Safety and Health at Work 11 (2020) 405–417

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Original Article

Analysis of Thermal Characteristics and Insulation Resistance Based on the Installation Year and Accelerated Test by Electrical Socket Outlets

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ARTICLE INFO

Article history:
Received 25 November 2019
Received in revised form
27 April 2020
Accepted 16 June 2020
Available online 30 June 2020

Keywords:
accelerated test
electrical fire
insulation resistance
outlet
thermal characteristics

ABSTRACT

Background: Electrical socket outlets are used continuously until a failure occurs because they have no indication of manufacturing date or exchange specifications. For this reason, 659 electrical fires related to electrical socket outlets broke out in the Republic of Korea at 2018 only, an increase year on year. To reduce electrical fires from electrical socket outlets, it is necessary to perform an accelerated test and analyze the thermal, insulation resistance, and material properties of electrical socket outlets by installation years.

Methods: Thermal characteristics were investigated by measured the temperature increase of electrical socket outlets classified according to year with variation of the current level. Insulation resistance characteristics was measured according to temperature for an electrical socket outlets by their years of use. Finally, to investigate the thermal and insulation resistance characteristics in relation to outlet aging, this study analyzed electrical socket outlets' conductor surface and content, insulator weight, and thermal deformation temperature.

Results: Analysis showed, regarding the thermal characteristics, that electrical socket outlet temperature rose when the current value increased. Moreover, the longer the time that had elapsed since an accelerated test and installation, the higher the electrical socket outlet temperature was. With respect to the insulation resistance properties, the accelerated test (30 years) showed that insulation resistance decreased from 110 °C. In relation to the installation year (30 years), insulation resistance decreased from 70 °C, which is as much as 40 °C lower than the result found by the accelerated test. Regarding the material properties, the longer the elapsed time since installation, the rougher the surface of conductor contact point was, and cracks increased.

Conclusion: The 30-year-old electrical socket outlet exceeded the allowable temperature which is 65 °C of the electrical contacts at 10 A, and the insulation resistance began to decrease at 70 °C. It is necessary to manage electrical socket outlets that have been installed for a long time.

1. Introduction

Of the fire accidents in the Republic of Korea at 2018, the number of fires caused by careless mistakes fell by 3,076 from the year before; however, fires attributed to electrical causes, rose by as many as 1,205 year on year. In such fires attributed to electrical causes, tracking-caused short circuit was the most frequent, followed by insulation aging–caused short circuit, overload/overcurrent, and poor contact-led short circuit in that order. Regarding the ignition devices related to electrical causes, wiring/wiring appliances accounted for 2,668 accidents (25.5%), the highest. Of the wiring/wiring appliance-related fires, electrical socket outlet-related fire accidents were as many as 659 (24.7%) [1]. Such electrical socket outlet–related fires rarely take place during the manufacturing or installation period, but over several months or years; heat from overload/overcurrent affects an electrical socket outlet, causing insulation aging [2]. Insulation aging, in turn, carbonizes an insulator to cause insulation breakdown and short circuit. Short circuit often destroys the conductor and insulator completely with surrounding spark scars [3]. Such electrical socket outlet–caused fires may vary depending upon the environment of use, conditions of use, and so forth. First of all, rapid temperature

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https://doi.org/10.1016/j.shaw.2020.06.004

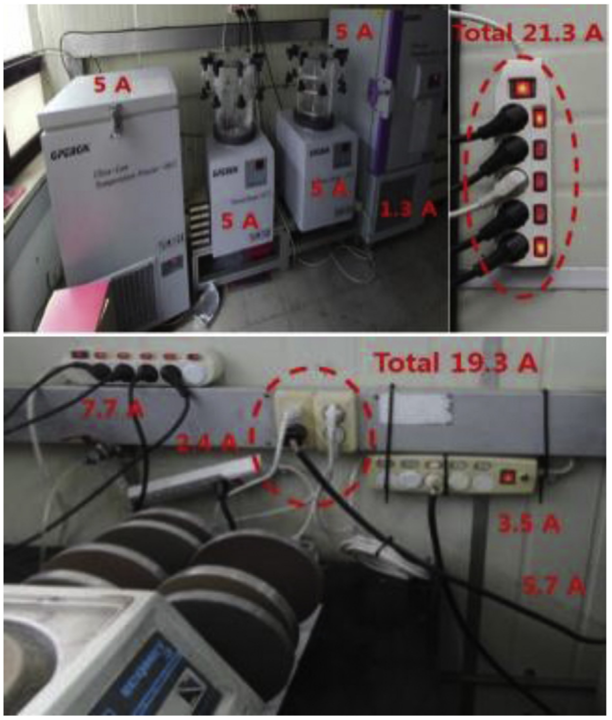


Fig. 1. Usage of overloaded electrical socket outlets in the laboratory.

and humidity changes in the environment of use accelerate conductor corrosion [4]. Once corrosion occurs, the conductor's cross-section area decreases, undermining its mechanical properties [5]. Conductor corrosion is one of the main causes of degradation [6]. Foreign substances, such as dust, also lead to contact failure, causing degradation. The following are the conditions of use: impacted by current of use, frequency of use, frequency of plug contact, and so forth. Electrical socket outlets, however, are typically installed when the construction of a building is completed and continue to be used without any maintenance management unless there is a reason to replace them, such as remodeling.

Against this backdrop, the present study compared the accelerated test with the actually used electrical socket outlets (10, 20, 30) to check their thermal characteristics and insulation resistance properties and identified problems in accordance with the environment of use. The accelerated test was implemented based on the Arrhenius equation considering the hours of use and temperature. Electrical socket outlets that had been used for 10 years, 20 years, and 30 years were collected from the machinery laboratories of Korea Institute of Machinery & Materials. Each of these outlets was investigated for the currency of use of its connected research equipment, frequency of use, and so forth. In the laboratories, current value–specific thermal characteristics and temperature value–specific insulation resistance properties were compared and analyzed. In addition, electrical socket outlets' material properties were examined to identify the conductor's thermal characteristics and insulator's insulation resistance property causes.

2. Theoretical background

2.1. Actual condition of electrical socket outlet use

Electrical socket outlets had the rated capacity of 16 A/AC 250 V of the commonly used electrical socket outlets in home and offices, certified under the KS C 8305 (plugs and socket outlets for domestic and similar purposes), and KS C IEC 60884-1 (plugs and socket outlets for household and similar purposes). Rated current was amended (2018.09.29.) as the KS C 8305 was realigned with the global standard to become 16 A from the initial 15 A [7]. The machinery laboratories of K institution were selected for the actual condition investigation of electrical socket outlets. The experimental equipment's current of use and management state were analyzed. Electrical socket outlets were collected based on the installation year.

The average current of use ranged from 3 A to 7.7 A. As seen in Fig. 1, some of the labs were found to have connected 4 (each 5 A) units and 1 (1.3 A) unit in a single electrical socket outlet. They could reach up to 21.3 A in total, exceeding the rated level of electrical socket outlets (16 A). In another lab, a 2-outlet electrical socket outlet was connected with a multitap (7.7 A, 2.4 A, 3.5 A, 5.7 A) in excess of the rated current.

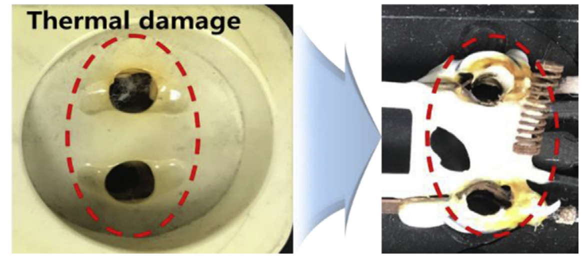


Fig. 2. Electrical socket outlets' contact hole carbonization on the inside and outside.

Fig. 2 shows the management state of electrical socket outlets. Plug contact holes were found to have been carbonized (thermal damage). This indicates serious carbonization inside the electrical socket outlets [8].

Installation year–specific electrical socket outlets were collected and classified based on the day of building construction completion. Electrical socket outlets are installed upon building construction completion. Buildings are generally remodeled after 30 years, and electrical socket outlets are also replaced during remodeling. For this reason, they were selected and classified under the criteria of 10, 20, and 30 years. Table 1 exhibits the environment of use and details of use of the collected electrical socket outlets. The environment of use was determined to be that of the laboratory on 1F of the machinery labs, where the area of research had not changed since the building construction completion. For the details of use, researchers were interviewed to investigate research equipment's current and average frequency of use. As a result, the main currency of use ranged from 3 A to 13 A, and the average frequency of use was 9 to 13 times a week. The collected electrical socket outlets, as seen in Fig. 3, were found to have various manufacturers, structures, materials, and so forth.

2.2. Thermal and insulation resistance properties

Electrical socket outlets consist of an electrifying conductor and a nonelectrifying insulator. The insulator surrounding the conductor (Cu) is usually composed of polybutylene terephthalate (PBT), and its appearance is mainly made from polycarbonate. The thermal characteristics of an electrical socket outlet conductor mainly include Joule's heat and poor contact. The insulator has an insulation resistance property, and the Arrhenius equation (accelerated test) is applied.

With respect to Joule's heat, the loss of total Joule's heat ***HT*** occurring in the outlet conductor with the power supply depends upon the relationship between the current flowing through the conductor (***I***) and conductor resistance, as expressed in the Eq. (1). The heat generated by ***HT*** is delivered to the insulator in the radiating process [9].

Table 1
The environment of use and details of use of the collected installation year–specific electrical socket outlets

Division	Installation years			
	0 Y	10 Y	20 Y	30 Y
Electrical socket outlet installation years	Not used	Used between 8 and 12 years	Used between 18 and 22 years	Used between 28 and 32 years
Allowable current [A]	16		15	
Year and month of building construction	—	‘07.12. (11Y)	‘98.9. (20Y)	‘90.10. (28Y)
Lab position [floor]	—	1	1	1
Change history of lab research field	—	Machine	Machine	Machine
Current of the main research equipment using electrical socket outlets [A]	—	4–11	3–13	5–10
The average use frequency of electrical socket outlets [times/week]	—	10	13	9
Collection quantity [EA]	12	12	12	12
		Total 48		

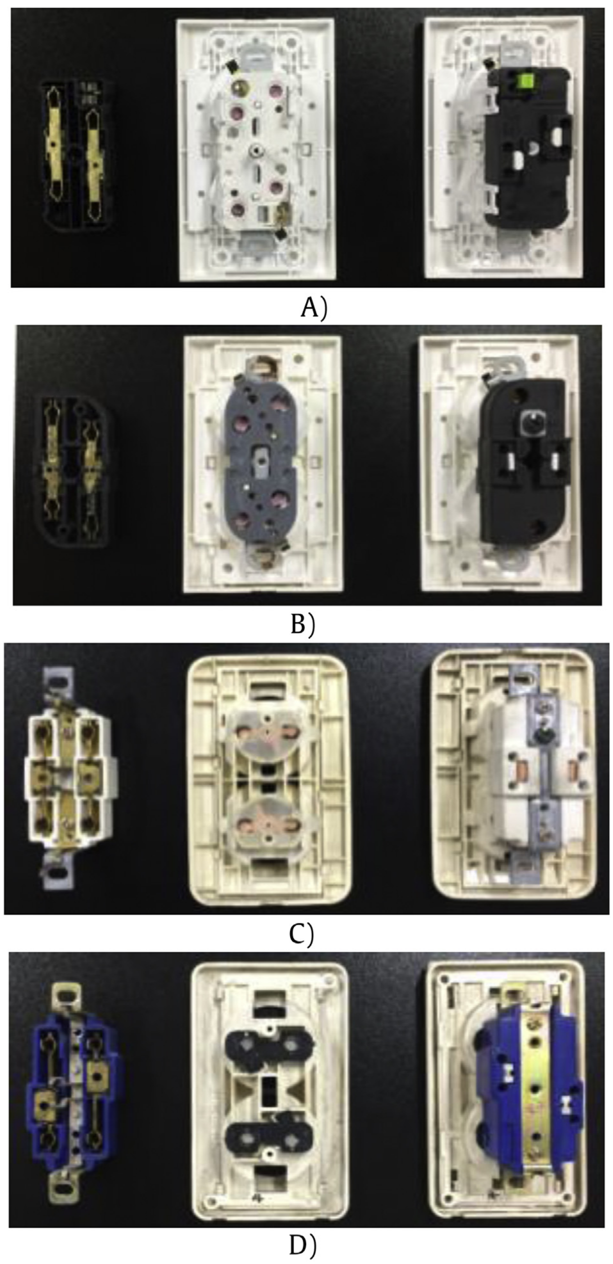


Fig. 3. Color and structural change of the collected installation year–specific electrical socket outlets. (A) 0 year. (B) 10 years. (C) 20 years and (D) 30 years.

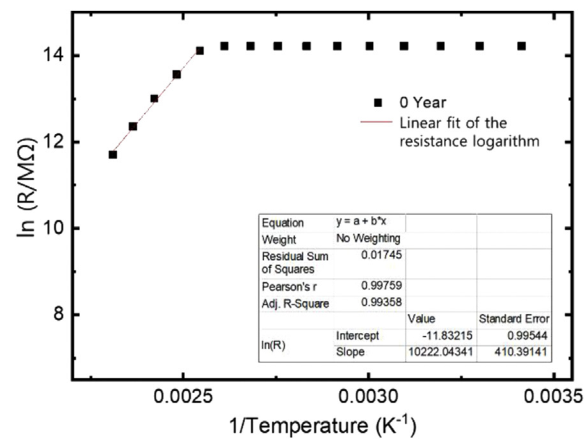


Fig. 4. Inclination based on electrical socket outlet temperature and insulation resistance.

Table 2
Accelerated test's aging time by year in electrical socket outlets

Division	0 Y	10 Y	20 Y	30 Y
Time	0 h 0 m	236 h 51 m	473 h 43 m	710 h 34 m
Quantity [EA]	—	12	12	12
		Total 36		

To maintain the necessary temperature for the accelerated test, EMS' Temp and Humidity Chamber, ECTH-700A was used with an error range of about ±0.8 °C.

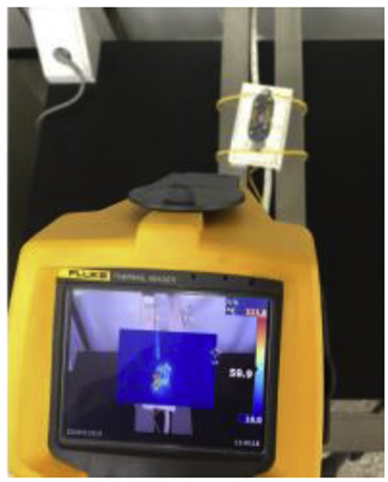
$$H_T = I^2R(t) \tag{1}$$

Conductor resistance ***R(t)*** is a function of temperature in accordance with time as expressed in Eq. (2), where ρ is the original resistance of the conductor, S is the conductor's cross-section area, and l is the conductor length. With respect to conductor resistivity, when the temperature rises as a result of Joule heating, the specific resistivity increases as well. However, such increasing specific resistivity was not considered in this study.

$$R(t) = \rho - \frac{l}{S}(t) \tag{2}$$

One primary mechanism leading to overheating of electrical socket outlet and plug connections was the formation of copper oxides at terminal connections involving copper wiring. In the event of poor contact of an electrical socket outlet, if the contact part of a conductor is loosely connected, conductor oxide is formed, which reduces the conductor contact area, generating heat first in the contact part [10].

A)



B)

Fig. 5. Experimental process for the thermal characteristics of electrical socket outlets. (A) Experimental device for current application and analysis points of thermal characteristic of electrical socket outlet. (B) Measurement using thermal imaging camera.

The insulator provides insulation to prevent short circuit between two phases. If the applied voltage is high or the temperature or humidity increases, the insulation resistance tends to drop [11]. Insulation resistance is the value of the direct current voltage divided by the sum of the charging current and leakage current as expressed in Eq. (3):

$$\boldsymbol{R} = \frac{\boldsymbol{V}}{\boldsymbol{I}} \tag{3}$$

As mentioned earlier, electrical socket outlets show temperature increases depending upon current values, and if the temperature rises, the insulation resistance becomes weaker.

The Arrhenius equation is broadly used to calculate the life of system parts. If a product's life is accelerated based upon temperature, its life depending upon temperature variation can be predicted. The Arrhenius equation represents an acceleration model based on temperature and time variations and has been most useful in the accelerated test. The Arrhenius equation is written as Eq. (4), where ***A*** is a constant gained through an experiment [12]:

$$\lambda = \boldsymbol{A} \bullet \boldsymbol{exp}(-\boldsymbol{ElK} \bullet \boldsymbol{T}) \tag{4}$$

E: activation energy
T: absolute temperature (T = 273+ °C)
k: Boltzmann constant ($8.617 \times 10^{-5}\ eV/K$)

The Arrhenius equation expressing the relationship between the acceleration factor and time is converted into an equation based upon the acceleration factor of temperature as Eq. (5) [13]:

$$\boldsymbol{K_2} = \boldsymbol{K_1} \bullet \boldsymbol{exp}\left(\frac{\boldsymbol{E_a}}{\boldsymbol{K}}\left(\frac{\boldsymbol{1}}{\boldsymbol{T_2}} - \frac{\boldsymbol{1}}{\boldsymbol{T_1}}\right)\right) \tag{5}$$

K2: accelerated aging [***K2***] = yr
K1: accelerated deterioration time [***K1***] = hr
$\boldsymbol{E_a}$: activation energy [$\boldsymbol{E_a}$] = eV
T1: accelerated deterioration temperature [***T1***] = K
T2: temperature of use [***T2***] = K

The activation energy ($\boldsymbol{E_a}$) of PBT, the insulator of a directly electrified live conductor is 84.2 kJ/mol or 0.872629 eV, if unit conversion [14]. Here, ***T1,*** the accelerated deterioration temperature, was set at 383 K (110 °C); ***T2,*** the temperature of use, was set at 313 K (40 °C).

3. Materials and methods

3.1. Accelerated test

To make 10- /20- /30-year-old electrical socket outlets according to the Arrhenius equation, an accelerated test was

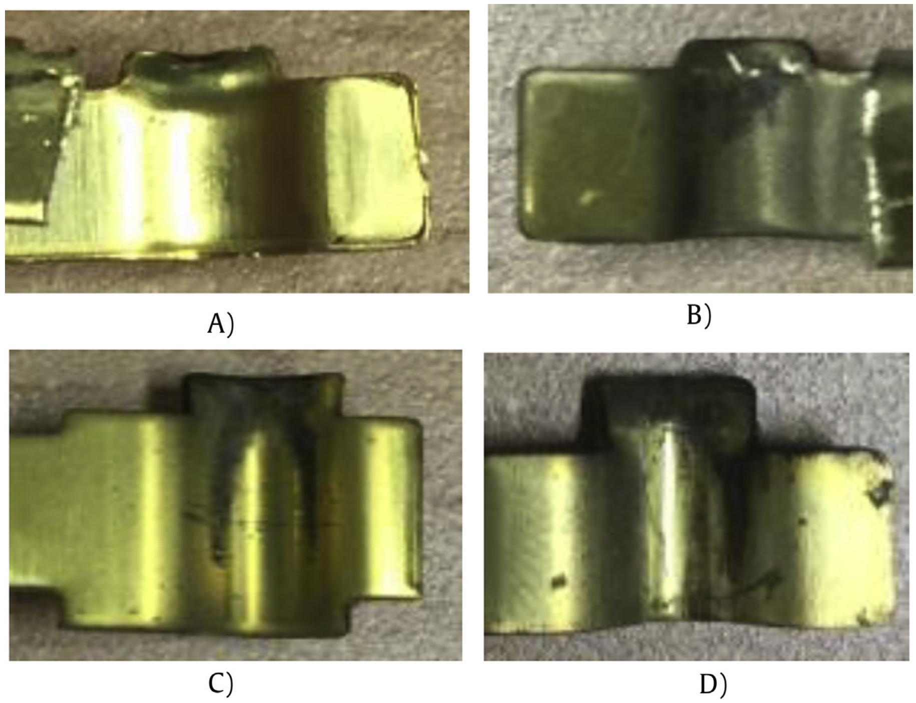


Fig. 6. Conductor contact point of electrical socket outlets by installation year. (A) 0 year. (B) 10 year. (C) 20 years and (D) 30 years.

implemented. To verify the PBT activation energy, 0.872629 eV, the temperature-specific insulation resistance of 0-year-old electrical socket outlets was measured, and the inclination of insulation resistance of a natural logarithm in accordance with temperature was obtained as 10,222.04, as in Fig. 4. The inclination unit was converted into 84996.26 J/mol, and then it was converted into activation energy to become 0.880882 eV. The deviation of activation energy was 0.008252 eV. The value found in a previous study was smaller. To improve the accuracy of the experimental results, the lower value was applied. By applying the activation energy, the time required for the accelerated test aging by year was found as shown in Table 2. The 10-year-old electrical socket outlets should be accelerated for 236 hr 51 min at the temperature of 383 K.

3.2. Thermal property experiment

To analyze the thermal characteristics of the electrical socket outlets, an accelerated test was implemented, and the actually used 0- /10- /20- /30-year-old electrical socket outlets were tested. The experimental ambient temperature was set at 20 °C, and 10 A, 20 A, and 30 A currents were applied. Although the rated capacity of the electrical socket outlets was 16 A, measurement of the actual outlet usage showed that the average consumption was 10 A, but sometimes it exceeded 16 A or was even 20 A in some cases. Although the circuit breaker for electric wiring connected to an electrical socket outlet was 20 A, 30 A was selected because electrical socket outlets are shut off at 30A. The time of application was the time of temperature saturation (the time when temperature is maintained

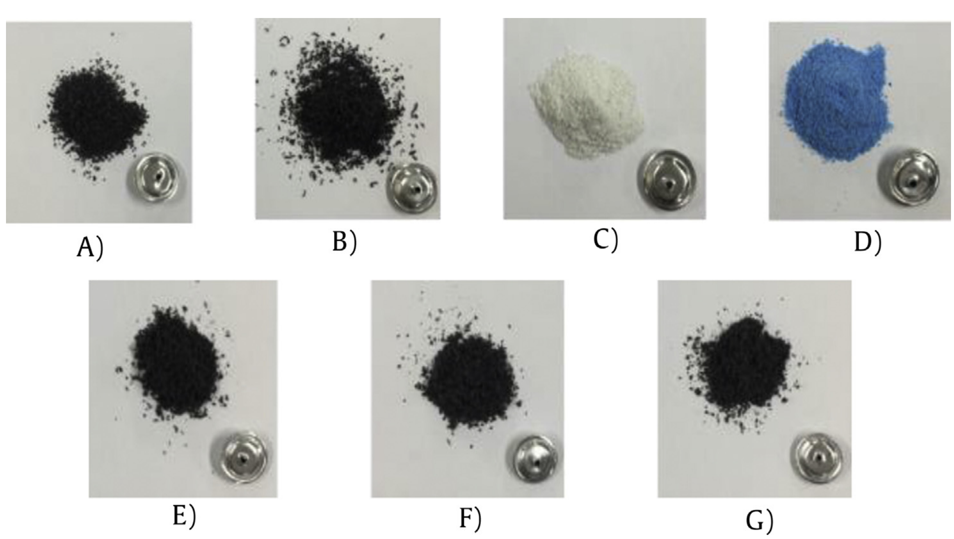
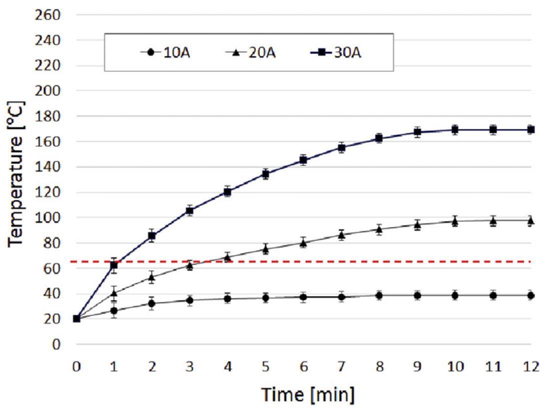
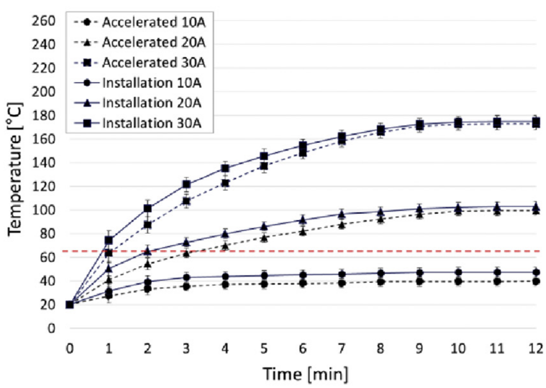


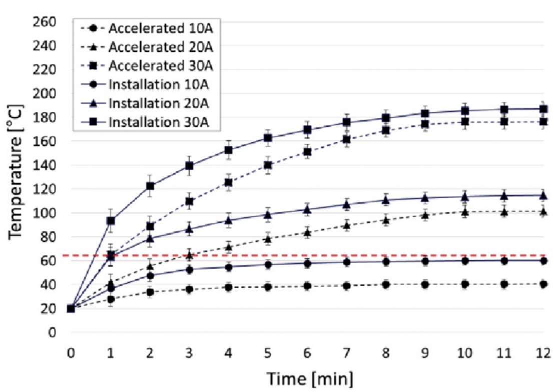
Fig. 7. Measurement powder of insulators by electrical socket outlets. (A) Y. (B) 10Y. (C) 20 Y. (D) 30Y. (E) A 10 Y. (F) A 20 Y and (G) A 30 Y.



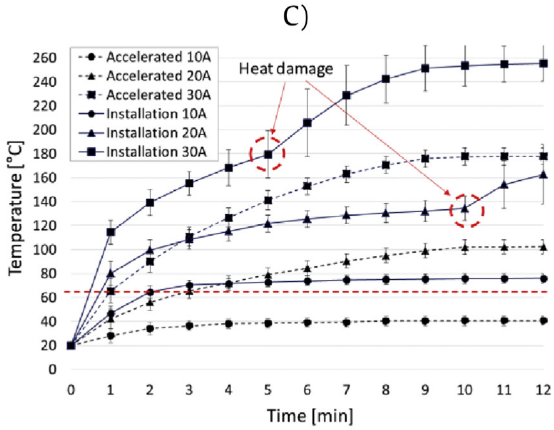
A)



B)



C)



D)

without change after rising). Average data were obtained by measuring three times for 12 min for each current level. As shown in Fig. 5, in the experimental procedure, two thermal imaging cameras were used to observe temperature change. The main measurement was done using Fluke Ti25. The testo 872 was used for data correction. Thermal imaging cameras are examined and calibrated each year by a specialized agency, contributing to higher reliability of measurements. For the purposes of this study, an alternating current generator (0~40 A) was used. It is adjustable at intervals of 1 A. However, error of ±0.4 A occurred with the current increase; therefore, the application range of 10.12~10.25 A was given for 10 A. Fig. 5A shows the AC generator and electrical socket outlet temperature measurement point. Fig. 5B shows temperature measurement using the thermal imaging camera, Fluke Ti25. The thermal property experiment was implemented while the electrical socket outlets were plugged in.

3.3. *Insulation resistance property experiment*

To analyze insulation resistance variance in electrical socket outlets, an accelerated test was performed, and the actually utilized 0- /10- /20- /30-year-old outlets were tested. The experimental ambient temperature was set at 20 °C. The insulation resistance measurement temperature was increased by 10 °C from 20 °C to 160 °C in consideration of electrical socket outlet temperature rise depending upon the current value. In accordance with the insulation resistance standard of the KS C IEC 60884-1, DC 500 V was applied, and insulation resistance was measured for 1 min three times each to obtain the average. To raise the internal temperature of electrical socket outlets, a forced convection oven (JEIOTECH) was used. Temperature differences of ±3 °C were observed with temperature rise. An insulation resistance meter, Megger S1-1568, was used to apply DC 500 V, and insulation resistance was measured within the error range of ±10 V. Insulation resistance was measured with the electrical socket outlets unplugged.

3.4. *Material property experiment*

To analyze the material property of the electrical socket outlets, their weight, surface of conductor contact point, and insulator thermal deformation changes were examined. The electrical socket outlets under acceleration test were made by the same manufacturer with the same materials. However, the outlets that were selected based on years of use were made by various manufacturers; therefore, it could not be ascertained that they had been made of the same materials. Still, it seems possible to compare the analysis results obtained under the same experimental conditions.

A METTLER TOLEDO electronic scale was used to measure weight change based on the actual time of use and for the accelerated test of the electrical socket outlets.

To observe changes in the surface of the conductor contact point, optical microscopy, and electronic microscopy were used for analysis. The optical microscope (Nikon ECLIPSE LV100) magnified the surface of the conductor contact point 10 times for measurement. Fig. 6 exhibits specimens that were examined to assess the surface of the conductor contact point by installation year.

The electronic microscope (field-emission scanning electron microscope, JSM-7800F, JEOL) was used to magnify 250 and 5,000 times for measurement and analysis of conductor content.

The insulator thermal deformation temperature was investigated using a differential scanning calorimeter (METTLER TOLEDO,

Fig. 8. Results of analysis of the thermal characteristics of electrical socket outlets. (A) 0 year. (B) 10 years. (C) 20 years and (D) 30years.

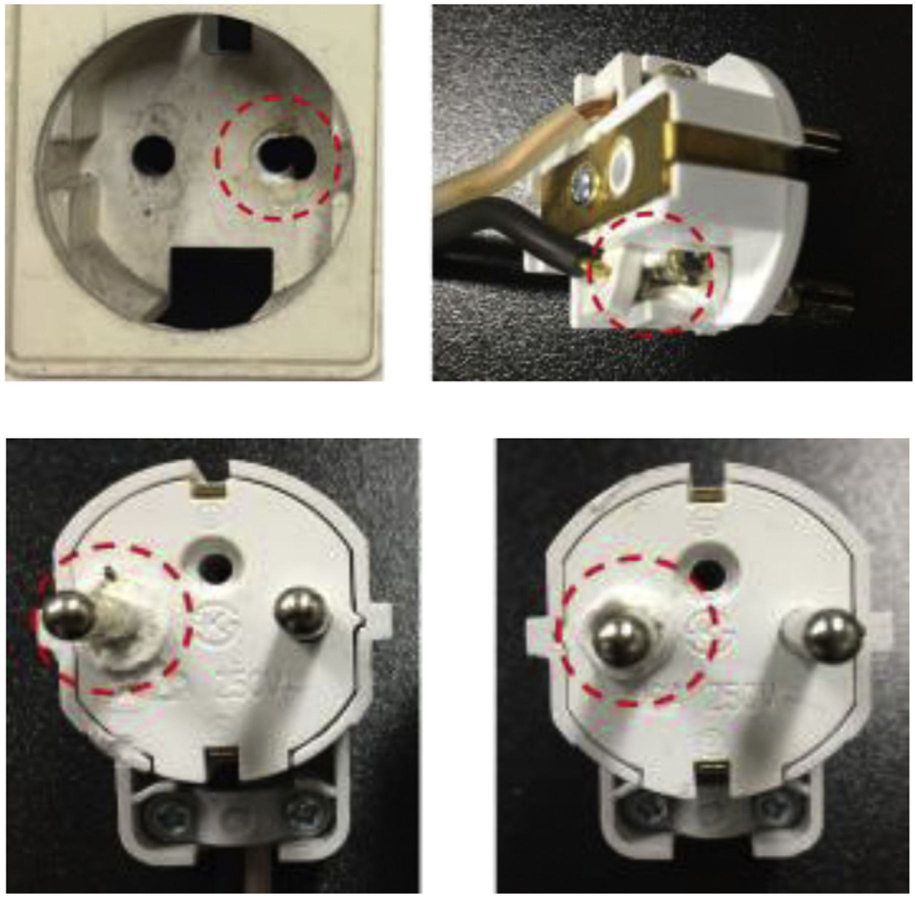


Fig. 9. Cases of thermal damage of electrical socket outlets and plugs.

DSC 1 STARe System). Fig. 7 shows the electrical socket outlet–specific insulator powder that was used for measurement. The powder weight was kept at 7.6 mg.

4. Results and discussion

4.1. Thermal property

With respect to the thermal characteristics in relation to current value, 10 A, 20 A, and 30 A currents were applied for the accelerated test, and 63EA 0- /10- /20- /30-year-old electrical socket outlets were tested. Fig. 8 presents the results.

With a 12 min testing time, for the current values of 10 A, 20 A, and 30 A, the average temperature of the 0-year outlet rose to 38.8 °C, 97.5 °C, and 169.4 °C; that of the 10-year outlet rose to 39.6 °C, 99.5 °C, and 172.8 °C; that of the 20-year outlet rose to 40.4 °C, 101.4 °C, and 176.2 °C; and that of the 30-year outlet rose to 40.7 °C, 102.4 °C, and 177.9 °C. In the case of the accelerated test, the temperature increases were not large even though the acceleration period had passed.

In 12 minutes of the experiment in accordance with the current values of 10 A, 20 A, and 30 A for electrical socket outlets, the average temperature of 0 year rose to 38.8 °C, 97.5 °C, and up to 169.4 °C; 10-year 47.4 °C, 102.9 °C, and 174.9 °C; 20-year 60.3 °C, 114.6 °C and 186.9 °C; and 30-year 75.9 °C, 162.7 °C, and 255.4 °C. In the 30-year-old electrical socket outlets, in particular, rapid thermal damage began at 134.5 °C at 20 A in 10 min on average; at 179.5 °C at 30 A in 5 min on average. As shown in Fig. 9, the interface space between the conductor (Cu) and insulator and plug area were carbonated, or the insulation therein was destroyed. The criteria for thermal burn in the Handbook on Electricity Safety Technique of Korea Electrical Safety Corporation requires extra caution if the allowable temperature of an electrical contact part is 65 °C or higher [15].

With respect to the thermal property, the higher the applied current, the higher the temperature of electrical socket outlets was, and the longer the lapse of time, the higher the outlet temperature. Abnormality arises in contact over time as a contacting conductor is deformed because of repeated use, and so forth.

4.2. Insulation resistance property

For insulation resistance analysis based on temperature value, the temperature was increased from 20 °C to 160 °C for the accelerated test, and 21EA 0- /10- /20- /30-year-old electrical socket outlets were tested. As a result, the insulation resistance was found to have decreased. As seen in Fig. 10, the longer the accelerated test and installation years, the lower the temperature at which the insulation resistance began to drop. Moreover, the measured insulation resistance values approximately halved with every temperature increase by 10 °C. Here, 1,600,000 MΩ means an infinite measurement value in the case of measuring when an insulation resistance measuring device is set at DC 500 V, and MΩ is the basic measurement unit of the measuring device.

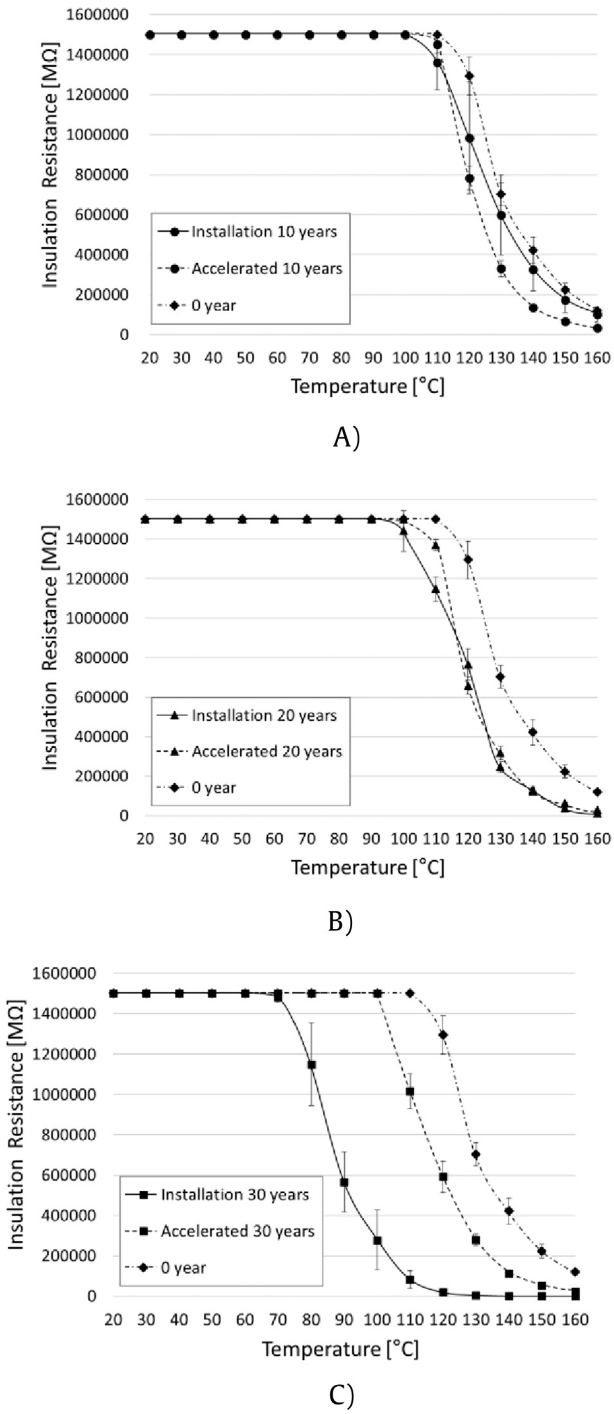


Fig. 10. Results of analysis of the insulation resistance characteristics of electrical socket outlets. (A) 10 years. (B) 20 years and (C) 30 years.

The average temperature of 0-year-old outlets where the accelerated-test insulation resistance began to fall was 120 °C; for all of the 10- /20- /30-year outlets, it was 110 °C. There was no case of rapid fall of insulation resistance. When the electrical socket outlets reached 160 °C, the average insulation resistance of the 0-year outlets was 119,669 MΩ; that of the 10-year outlets was 34,990 MΩ; that of the 20-year outlets was 29,732 MΩ; and that of the 30-year outlets was 23,995 MΩ.

The average temperature of the 0-year outlets where insulation resistance began to drop was 120 °C; that of the 10-year outlets was 110 °C; that of the 20-year outlets was 100 °C; and that of the 30-year outlets was 70 °C. For the 30-year-old electrical socket outlets, in particular, the temperature with rapid insulation resistance downturn plummeted. When the specific electrical socket outlets by installation year reached 160 °C, the average insulation resistance of the 0-year outlets was 119,669 MΩ; that of the 10-year outlets was 101,117 MΩ; that of the 20-year outlets was 11,886 MΩ; and that of the 30-year outlets was 1,599 MΩ.

Conductor heat deterioration impacts insulator(s) around the conductor. The conductor temperature repeatedly rises, and with time, insulation resistance is decreased.

4.3. Material property

The material properties of the electrical socket outlets were examined including weight change, change in the surface of the conductor contact point, and insulator thermal deformation temperature variation. The accelerated test found that electrical socket outlets in the same structure and made by the same manufacturer showed weight decrease as the accelerated test progressed. As seen in Table 3, the 10-year outlets were reduced by 48 mg in their weight, the 20-year outlets by 94 mg, and the 30-year outlets by 114 mg. Because the electrical socket outlets by installation year had various manufacturers, structures, and so forth, it is not meaningful to compare their weights. Still, recently used electrical socket outlets weighed less.

To analyze the temperature increase in the conductor contact point in accordance with current value, the electrical socket outlets by installation year were examined by optical microscopy with 10 times magnification. As a result, the accelerated-test electrical socket outlets all showed similar measurement values. However, for the electrical socket outlets by installation year, as seen in Fig. 11, the 0-year outlets showed no abnormality on the surface, whereas the 10-year or older outlets had rough surface of the conductor contact point. This is attributed to repeated abrasion in the process of plug contact.

Examining using electronic microscopy with 250 and 5,000 times magnification, no change was found in the 0-year and 10-year accelerated-test outlets as shown in Fig. 12. Cracks occurred on the surface of the 20-year accelerated-test outlets, and the 30-year outlets showed more cracks than the 20-year outlets. The electrical socket outlets that had been installed for 10 years or more, as seen in Fig. 13, showed roughness and cracks on the surface. The longer the installation years, the rougher the surface, and

Table 3
Results of measuring the average weights of electrical socket outlets

Division		0 Y	10 Y	20 Y	30 Y
Average weight of accelerated-test electrical socket outlets [mg]	Pre-test weight	94,344	94,070	94,288	94,676
	Post-test weight	—	94,022	94,194	94,562
	Reduced weight	—	48	94	114
Average weight of electrical socket outlets by installation year [mg]		94,344	104,989	103,764	103,502

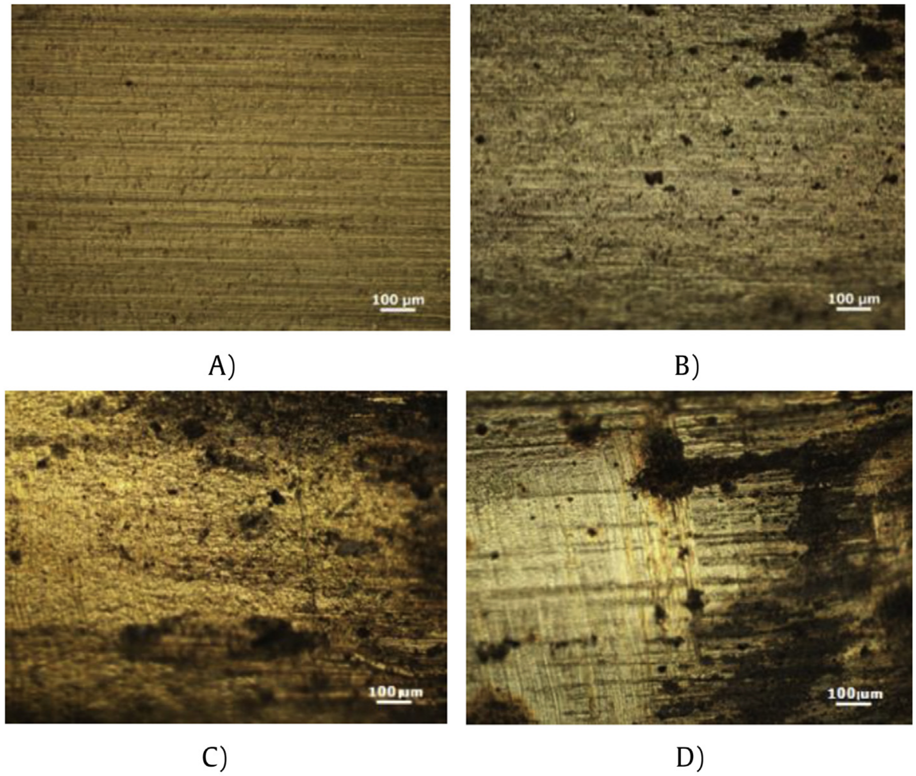


Fig. 11. Results of optical microscopic examination of the conductor contact point of electrical socket outlets by installation year. (A) 0 year. (B) 10 years. (C) 20 years and (D) 30 years.

more cracks were found on. In addition, the conductor content was analyzed, and the longer the time elapsed, the lower the Cu content and the higher the oxygen content as seen in Table 4a,b. The Cu contents of the 30-year accelerated-test and installation year–specific electrical socket outlets were 13.02% and 6.35%, respectively, and the oxygen (O) contents were 39.93% and 44.87%, respectively. The 30-year outlets by were found to have smaller Cu content but larger oxygen content.

Fig. 14 exhibits the results of measuring thermal deformation temperature using DSC. As seen in Fig. 14A, the accelerated-test electrical socket outlets were measured to have similar thermal deformation temperatures, and the melting point of the insulator of 10-year outlets was 222.4 °C, that of the 20-year outlets was 223.4 °C, and that of the 30-year outlets was 222.2 °C, demonstrating no change. Fig. 14B also showed that insulators that had been installed for at least 20 years had unstable thermal deformation at 90 °C. The melting point of the installation year–specific insulator of the 0-year outlet was 222.5 °C, that of the 10-year outlets was 223.2 °C, that of the 20-year outlets was 257.6 °C, and that of the 30-year outlets was 248.6 °C, showing higher melting points for the 20-year-old or older outlets because of unstable thermal deformation.

Electrical socket outlets, over time, were repeatedly used, and their surfaces grew rough and oxidized, decreasing the copper (Cu) content while increasing the oxygen (O) content. The insulators' weight also dropped with time. Their thermal deformation temperatures were different, which may be attributed to the fact that these insulators were not made of the same materials.

5. Conclusion

In this study, to prevent electrical socket outlet fires, an accelerated test was conducted, and actually utilized installation year–specific (0 year, 10 years, 20 years, 30 years) electrical socket outlets were examined to assess their thermal characteristics based on the current value and their insulation resistance variation with temperature rise. Their material properties were also investigated to identify factors that influence the thermal and insulation resistance properties. This study has found the following:

1) With respect to thermal characteristics based on current value, the electrical socket outlet temperature rose as the applied current value increased. The longer the accelerated test and installation years, the higher the electrical socket outlet temperature was. The electrical socket outlets that had been used for 30 years were found to have temperatures exceeding 65 °C, the threshold of permissible temperature at electrical connection parts. Such 30-year-old or older outlets should be replaced for fire prevention.
2) Regarding the electrical socket outlets' insulation resistance properties according to temperature, the insulation resistance began to decrease as the temperature rose to a certain

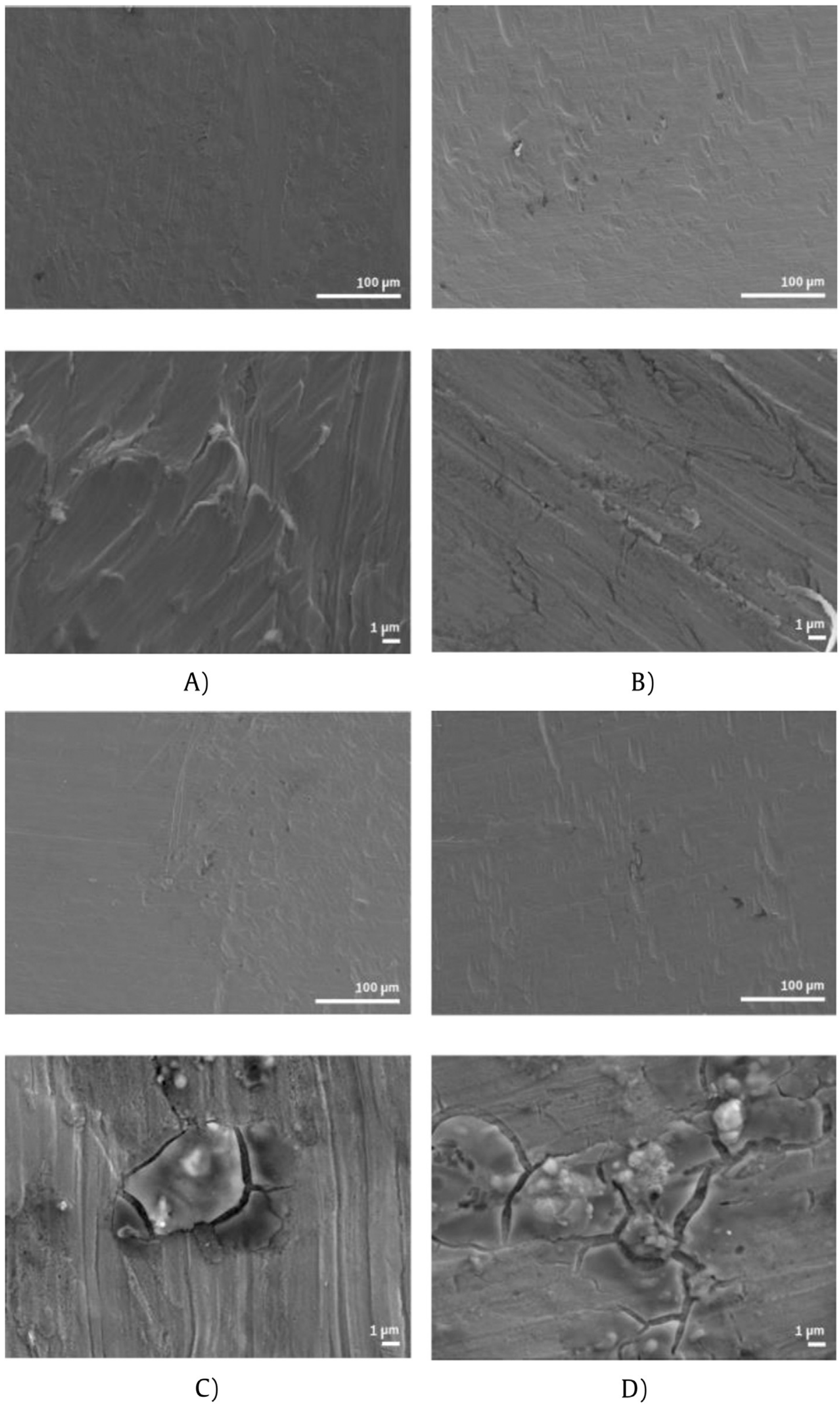


Fig. 12. Results of electronic microscopic examination of accelerated-test electrical socket outlets' conductor contact point. (A) 0 year. (B) 10 years. (C) 20 years and (D) 30 years.

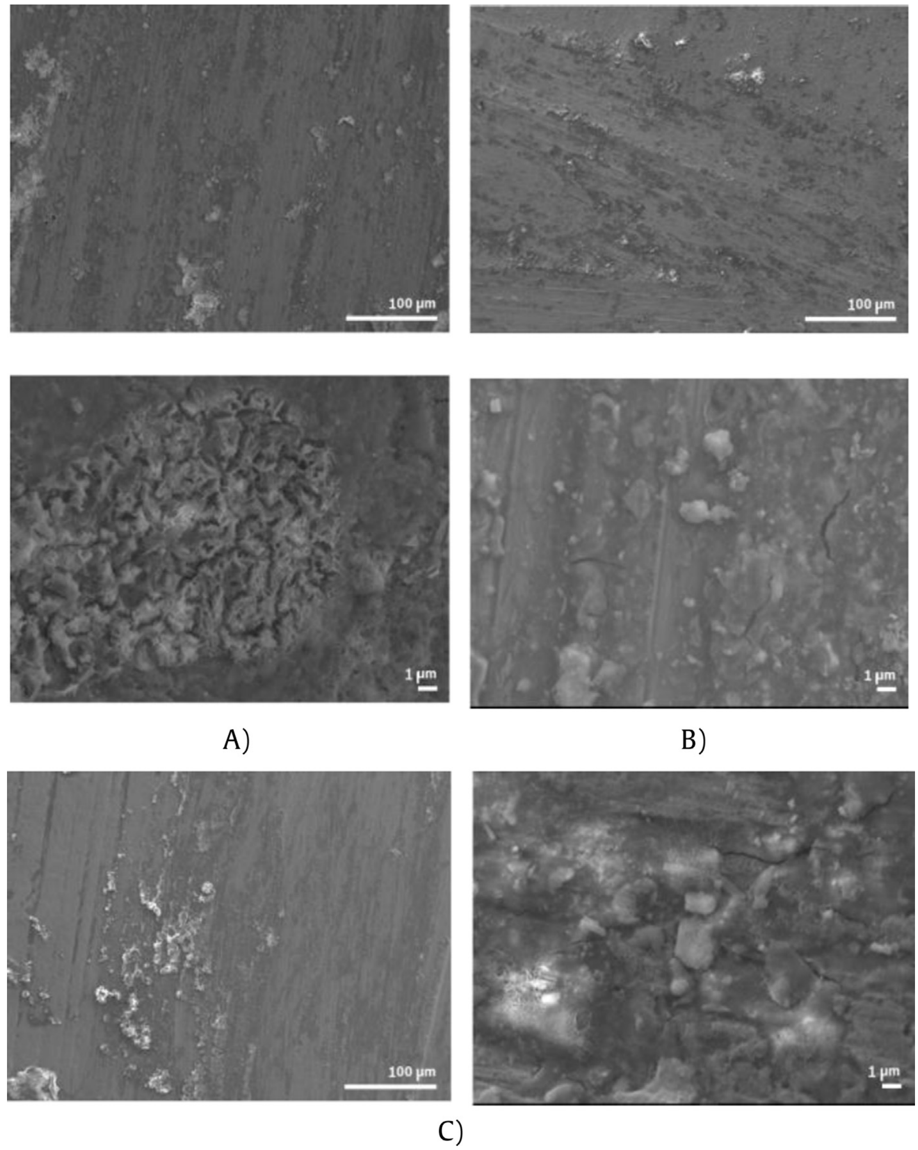


Fig. 13. Results of electronic microscopic examination of installation year–specific electrical socket outlets' conductor contact point. (A) 0 year. (B) 10 years and (C) 30 years.

Table 4
Results of conductor content of electrical socket outlets. a) Conductor content of accelerated-test electrical socket outlets. b) Conductor content of installation year–specific electrical socket outlets

Element	Atomic (%)			
	0 Y	A 10 Y	A 20 Y	A 30 Y
C	42.88	62.74	66.89	47.05
O	4.82	7.38	8.64	39.93
Cu	52.30	29.88	24.47	13.02
Total	100.00	100.00	100.00	100.00

Element	Atomic (%)		
	10 Y	20 Y	30 Y
C	48.92	41.33	48.78
O	11.75	38.15	44.87
Cu	39.33	20.52	6.35
Total	100.00	100.00	100.00

level. The longer the accelerated test and installation years, the lower the temperature was where insulation resistance began to drop. The accelerated-test (30 years) electrical socket outlets showed insulation resistance drop from 110 °C, and it was 23,995 MΩ at 160 °C. The electrical socket outlets by installation year (30 years) were found to have insulation resistance fall from 70 °C, and it was 1,599 MΩ at 160 °C. Thirty-year-old outlets have lower temperature from which insulation resistance begins to fall. Therefore, such outlets older than 30 years should be regulated by law for their replacement period.

3) The material properties of the electrical socket outlets were examined. As a result, the 0 installation year outlets showed no abnormality, and the longer the installation years, the rougher and the more cracked the surface of the conductor contact point was. Twenty years or older insulators showed unstable thermal deformation at 90 °C. Electrical socket outlets are

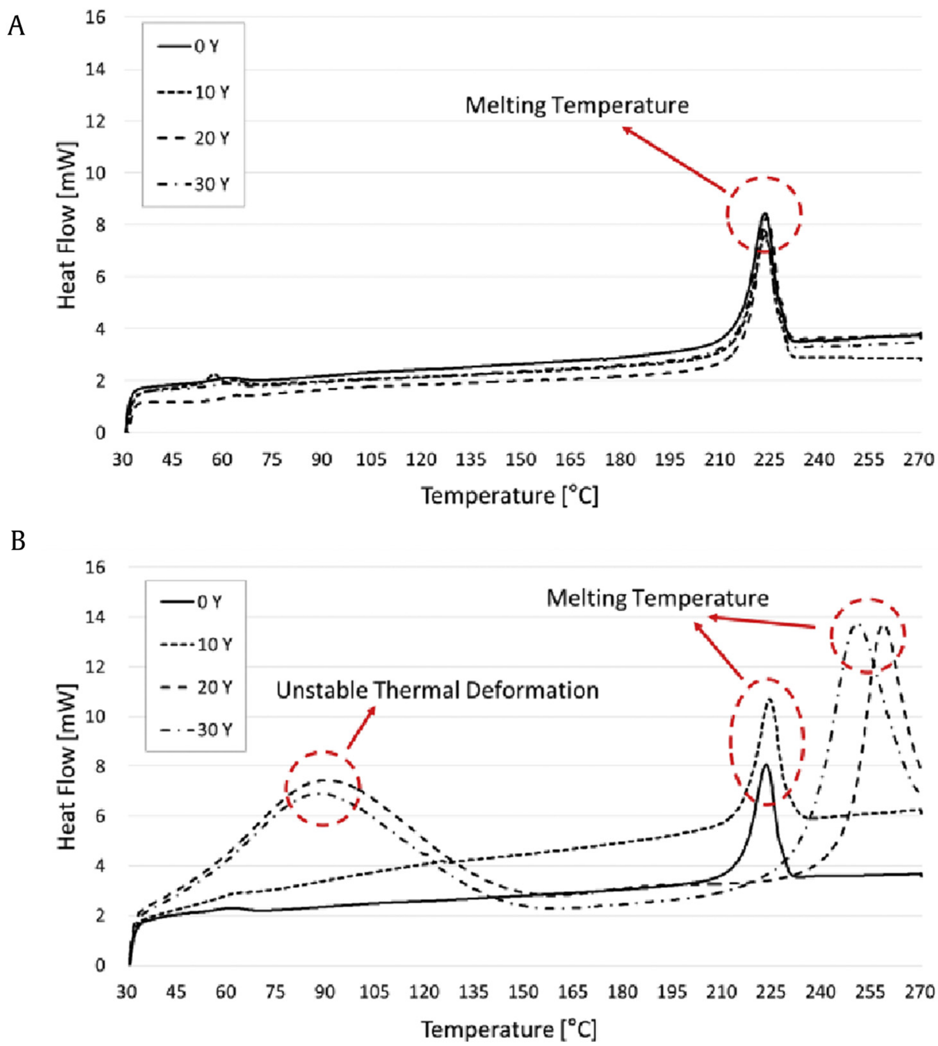


Fig. 14. Thermal deformation temperature results of electrical socket outlet insulators. (A) Thermal deformation temperature of accelerated test electrical socket outlets. (b) Thermal deformation temperature installation year-specific electrical socket outlets.

deformed as they are repeatedly utilized over time. Overloading accelerates such deformation. Therefore, it is necessary to indicate the date of manufacturing for electrical socket outlets, and users should handle them carefully. Managers should check for any abnormality against such a risk.

Author contribution

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version. All authors have approved the manuscript and agree with submission to the Safety and Health at Work. The authors have read and have abided by the statement of ethical standards for manuscripts submitted to the Safety and Health at Work.

This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

D.H.K. has affiliation with Chungbuk National University with direct or indirect financial interest in the subject matter discussed in the manuscript.

Conflicts of interest

All authors have no conflicts of interest to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.shaw.2020.06.004.

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