 따른 반도전 재료의 밀도

Table 3. Density of semicons according to contents of carbon black

Content	Dsity[g/cm^3]
#1	1.045
#2	1.108
#3	1.170
#4	1.034
#5	1.098
#6	1.168
#7	1.033
#8	1.092
#9	1.155
A1	1.169
A2	1.148
A3	1.137

In other words, although the mechanical rigidity and hardness were good, thermal analysis tests indicated that the crystallization level and melting point decrease as the density increases because it increases impurities as well as the contents of carbon black.

For references, the qualities of the semiconductive specimens following the increase of density measured in this test were measured and predicted, and the results are shown in Figure 1. Please refer to the following.

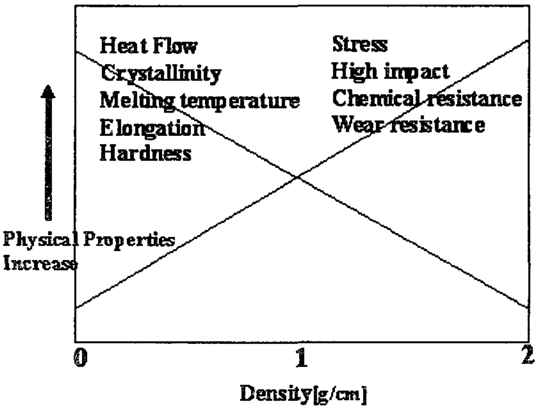

그림 1. 밀도에 따른 반도전 재료의 물성 변화

Fig. 1 Physical properties change of semicons according to density

3.3 Specificheat, Melting temperature and HeatFlow

Table 4 shows the specific heat generated, the melting point (Tm) and Heat Flow (H) when the content of carbon black is changed in the semiconductive material. Generally, the change in temperature is lower as the specific heat becomes higher.

표 4. 카본블랙의 함량에 따른 반도전 재료의 열적 특성
Table 4 Thermal properties of semicons by content of carbon black

Content	Specific heat[J/g℃]		Tm[℃]	H[J/g]
	25[℃]	90[℃]		
#1	0.1151	0.1157	65.21	56.57
#2	0.1139	0.1106	64.13	45.10
#3	0.1121	0.1091	63	39.27
#4	0.1429	0.2513	70.53	58.12
#5	0.1378	0.2167	69.35	49.22
#6	0.1166	0.1689	67.22	39.08
#7	0.1356	0.1862	66.81	54.41
#8	0.1353	0.1726	64.53	44.80
#9	0.1154	0.1376	64.30	37.20
A1	0.1083	0.1700	73.61	45.72
A2	0.1115	0.1837	64.07	45.97
A3	0.1042	0.0950	65.83	31.84

For example, water, having a specific heat of 4.2[J/g℃], boils at 100[℃] because water has a specific heat higher than other materials. In other words, this means that the resistance against temperature drops as the specific heat lowers. These trends were found in this test, too.

As the content of carbon black increased, the specific heat of the specimens dropped between 0.0950[J/g℃] and 0.2513[J/g℃]. The melting point dropped between 63[℃] and 73.61[℃] as well.

Furthermore, Heat Flow (H) dropped between 31.84[J/g] and 58.12[J/g] because of impurities increasing by the contents of carbon black. This indicates that the effects of the impurities within carbon black are big [10]. In the future, the results above will be proved more objectively through thermal conductivity measurements.

4. Conclusions

In this paper, the density and thermal characteristics of semiconductive materials following the ionic impurities included in carbon black were investigated.

As a result, ionic impurities were greatly detected in many specimens. In particular, many impurities are found in the base polymer.

The density test based on these impurities showed that the density increases as the content of carbon black decreases. Yet, at the same time, it was observed that the thermal characteristic decreases to some extent. This is considered to be occurring by the effects of impurities included in the carbon black. In other words, it seems that the free kinetic energy of the ionic impurities included in carbon black increases by being stimulated by outer energy.

The final conclusion through these results is that the ionic impurities included in carbon black give massive negative effects to the semiconductive shield, bringing aging. A method to minimize ionic impurities should be studied.

Acknowledgment

This study was supported by the Korea Electrical Engineering and Science Research Institute Project R-2003-B-335 of the Ministry of Commerce, Industry and Energy

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