A Study on the Thermal Properties of CNT reinforced Semiconductive Shield Materials Used in Power Cables

Hoon Yang†, Jeong-Hwan Bang*, Hong-Soon Chang, Chang-Woon Nah*** and Dae-Hee Park******

Abstract – Use of the carbon nanotube is superior to general powder state materials of mechanical and electrical properties. Because its ratio of diameter and length (aspect ratio) is very large, it has been known as a type of ideal nano-reinforcement material. Based on this advantage, the existing carbon black of semiconductive shield materials used in power cables can acquire excellent properties by using a small amount of carbon nanotubes. Thus, we investigated the thermal properties of the carbon nanotube, such as thermal conductivity, specific heat, and DSC (Differential Scanning Calorimetry). We found that a high thermal resistance level is demonstrated by using a small amount of carbon nanotubes. *As a result, this tendency confirms high cross-linking density in a new network in which the carbon nanotube between carbon black constitute molecules shows a bond by similar constructive properties.*

Keywords: CNT, Cable, Thermal, Crystallinity

1. Introduction

If sizes in material were decreased as nano-scale, material characteristics should be changed. Such changes represent significantly different characteristics compared to that of existing materials and that lead to actively conduct various studies on the development new materials and their applications[1]. Recent studies that have been focused on the improvement of underground power transmission cables prolong the service life of cables, and electric and fundamental characteristics of cables have been largely conducted in a certain limited field, such as XLPE (cross-linked polyethylene) insulation shield. This study attempts to newly recognize the role and function of semiconductive shield materials by emphasizing the importance of such materials through deep analysis on the usage of semiconductive shield materials in power transmission cables.

Present day power cables consist of conductor shield (strand shield), insulation shield, neutral wire, and jacket based on conductor. In recent years, a type of water tight tape has been used between insulation shields and jackets in Korea. Each specific shield plays a unique role in such a composition. If a part represents certain malfunctions in such specific shields, it causes dielectric breakdown and that leads to power cable faults. Many researchers have been devoted to study of power cables and electrical characteristics of the materials used in power cables. However, most studies have been focused on insulation layers [2, 3].

Therefore, this work attempts to inspire a new recognition in the role and function of semiconductive shield based on its importance through performing an intensive analysis on the semiconductive shield materials used in power cables [4, 5].

Furthermore, this study focuses on specific heat, thermal conductivity, heat capacity, and melting temperature.

The carbon nanotube is superior to general powder state materials of mechanical and electrical properties. Because its ratio of diameter and length (aspect ratio) is very large, it has been known as a type of ideal nano-reinforcement material [6-8]. But, semiconductive shield materials used in power cables include lots of carbon black. Spherical shaped carbon black represents higher specific gravity than that of long tube shaped carbon nanotube. Based on these properties, it is a very significant study on the use of carbon nanotube, which shows a sufficient efficiency in thermal properties by only a small amount of carbon nanotube and comparing it with a production process that adds about 35[wt%] ~ 40[wt%] of carbon black in order to present semiconductive properties in a semiconductive shield material process. Because such complex materials

† Corresponding Author: Department of Electrical Electronic and Information Engineering, Wonkwang University, South Korea. (hero6701049@naver.com)
* Department of Environmental Health, Seonam University, South Korea. (bjh144@hanmail.net)
** Department of Knowledge-based Technology and Energy, Korea Polytechnic University, South Korea. (hschang@kpu.ac.kr)
*** BK-21 Polymer BIN Fusion Research Team, Chonbuk National University, South Korea. (cnah@chonbuk.ac.kr)
**** Department of Electrical Electronic and Information Engineering, Wonkwang University, South Korea.(parkdh@wonkwang.ac.kr)
Received 18 October, 2007 ; Accepted 14 January, 2008

using carbon nanotube show a wide contact area compared to that of reinforced materials, it has been attracted as a new material that is able to perform various functions by improving their mechanical, thermal, and electrical characteristics [9-11].

This study analyzes and compares the thermal property of the conventional semiconductive shield materials according to the applied carbon black, carbon nanotube, and two fillers.

2. Experiment

2.1 Experimental Materials

The polymer matrix used in this experiment was EEA (Ethylene Ethyl Acrylate, Dupont-Mitsui Polychemicals Co. Ltd). Also, the filler that improves conductivity and strength was ACB (Acetylene Carbon Nanotube, LG Chemical Co. Ltd) and CNT (Carbon Nanotube, Iljin Nanotech Co. Ltd: CM-95, diameter: 10~15nm, length: 10~20μm, and purity: >95%) were used. In addition, the solvent used in a solution mixing process was Xylene (purity: 95%, Samchun Pure Chemical Co. Ltd). Table 1 represents the composition of the applied polymer nano complex.

Table 1. Compound Formulation

Compound	Polymer	CNT	CB
A1	53.8[EVA]	-	38.7
A2	53.8[EBA]	-	38.7
A3	57.8[EBA]	-	37.2
CNT:CB=0:100		-	10
CNT:CB=20:80		2	8
CNT:CB=50:50	90[EEA]	5	5
CNT:CB=80:20		8	2
CNT:CB=100:0		10	-

Furthermore, this study investigated the influence of the filler for the base polymer ethylene ethyl acrylate polymer matrix to examine the influence caused by the types of fillers.

2.2 Fabrication of specimens

As shown in Fig. 1, this study used a solution mixing method to improve the dispersibility. A dispersible solution was produced by dispersing the carbon nanotube in a good solvent uniformly after producing an ethylene ethyl acrylate solution by adding the ethylene ethyl acrylate in a good solution.

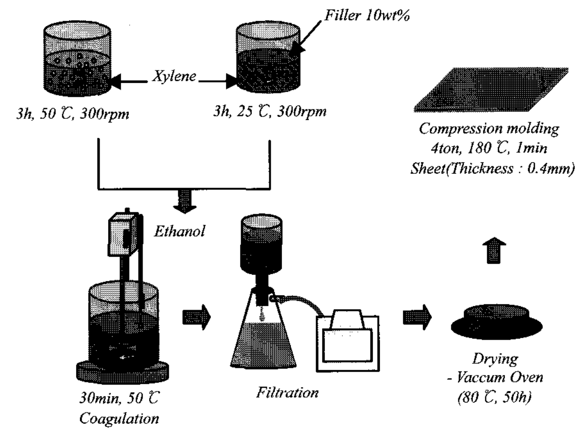


Fig. 1. Schematic of solution mixing method

Then, sediments were obtained by mixing the ethylene ethyl acrylate solution and carbon nanotube uniformly. Also, the sediments were filtered and dried. The applied solution was removed in which the sediments were compressed as a shape of sheets. The solution mixing method dissolved and dispersed the ethylene ethyl acrylate and carbon nanotube in a good solvent and mixing it again whereas an adding process of extra additives was neglected. Thus, it was possible to fabricate a certain type of semiconductive shield material that satisfies the thermal property of power cables by dispersing the carbon nanotube with a high level of dispersibility.

Regarding the specimens used in this experiment, the base polymer was configured using the ethylene ethyl acrylate.

Also, the specimens that were configured as five different types according to their composition ratios in the carbon nanotube and carbon black, such as 0:100, 20:80, 50:50, 80:20, and 100:0, using a DFS (Dual Filler System) was compared with three conventional semiconductive shield materials.

2.3 Measurement of thermal conductivity and specific heat

The thermal conductivities of the specimens were measured using a laser flash method with the LFA 447 by NETZSCH. The measured temperature for the specimens was configured as 25[℃] and 55[℃], respectively, by following the ASTM E1461.

The specific heat (Cp) of the specimens was measured by using a specialized DSC with a μ-sensor (DSC 204F1 by NETZSCH). Also, the measurement temperature was configured as 25[℃] and 55[℃], respectively. The temperature determined by 55[℃] was due to the fact that the melting temperature of the materials used in this experiment was ranged around 60[℃].

2.4 Measurement of DSC

A DSC (Difference Scanning Calorimetry) is a device that measures the thermal values of materials when physical and chemical transitions occurred in such materials. It is possible to analyze melting temperature (Tm), heat capacity (ΔH), and specific heat (Cp) that demonstrate the quantitative and qualitative information generated in the physical and chemical change including the endothermic and exothermic reaction of the specimens.

The measurement was performed using a DSC (DSC 2920 by TA Instrument), and the measurement range was -100[℃] to 100[℃] in which the temperature increment was configured as 4[℃/min].

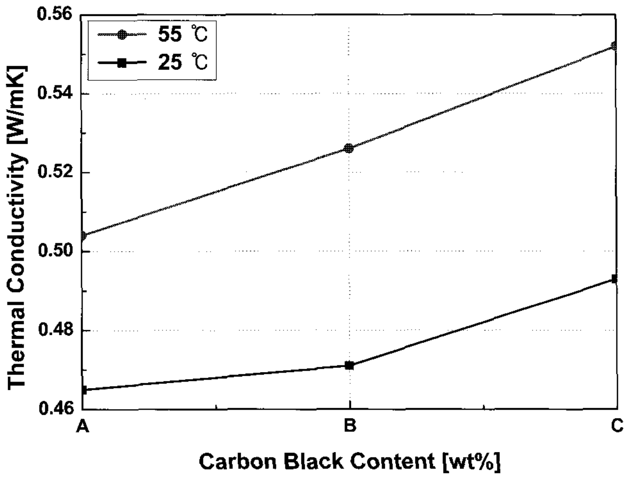


Fig. 3. Conventional materials of thermal conductivity

3. Results and consideration

3.1 Measurement of thermal conductivity

The wire used in power cables generates a high level of heat as much as the Joule heat when high voltages are applied. If there are no specific semiconductive shields between the wire and the insulation shield in power cables, certain dielectric breakdown will be occurred like thermal degradation or electric tree by transferring the heat generated in such wires to insulation materials directly.

If semiconductive shield materials used in the internal environment of power cables show a high level of thermal conductivity, rapid thermal conduction and convection to insulation materials will be occurred and that are able to protect the insulation materials from thermal stresses by releasing generated heat into the air.

A laser flash method was applied to measure the mentioned characteristics.

Fig. 2 and 3 illustrate the results of the measurement. As shown in Fig. 2, the thermal conductivities of the carbon nanotube reinforced semiconductive shield materials were measured as 0.307[W/mK] ~ 0.358[W/mK] and 0.312[W/mK] ~ 0.363[W/mK] at 25[℃] and 55[℃], respectively. Thus, it was evident that the thermal conductivity increased according to the increase in the applied temperature of such carbon nanotube reinforced semiconductive shield materials.

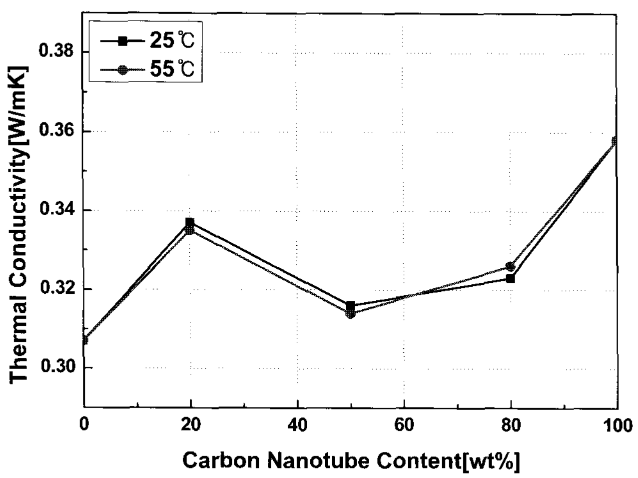


Fig. 2. CNT reinforced materials of thermal conductivity

However, it showed a low level in the thermal conductivity with a very small amount of the carbon nanotube compared to that of the composition rate of carbon black, 37[wt%] ~ 39[wt%], used in the conventional semiconductive shield materials. As illustrated in Fig. 3, the semiconductive shield materials used in the present time show higher thermal conductivities than that of the carbon nanotube reinforced semiconductive shield materials.

In addition, it represents an increase in the thermal vibration between the atom in the base polymer and the thermal electron in the carbon black by adding carbon nanotube that shows excellent thermal conductivities. Therefore, it is nature that the conventional semiconductive shield materials represent an increase in thermal conductivities.

Based on these results, it was evident that the carbon nanotube reinforced semiconductive shield materials could not be easily reacted to the external heat compared to that of the conventional semiconductive shield materials.

3.2 Measurement of specific heat

Fig. 4 and 5 depict the measured specific heat. The specific heats of the carbon nanotube reinforced semiconductive shield materials at 25[℃] and 55[℃] were measured as 2.115[J/g℃] ~ 2.237[J/g℃] and 2.774[J/g℃] ~ 2.985[J/g℃], respectively

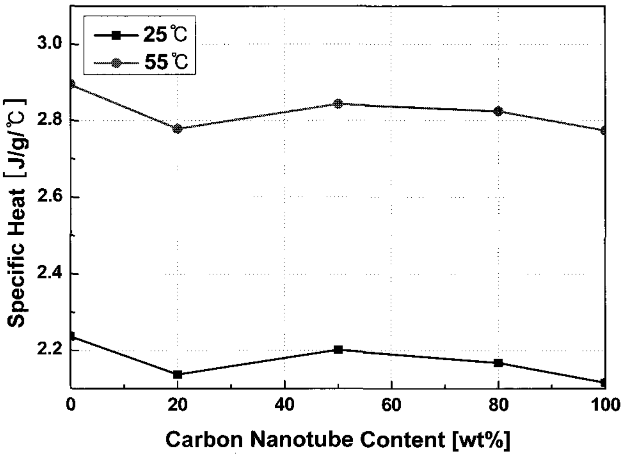


Fig. 4. CNT reinforced materials of specific heat.

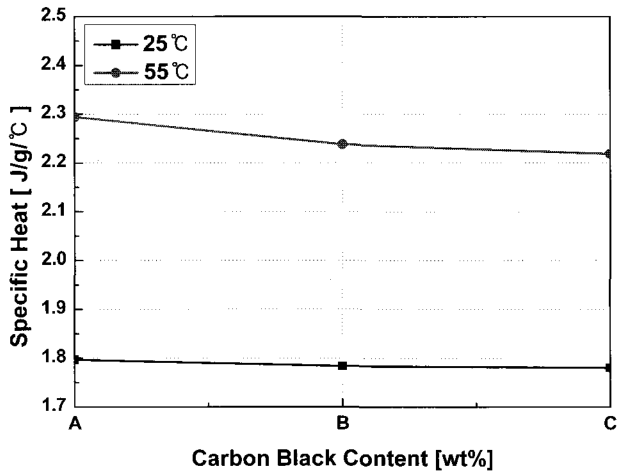


Fig. 5. Conventional materials of specific heat

As shown in Fig. 5, the specific heats of the conventional semiconductive shield materials at 25[℃] and 55[℃] were 1.782[J/g℃] ~ 1.799[J/g℃] and 2.219[J/g℃] ~ 2.294[J/g℃], respectively. The specific heat of the carbon nanotube reinforced semiconductive shield materials showed higher values than that of the conventional semiconductive shield materials.

Thus, it was cleared that the carbon nanotube reinforced semiconductive shield materials could not be easily reacted to the externally generated heat compared to that of the conventional semiconductive shield materials. It was the same manner as the previous results of the measurement of thermal conductivities.

3.3 Measurement of DSC

Fig. 6 and 7 illustrate the heat capacity (ΔH), melting temperature (Tm) of the carbon nanotube reinforced semiconductive shield materials and conventional semiconductive shield materials measured at -100[℃] ~

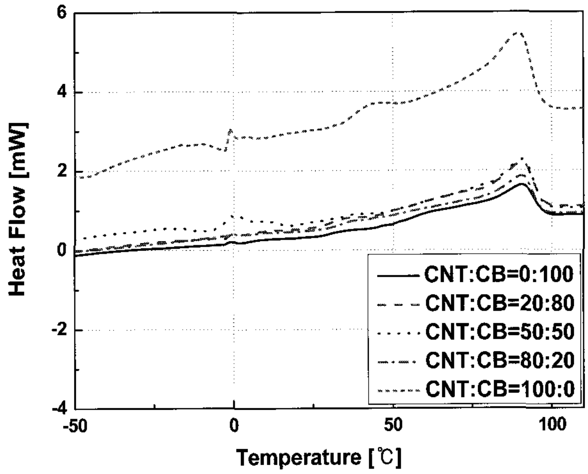


Fig. 6. CNT reinforced materials of DSC

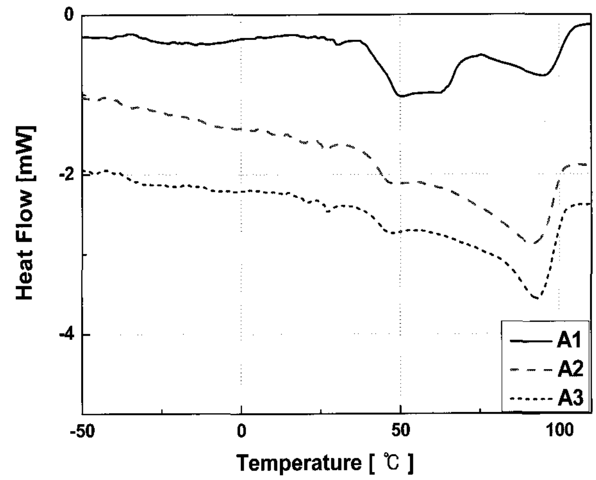


Fig. 7. Conventional materials of DSC

100[℃] according to the composition rate of the carbon nanotube.

It was possible to recognize the generation of the glass transition temperature that is the beginning of the internal segmentation of main chains (micro Brownian motion) according to the increase in temperature as the circles shown in Fig. 6 and 7.

As noted in Table 2, the comparison between the conventional and the carbon nanotube reinforced semiconductive shield materials improved heat capacity of complex materials when the carbon nanotube was added.

Based on these results, certain mechanical properties were improved due to the increase in the crystallinity of the carbon nanotube reinforced semiconductive shield materials that represent a high level in thermal conductivities. However, it was known that the carbon nanotube reinforced semiconductive shield materials were able to prolong the service life of such materials due to the strong thermal resistivity even though it demonstrated low workabilities due to their high melting temperatures.

Table 2. Specimen of T_m, $\triangle H$

Compound	T_m [℃]	$\triangle H$ [J/g]
A1	41.06	16.68
A2	68.00	21.67
A3	76.01	26.49
CNT:CB=0:100	92.79	39.18
CNT:CB=20:80	92.23	39.99
CNT:CB=50:50	92.08	40.61
CNT:CB=80:20	92.34	39.92
CNT:CB=100:0	90.36	35.94

4. Conclusion

This study fabricated polymer complex with the carbon nanotube using a solution mixing method and investigated the thermal properties by comparing it with the conventional semiconductive shield materials. Based on the results of this investigation, the conclusion of this study can be summarized as follows:

Although the carbon nanotube reinforced semiconductive shield materials showed low thermal conductivities compared to the conventional semiconductive shield materials, it represented high values in specific heat, melting point, and heat capacity. The heat capacity was significantly related to the crystallinity of materials. The semiconductive shield materials that contained a very small amount of the carbon nanotube were recognized as excellent materials due to the improvement in the mechanical properties of such materials because the crystallinity increased according to the increase in heat capacities.

In addition, the conventional semiconductive shield materials represented an excellent property in their workabilities even though it could not be easily reacted to external heats in certain specific heats, melting points, and thermal conductivities.

From these results, the carbon nanotube reinforced semiconductive shield materials demonstrated stable characteristics in thermal influences due to the improvement in the degree of cross-linking in the base polymer according to the increase in the applied carbon nanotube.

Acknowledgements

This study was supported by the incubation and support project of University Power Research Centers (I-2004-0-074-0-00) sponsored by the Korea Electrical Engineering & Science Research Institute (R-2005-7-100) and the Ministry of Commerce, Industry, and Energy.

References

[1] H. C. Kim, "A study on the change in mechanical and physical characteristics of carbon nanotube added nano complex materials", Master's thesis, pp. 1-2, 2002.

[2] T. Tanaka and A. Greenwood, Advanced Power Cable Technology, CRC Press, Florida, 1983.

[3] R. Bartnikas and K. D. Srivastava, Power Cable Engineering, Sandford Educational Press, Waterloo, Ontario, 1987.

[4] J. H. Han, S. J. Kim, O. H. Kwan, H. T. Kang, K. S. Seo, "Impurities Effect of Semiconductive Shield Materials in Power Cables", KIEE, Vol. 46, No. 1, pp. 19-27, 1997.

[5] J. H. Han, I. K. Song, J. S. Lim, D. Y. Lee, "Design Technology of Semiconductive Shield Materials in Power Cables", KIEEME, Vol. 13, No. 2, pp. 12-17, 2000.

[6] Iijima, S., 1991, "Helical Microtubules of Graphitic Carbon", Nature, Vol. 354, pp. 56-58.

[7] Gojny, F. H., Nastalczyk, J., Roslaniec Z., and Sculte, K., 2002, "Surface Modified Multi-walled Carbon Nanotubes in CNT/Epoxy-composites". Physical Chemistry Letters, Vol. 370, pp. 820-824.

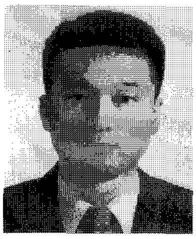
[8] Ishii., T., Nozawa, H., Tamamum, T., 1997, "A Nano-composite Resist System: A New Approach to Nanometer Patten Fabrication", Microelectronic Engineering, Vol. 35, pp. 113-116.

[9] Allaoui, A., Bai, S., Cheng, H. M., and Bai, J, 2002, "Mechanical and Electrical Properties of a MWNT/Epoxy Composites", Composite Science and Technology, Vol. 62, pp. 1993~1998.

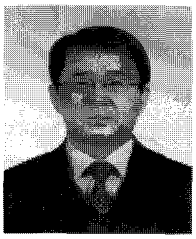
[10] Andrews, R., Jacques, D., Qian, D., and Dickey, E. C., 2001, "Purification and Structural Annealing of Multiwalled Carbon Nanotubes at Graphitization Temperatures", Carbon, Vol. 35, pp. 1681~1687.

[11] Wang, L. Y., Tu, J. P, Chen, W. X., and Zhang, X. B., 2003, "Friction and Wear Behavior of Electroless Ni-Based CNT Composite Coatings", Wear, Vol. 254, pp. 1289~1293.

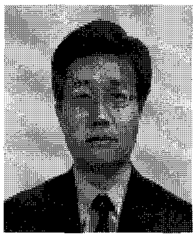
Hoon Yang
He graduated from the Division of Electrical Electronic Engineering at Wonkwang University in 2007. He is currently taking a master's course in the Department of Electrical Materials, Wonkwang University. His main research interests are insulation, semiconductive composites in power cables.



Jeong-Hwan Bang
He received B.S., M.S., Ph.D. degree in department of chemistry from Hanyang university in 1988. He worked at the Namyang Special Rubber Co., Ltd. as a Senior Researcher from 1988 to 1994. After that, he joined the School of Department of Environmental Health at Seonam University where he is currently employed as a assistant Professor. His main research interests are in the areas of nanoparticle, nanocomposite.



Hong-Soon Chang
He received B.S. in Electrical Engineering from Hanyang University in 1978, M. E. degree in Electronic Computer Science from the Graduate School of Industry, Hanyang University in 1986, M. A. degree in Business Administration from the University of IOWA in U.S.A. and respectively his Ph.D. degree from Dongguk University in 2001. He worked at IAA, SMBA and MOCIE as a Government official from 1978 to 2007. He joined the Graduate School of Knowledge-Based Energy and Technology at Korea Polytechnic University where he is currently employed as an Inviting Professor from 2007. His main research interests are in the areas of new lighting source and renewable energy including solar cell.



Chang-Woon Nah
He received B.S., M.S. degrees in Electrical Engineering from Ajou University in 1984 and 1986, respectively and his Ph.D. degree from Akron University in 1995. He worked at the Kumho Tire Research Institute as a Senior Researcher from 1985 to 1998. After that, he joined the School of Macromolecule Engineering at Chonbuk National University where he is currently employed as an Associate Professor. He was at Virginia Polytech Institute and State University as a Visiting Professor from 2005 to 2006. His main research interests are in the areas of Deformation, Fracture Process, Adhesion and Viscoelastic Properties in Polymer & Elastomer.

Dae-Hee Park
He received B.S., M.S. degrees in Electrical Engineering from Hanyang University in 1979 and 1983, respectively and his Ph.D. degree from Osaka University in 1989. He worked at the LG Cable Research Institute as a Senior Researcher from 1974 to 1992. After that, he joined the School of Electrical, Electronics and Information Engineering at Wonkwang University where he is currently employed as a Professor. He was at MSU in the USA as a Visiting Professor from 1999 to 2000. His main research interests are in the areas of insulting and dielectric materials, new lighting source and discharge.