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Effect of Ambient Temperature on Insulation Lifetime of Winding Coil Prepared with Polyamideimide/Nanosilica Enamelled Wire

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The effects of ambient temperature and diameter on the insulation lifetime of winding coils prepared with polyamideimide (PAI), flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%) wires were investigated. The winding coils were made of enameled wire with enamel thickness of 30~50 μm. The thickness and width of the rectangular copper wires were 0.77~0.83 mm and 1.17~1.23 mm, respectively. The insulation breakdown lifetime decreased with increasing ambient temperature regardless of wire type and winding coil diameter under an inverter surge of 1.5 kV/20 kHz. The insulation breakdown lifetimes of φ5 mm winding coils at 150, 200, and 250℃ were 11.38, 5.19, and 4.22 min respectively, and those of φ10 mm winding coils at 150, 200, and 250℃ were 11.32, 5.79, and 4.57min respectively. The winding coil diameter had little effect on the insulation lifetime.

Keywords: Enamel insulated wire, Partial discharge, Insulation lifetime, Insulation breakdown voltage

1. INTRODUCTION

Polyamideimide (PAI) enameled wires have good thermal and electrical insulation properties. Polyamide is a sort of polymer with high insulation breakdown strength and good heat resistance, mechanical strength and chemical resistance. Consequently, polyamide insulated wires are used in harsh environmental conditions [1-3]. Polyimides are used in inverter-fed motor windings and high pressure coils for electric translators.

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In recent years, elements with high-speed switching such as insulated-gate bipolar transistors (IGBTs) have been developed as inverter power devices.

In recent years, many researchers have focused on the application of nano-sized fillers on a polymer matrix [4-7] because polymer nanocomposites have much better insulation characteristics than neat polymers without nanofiller. It was also found that nanofillers improved the electrical and mechanical properties of polymers.

As environmental issues have attracted much interest at the international, national and local levels in recent years, energy efficiency issues have become more important. In the industrial motor area, an increasing number of motors now have inverters or adjustable-speed drives to deliver the higher efficiency required for today's industrial motors. Inverter power supplies that apply the pulse modulated (PWM) technique, in which insulated gate bipolar transistors (IGBTs) are used as high speed switching devices, can improve the controllability of the motor torque and reduce switching loss [8-10].

In this study, the insulation lifetime was investigated using coil-wound specimens prepared with polyamideimide (PAI), flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%) wires in close contact with the cylinder. The enamel thickness was 30~50 μm.

2. EXPERIMENTS

PAI wires were prepared by coating rectangular copper wires with seven types of PAI/nanosilica (15 wt%) enamels (Sam Dong Co., Ltd., Korea) with thickness of 30~50 μm. The thickness and width of the rectangular copper wires were 0.77~0.83 mm and 1.17~1.23 mm, respectively. The first wire was coated with original PAI, the three types of wires in the second group were coated with double layers of flexural PAI and anti-corona PAI (nanosilica 15 wt%), and the three types of wires in the third group were coated with double layers of flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%). Type_1 and Type_4 were dried at 220℃, Type_2 and Type_5 were dried at 240℃, and Type_3 and Type_6 were dried at 260℃.

In order to study the insulation lifetime, an inverter surge voltage of 1.5 kV/20 kHz was applied to the samples through close contact with the cylinder as shown in Fig. 1. A straight piece of wire with the insulation removed at one end was connected to the upper terminal as shown in Fig. 1 and wound once around the cylinder [11]. A load of 380 g was applied to the lower end of the wire to keep the specimen in close contact with the cylinder. The cylinder diameters were φ5 mm or φ10 mm.

A sinusoidal waveform voltage of 1.5 kV with 20 kHz was applied to the coil specimens using a withstanding voltage tester (Model: APCP-12 kV-100, Sky Innotek Co., Ltd.) for frequency acceleration. Insulation lifetime was measured at a speed of 40 V/s until 1.5 kV maintained at 1.5 kV until electrical insulation breakdown took place. The test apparatus with the wire samples was placed in a convection oven set at 150℃, 200℃, or 250℃, and 1.5 kV was applied to the samples at the same temperature until insulation breakdown took place.

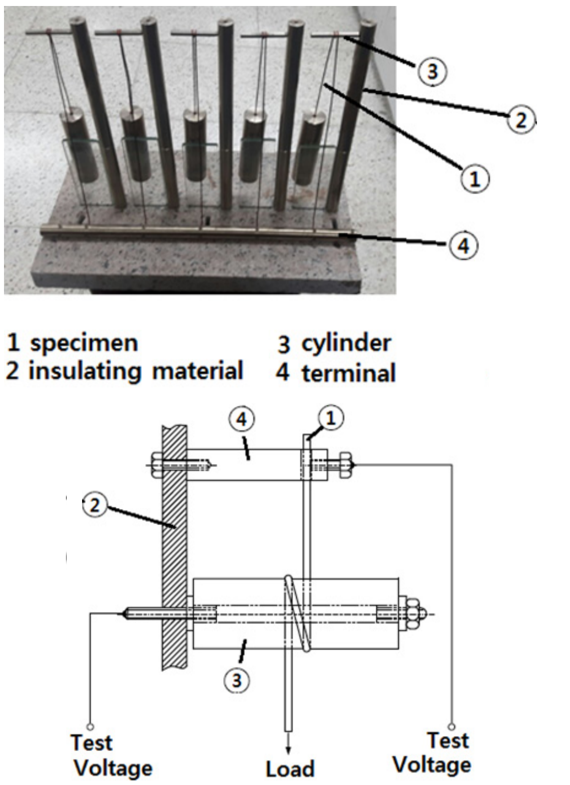

Fig. 1. Arrangement of cylinder and specimen for the breakdown voltage test.

3. RESULTS AND DISCUSSION

Figure 2 shows the Weibull statistical analysis (Weibull++ 7.0) for insulation lifetime for original PAI wires of (a) φ5 mm and (b) φ10 mm ambient temperatures of(●) 150℃, (■) 200℃, and (▲) 250℃. The scale and shape parameters as well as the B10 value were obtained from the Weibull plots and are listed in Table 1. Here, the scale parameter corresponds to the AC electrical lifetime by which the coils is expected to fail with a cumulative probability of 63.2%. The shape parameter was obtained from the slope and represents the data distribution. The B10 value represents the electrical lifetime at which 10% of the coils are expected to fail(90% would survive) under a given test condition

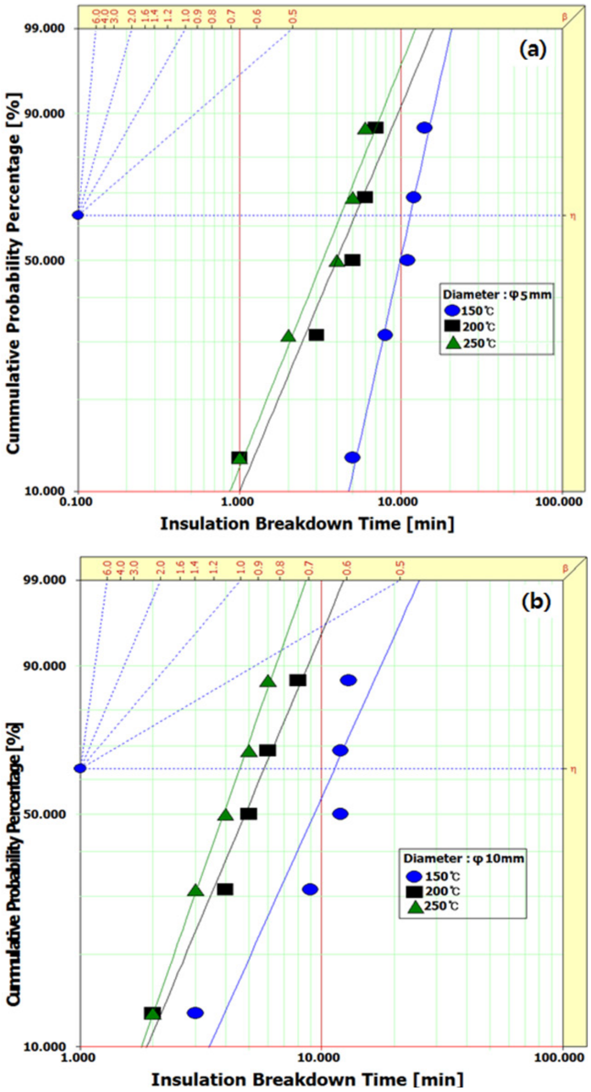

Fig. 2. Weibull statistical analysis for insulation lifetime for original PAI wires with diameters of (a) φ5 mm and (b) φ10 mm. Ambient temperature was (●) 150℃, (■) 200℃, and (▲) 250℃.

Table 1. Weibull parameters for the insulation lifetime for original PAI wires shown in Fig. 2.

Winding Coil Diameter (mm)	Temperature (℃)	Scale Parameter (min)	B10 Value (min)	Shape Parameter
5	150	11.38	4.78	2.58
	200	5.19	0.99	1.36
	250	4.22	0.87	1.42
10	150	11.32	3.43	1.88
	200	5.79	1.90	2.00
	250	4.57	1.53	2.39

Table 2. Weibull parameters for insulation lifetime for Type_1 wires shown in Fig. 3.

Winding Coil Diameter (mm)	Temperature (℃)	Scale Parameter (min)	B10 Value (min)	Shape Parameter
5	150	15.42	12.5	10.88
	200	14.95	9.98	6.42
	250	10.92	6.62	4.50
10	150	20.42	14.78	14.78
	200	10.05	6.96	6.96
	250	6.63	3.67	3.67

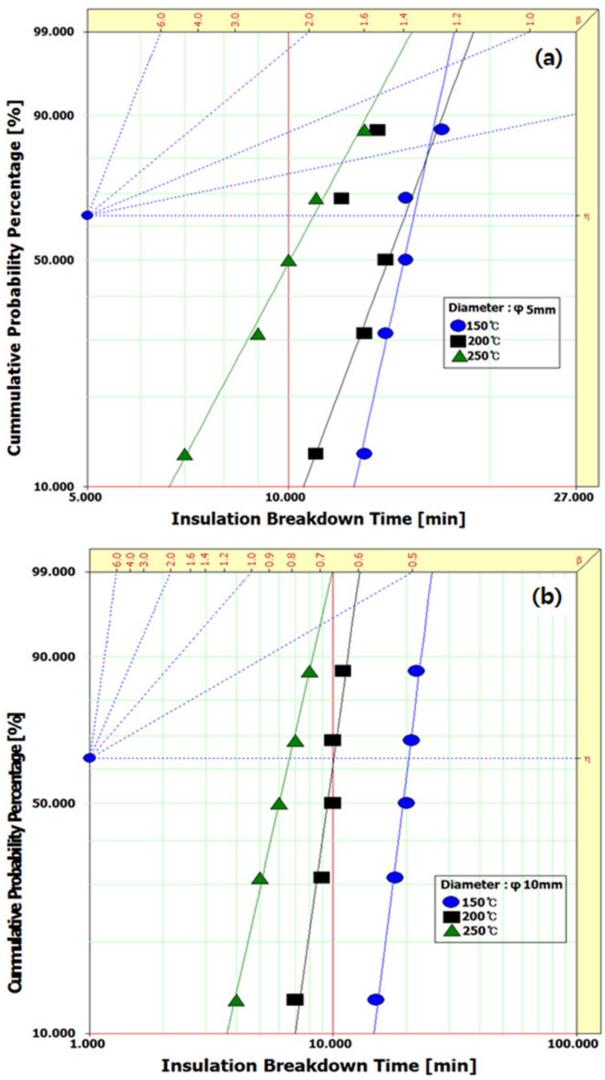

Fig. 3. Weibull statistical analysis for insulation lifetime for Type_1 wires with (a) φ5 mm and (b) φ10 mm diameters . Ambient temperature was (●) 150℃, (■) 200℃, and (▲) 250℃.

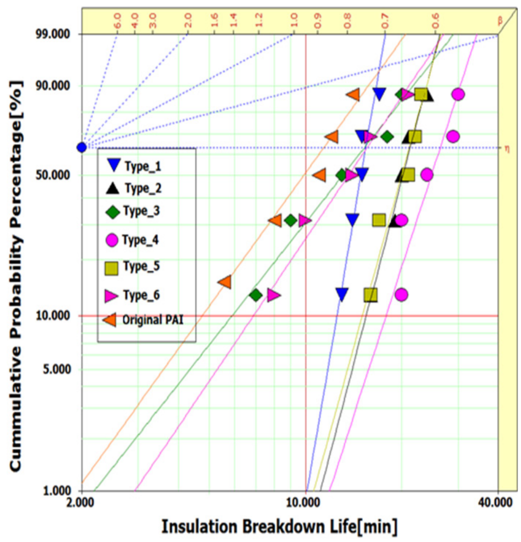

Fig. 4. Weibull parameters for insulation lifetime for various types of wires with φ5 mm winding coil diameter at 150℃.

[12]. The scale parameters of the original PAI wires with a diameter of φ5 mm at 150℃, 200℃, and 250℃ were 11.38, 5.19, and 4.22 min, respectively. These corresponding values for original PAI wires with diameters of φ10 mm at 150℃, 200℃, and 250℃ were 11.32, 5.79, and 4.57 min, respectively. Insulation breakdown lifetime decreased with increasing ambient temperature regardless of winding coil diameter, and the winding coil diameter had little effect on the insulation lifetime.

Figure 3 shows the Weibull statistical analysis for the insulation lifetime for Type_1 wires with (a) φ5 mm and (b) φ10 mm diameters ambient temperatures of(●) 150℃, (■) 200℃, and (▲) 250℃. The scale and shape parameters as well as the B10 value were obtained from the Weibull plots and are listed in Table 2. The Type_1 wire was prepared by coating a copper conductor with double layers of flexural PAI and anti-corona PAI (nanosilica 15 wt%),and drying at 220℃. The scale parameters of the Type_1 wire with a diameters of φ5 mm at 150℃, 200℃, and 250℃ were 15.42, 14.95 and 10.92 min, respectively. The corresponding values for the Type_1 wire with φ10 mm diameter at 150℃, 200℃, and 250℃ were 20.42, 10.05, and 6.63 min, respectively. In this system, the insulation breakdown lifetime also decreased with increasing ambient temperature regardless of winding coil diameter.

Figure 4 shows the Weibull statistical analysis results for insulation lifetime for various types of wires with φ5 mm winding coil diameter at 150℃. The scale and shape parameters as well as the B10 value were obtained from the Weibull plots and are listed in Table 3. Type_1, Type_2, and Type_3 wires were prepared by coating a copper conductor with double layers of flexural PAI and anti-corona PAI (nanosilica 15 wt%) and drying at 220℃, 240℃, and 260℃, respectively. And Type_4, Type_5, and Type_6 wires were prepared by coating a copper conductor with double layers of flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%) and drying at 220℃, 240℃, and 260℃, respectively. The insulation lifetimes of the two groups were higher than that of the original PAI. The corresponding values in the second group

Table 3. Weibull parameters for insulation lifetime for various types of wires with φ5 mm winding coil diameter at various temperatures.

Temperature (℃)	Wire Type	Scale Parameter (min)	B10 Value (min)	Shape Parameter
150	PAI	11.38	4.78	2.85
	Type_1	15.42	12.55	10.88
	Type_2	21.24	17.57	7.11
	Type_3	15.27	5.90	2.36
	Type_4	26.38	17.85	5.76
	Type_5	21.09	15.00	6.68
	Type_6	15.58	6.88	2.75
200	PAI	5.19	0.99	1.36
	Type_1	14.95	10.53	6.42
	Type_2	14.15	10.67	7.91
	Type_3	11.98	5.11	2.62
	Type_4	11.58	6.95	4.43
	Type_5	9.76	2.9	1.86
	Type_6	10.94	5.55	3.32
250	PAI	4.22	0.87	1.42
	Type_1	10.92	6.65	4.50
	Type_2	9.78	6.08	4.73
	Type_3	7.52	3.05	2.50
	Type_4	9.30	3.23	2.11
	Type_5	6.08	0.69	1.04
	Type_6	8.89	4.70	3.53

Table 4. Weibull parameters for insulation lifetime for various types of wires of φ10 mm winding coil diameter at various temperatures.

Temperature (℃)	Wire Type	Scale Parameter (min)	B10 Value (min)	Shape Parameter
150	PAI	11.32	3.43	1.88
	Type_1	20.42	14.78	6.91
	Type_2	16.45	4.76	1.82
	Type_3	11.68	4.39	2.30
	Type_4	7.86	5.69	6.99
	Type_5	12.37	4.08	2.00
	Type_6	20.3	7.00	2.12
200	PAI	5.79	1.90	2.00
	Type_1	10.05	6.96	6.20
	Type_2	9.90	3.89	2.42
	Type_3	7.65	3.39	2.75
	Type_4	6.85	4.71	6.03
	Type_5	11.13	4.08	2.23
	Type_6	12.48	4.99	2.45
250	PAI	4.57	1.53	2.39
	Type_1	6.63	3.67	3.80
	Type_2	8.65	5.58	5.26
	Type_3	4.57	1.78	2.39
	Type_4	5.54	3.91	6.46
	Type_5	5.63	1.00	1.31
	Type_6	9.62	3.19	2.05

with higher nanosilica content were higher than in the first group with lower nanosilica content. This meant that nanosilica had a positive effect on the insulation lifetime of the enamelled wires at high ambient temperature. This result was different from our previous report [13], that is to say, nanosilica did not have a positive effect on the insulation breakdown voltage of the same enamelled wires when the test was performed at room temperature. The results indicate that the nanosilica provided heat resistance to the enamel wires.

The Weibull parameters for various types of wires with φ5 mm and φ10 mm winding coil diameters at 150℃, 200℃, and 250℃ are also listed in Table 3 and Table 4.

Insulation breakdown lifetime decreased with increasing ambient temperature regardless of winding coil diameter, and the winding coil diameter had little effect on the insulation lifetime.

4. CONCLUSIONS

Insulation lifetime at high ambient temperature was investigated in winding coils with two enamel layers prepared using polyamideimide (PAI), flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%). The winding coil diameters were φ5 and φ10 mm. The enamel thickness ranged from 30~50 μm. The Insulation lifetimes of the original PAI wire with φ5 mm at 150℃, 200℃, and 250℃ were 11.38, 5.19, and 4.22 min, respectively. The lifetimes for the Type_1 wire, which had two enamel layers made of flexural PAI and anti-corona PAI (nanosilica 15 wt%) were 15.42, 14.95, and 10.92 min, respectively. The corresponding lifetimes for the Type_4 wire, which had two enamel layers made of flexural PAI (nanosilica 5 wt%) and anti-corona PAI (nanosilica 15 wt%) were 26.38, 11.58, and 9.30 min, respectively. Insulation breakdown lifetime decreased with increasing ambient temperature regardless of coil wire type, and nanosilica had a positive effect on the insulation lifetime of the enamelled wires at high ambient temperature because the nanosilica provided heat resistance to the wires. The winding coil diameter had little effect on the insulation lifetime.

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