

Research Article

Usage of an Excel Spreadsheet for a Thermal Endurance Test Report

Rabia Korkmaz Tan^{1,*}, Kaan Önder^{2,*}, Fatih Yerisenoglu^{3,*}, Reşat Mutlu^{4,*}

¹Computer Engineering Department, Çorlu Engineering Faculty, Tekirdağ Namık Kemal University, Çorlu-Tekirdağ, Türkiye, 59860

^{2,3}Unika Cable, Çerkezköy, Tekirdağ, Türkiye, 59500

⁴Electronics and Communication Engineering Department, Çorlu Engineering Faculty, Tekirdağ Namık Kemal University, Çorlu, Tekirdağ, Türkiye, 59860

¹rkorkmaz@nku.edu.tr, ²kaan.onder@unika.com.tr, ³fatih.yerisenoglu@unika.com.tr, ⁴rmutlu@nku.edu.tr

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Abstract: Power cables are one of the important parts of electrical power systems. It is important to know the materials that make up the cable or what the life of the cable will be at a given temperature. Therefore, aging tests are performed for the materials used in the cables. One of these tests is the thermal endurance test of the cable. The curve fitting process is performed to the data obtained as a result of this test and the temperature value (the temperature index) corresponding to the 20000-hour life of the cable is found. Automating the process of curve-fitting and finding the temperature index will be useful for companies or research centers that perform this test. Instead of expensive programs such as Matlab or Mathematica, the easy-to-use and accessible Excel program is a very economical and useful solution to evaluate these test results. In this study, the thermal endurance test was briefly described and a spreadsheet was prepared in Excel to evaluate the results of this test. Using the data taken from the measurements made for the EPR material, it has been checked that the spreadsheet works correctly. Such a spreadsheet can be easily used in cable factories to evaluate thermal endurance test results.

Keywords: Thermal Endurance Test, Cables, Curve Fitting, Excel Spreadsheet

Isıl Dayanım Test Raporu İçin Bir Excel Elektronik Tablosunun Kullanımı

Öz- Güç kabloları elektriksel güç sistemlerinin önemli parçalarından birisidir. Kabloyu oluşturan malzemelerin ya da kablunun hangi sıcaklıkta ömrününne olacağına bilinmesi önemlidir. Bundan dolayı kablolarında kullanılan malzemeler için yaşlandırma testleri yapılır. Bu testlerden biri kablunun termal dayanım testidir. Bu test sonucunda elde edilen dataya eğri uydurma işlemi yapılarak kablunun 20000 saatlik ömre karşılık gelen sıcaklık değeri (sıcaklık indeksi) bulunur. Bu eğri uydurma ve sıcaklık indeksini bulma işleminin otomatize edilmesi bu testi yapan firmalar veya araştırma merkezleri için faydalı olacaktır. Matlab veya Mathematica gibi pahalı programlar yerine kullanımı ve erişimi kolay Excel programının bu test sonuçlarını değerlendirmek için kullanımı oldukça ekonomik ve faydalı bir çözümdür. Bu çalışmada termal dayanım testi kısaca anlatılmış ve bu testin sonuçlarını değerlendirmek için Excel’de bir elektronik tablo hazırlanmıştır. EPR malzemesi için yapılan ölçümlerden alınan data kullanılarak programın doğru bir şekilde çalıştığı gösterilmiştir. Böyle bir elektronik tablo kablo fabrikalarında termal dayanım sonuçlarını değerlendirmek için kolaylıkla kullanılabilir.

Anahtar Kelimeler—Isıl Dayanım Testi, Kablolar, Eğri Uydurma, Excel Elektronik Tablosu

1. Introduction

Power cables are commonly used for electrical power transmission [1, 2]. The cable insulations are susceptible to

aging when exposed to the thermal, electrical, environmental, and mechanical stresses experienced under heavy operating conditions [3-5]. The insulation performance of aged cables decreases considerably [6]. That’s why insulation aging is an

*Corresponding author

E-mail address: rmutlu@nku.edu.tr (R. Mutlu)

important issue enough to use the leakage current for its evaluation [7] or radio frequency signals for diagnosis of its location [8]. A review of the aging of extruded dielectric cables is presented in [9]. Aging Models for Electrical Insulation in Power Cables are given in [10, 11]. The aim of the tests is to predict the lifetime of electrical cables operating at elevated temperatures by applying the Arrhenius aging model on thermally aged samples [12]. One of the test properties used for thermal aging tests is the “Elongation at break test” based on two reference standards [13, 14]. The endpoint of the test property can be chosen as 50 % Elongation at break. Arrhenius equation is an exponential function and the least squares method is used to evaluate the test results or to find the parameters of the equation [4, 12]. It is time-consuming to use the least squares method by hand. It is important to automatize such test results. Although programs such as Matlab or Mathematica can be used for the evaluation of the results, they may be expensive for companies in developing countries. Microsoft Excel, part of the Microsoft Office suite, is a popular electronic spreadsheet program that provides a wide range of features for data manipulation, analysis, and visualization. Excel is widely used in business, finance, engineering, education, and many other fields due to its versatility and powerful features. Proficiency in Excel is considered a valuable skill in the workplace. The use of linear algebra in Excel provides various advantages and conveniences, making it a powerful tool for mathematical and analytical tasks. Excel simplifies matrix operations, which form the basis of linear algebra. You can perform matrix multiplication, find the inverse of a matrix, and easily manipulate matrices using built-in functions. Linear algebra is essential for solving systems of linear equations, and Excel provides functions and tools that efficiently solve a system of equations. An Excel spreadsheet is a grid of cells organized into rows and columns, where each cell can contain text, numbers, or formulas. Many engineering and social science problems are solved using writing macros or Excel spreadsheets [15-20]. A power-system analysis has been made with Impedances using spreadsheets [21]. It is shown that a commonly available spreadsheet package is usable to solve a three-dimensional heat flow problem for underground cable rating [22]. To the best of our knowledge, a spreadsheet has not been used to evaluate the aging test results. In this study, an Excel spreadsheet is used to calculate the parameters of the Arrhenius equation using experimental aging data.

The paper is arranged as follows. In the second section, the thermal endurance test is briefly described. In the third section, an Excel spreadsheet is prepared to calculate the parameters of the thermal endurance test. The paper is concluded with the conclusion section.

2. Brief Introduction to Thermal Endurance Test and Calculation of the Temperature Index

2.1 Thermal Endurance Test

The experimental procedure of the thermal endurance test is briefly explained in [12]. The flowchart of the test procedure is given in Figure 1. Some results of thermal endurance tests

performed on samples of EPR (ethylene-propylene rubber) cables are presented in [23, 24]. However, the endpoint of the test property for Extruded EPR Insulation Material is chosen as 50 % Elongation at break in this study. The properties are monitored under standard IEC 60216-2 [12].

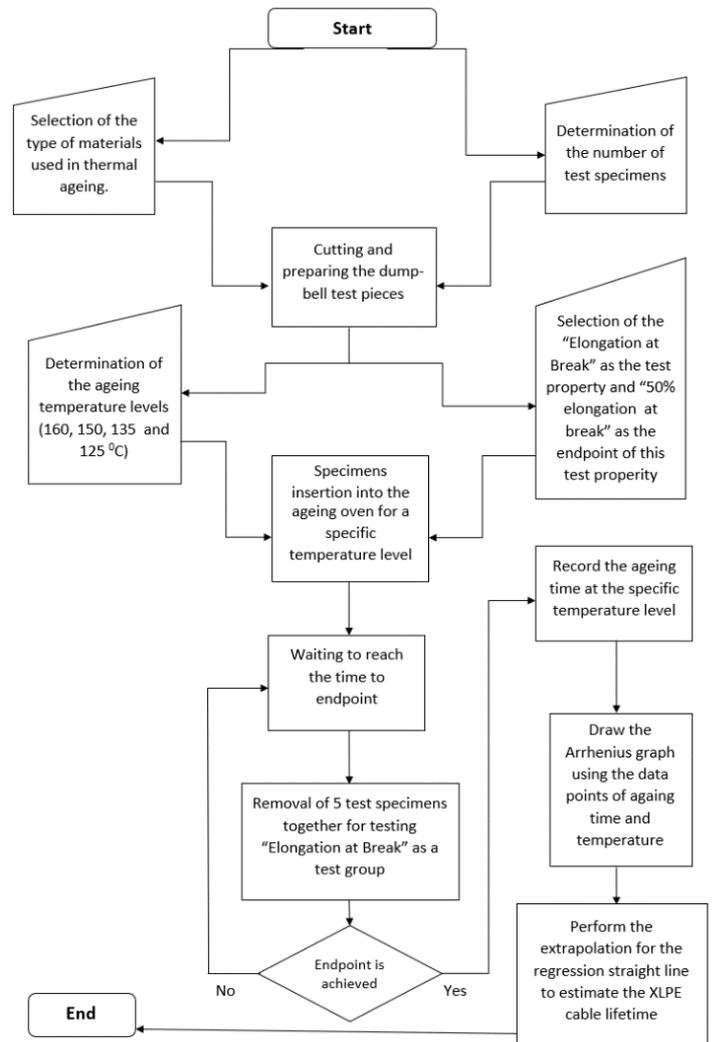


Figure 1. The experimental process flowchart [12].

The exposure temperatures and their duration are chosen according to standard IEC 60216-1 [12]. Dumb-bell test pieces are prepared with dimensions according to Standard IEC 60811-501 as seen in Figure 2 [25].

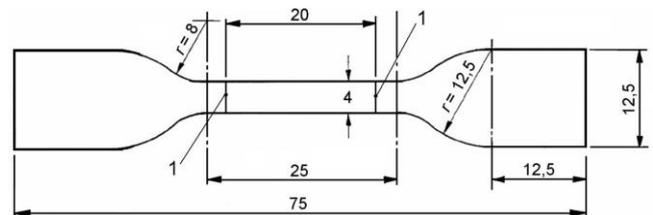


Figure 2. Dimensions of the Dumb-bell test pieces prepared according to Standard IEC 60811-501 [25]

The cutting of the dumb-bell pieces is shown in Figure 3. The prepared samples can be seen in Figure 4.

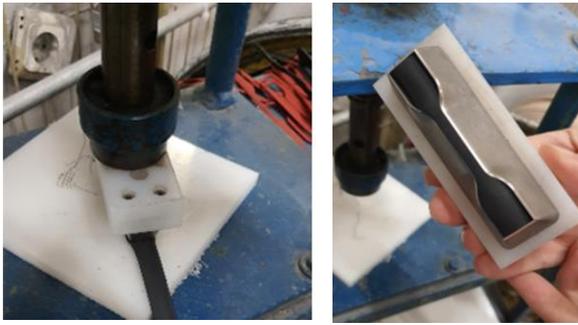


Figure 3. The cutting of the test pieces. **Figure 4.** The pieces cut.

The aging oven is shown in Figure 5. The dumb-bell pieces are inserted and suspended in the aging ovens as shown in Figure 6. At least three different exposure temperatures should be chosen with at least 10 °C intervals between temperatures. After the thermal exposure, a photo of the aged pieces is shown in Figure 7.



Figure 5. The drying oven used for the thermal endurance test



Figure 6. Placing and Suspension of the EPR test pieces inside the ageing oven.



Figure 7. The aged and unaged samples.

Mechanical tensile testing was performed according to international standard IEC 60811-501 [25] at room temperature using a Zwick/Roell Z010 10kN ProLine machine and a photo taken during an elongation at break test is shown in Figure 8. After the test, the broken EPR samples can be seen in Figure 9. The exposure temperatures and the average Time to end-point values for the temperatures obtained with the thermal endurance test to draw the Arrhenius plot are given in Table 1.



Figure 8. The elongation at break test with a Zwick/Roell Z010 10kN ProLine 739384.



Figure 9. A broken dumb-bell test piece after elongation at break test.

Table 1. Test Results

Temperature Exposure	165 °C	140 °C	115 °C
Time to end-point in hours corresponding to an elongation of less than 50%	255	1800	5308
Elongation at break			

2.2 Calculation of the Temperature Index

The thermodynamic variable is the reciprocal of the absolute temperature:

$$x = \frac{1}{273,15+\theta_i} \tag{1}$$

Logarithm of Time to end-point in hours corresponding to an elongation of less than 50% Elongation at break is assumed to be dependent on the thermodynamic variable as

$$\ln(t) = bx + a \tag{2}$$

The parameters of Eq. (2) can be obtained using the least squares method. The tangent and the vertical intercept of Eq. (3), respectively, are given as

$$b = \frac{n_i \sum_{i=1}^{n_i} x_i y_i - (\sum_{i=1}^{n_i} x_i)(\sum_{i=1}^{n_i} y_i)}{n_i \sum_{i=1}^{n_i} x_i^2 - (\sum_{i=1}^{n_i} x_i)^2} \tag{3}$$

and

$$a = \frac{(\sum_{i=1}^{n_i} y_i) \sum_{i=1}^{n_i} x_i^2 - (\sum_{i=1}^{n_i} x_i) \sum_{i=1}^{n_i} x_i y_i}{n_i \sum_{i=1}^{n_i} x_i^2 - (\sum_{i=1}^{n_i} x_i)^2} \tag{4}$$

The life of the cable is given as

$$t = \exp(bx + a) \tag{5}$$

Temperature index in °C at 20 kilohours (kh) can be calculated by submitting t=20000 h into Equation (2) by finding the temperature:

$$T_i = \frac{b}{\ln(20000)-a} - 273.15 \tag{6}$$

These values given in Table 1 are used to calculate the values of x and y and shown in Table 2. Using Gauss’s least squares method, the temperature index is found as 98.6525 °C with the data given in Table 2.

Table 2. Experimental data used for drawing of Arrhenius plot for the EPR insulator material

Aging Temperature in (°C)	T, Aging Temperature in (°K)	x, The thermodynamic variable Reciprocal of the aging temperature (°K ⁻¹)	Time to end-point in hours (h)	Time to end-pint in days (d)	y=ln(t), the natural logarithm of time to end-point in hours
165	438.15	0.002282323405227	255	36.42857	5.541263
140	413.15	0.002420428415830	1800	257.1428	7.495541
115	388.15	0.002576323586242	5308	758.2857	5308

3. Preparation of the Excel Spreadsheet

In this section, an Excel spreadsheet was created to automate calculations that are difficult and time-consuming to calculate manually. Engineers or researchers who evaluate the cable endurance test results will be able to easily make the necessary calculations using this spreadsheet application. Figures 10 and 11 show the necessary data and the calculation results to calculate the temperature index. Figure 10 shows the appearance of the complete spreadsheet. Figure 11 gives the zoomed sections of the spreadsheet for a better view. Its columns are explained as follows.

Column A is the temperature column (in Centigrade) at which the material is aged. Column B is the life in hours that decreases to 50 percent elongation at the temperature at which the material is aged. In column C, the absolute temperature (in Kelvin) is calculated. The thermodynamic variable, which is the inverse of the absolute temperature, is calculated in column D. Column E contains the logarithm of the life in hours. The values given in column D is squared for use in the formulas of the previous section and given in column F. Similarly, the square of column E is taken and presented in column G. Column I holds the summation of x values, $\sum_{i=1}^{n_i} x_i$, whereas Column J holds the summation of y values, $\sum_{i=1}^{n_i} y_i$. Column L

represents the total number of the calculated points (n_i). The average value of x values has been calculated and recorded in column M, while the average value of y values has been calculated and recorded in column N. Column O contains the sum of x^2 values, $\sum_{i=1}^{n_i} x_i^2$, and similarly, Column P contains the sum of y^2 values, $\sum_{i=1}^{n_i} y_i^2$. Column Q denotes the sum of the products of x and y values, $\sum_{i=1}^{n_i} x_i y_i$. The product of the sum of x and y values, $(\sum_{i=1}^{n_i} x_i)(\sum_{i=1}^{n_i} y_i)$, is calculated in column Q. The products of x and y values is calculated in Column R. Column S contains the result of subtraction of the sum of the x values from the sum of x^2 values times n_i . Similarly, Column T contains the result of subtraction of the square of the sum of y values from the sum of y^2 values times n_i . Column U comprises the result of subtracting the product of the sum of x and the sum of y values from the sum of the product of x and y values times n_i . Columns V and Y contain the calculated regression coefficients, a and b, respectively. Temperature index was calculated in the Z column using the regression formula given in Eq. 6. The life of the cable at the test temperatures is calculated in column AB to draw the Thermal Endurance plot or Arrhenius plot of the tested EPR material in Excel, which is shown in Figures 10 and 12, after the curve-fitting process. The accuracy of the results obtained as a result of testing on different data has been checked by

comparing the results obtained with other mathematical programs and by hand. The time to the end point criteria or the material life decreases with increasing temperature. The thermal endurance line is drawn from the calculated Temperature index (Ti) to the maximum exposed temperature, which was 165 °C in this study.

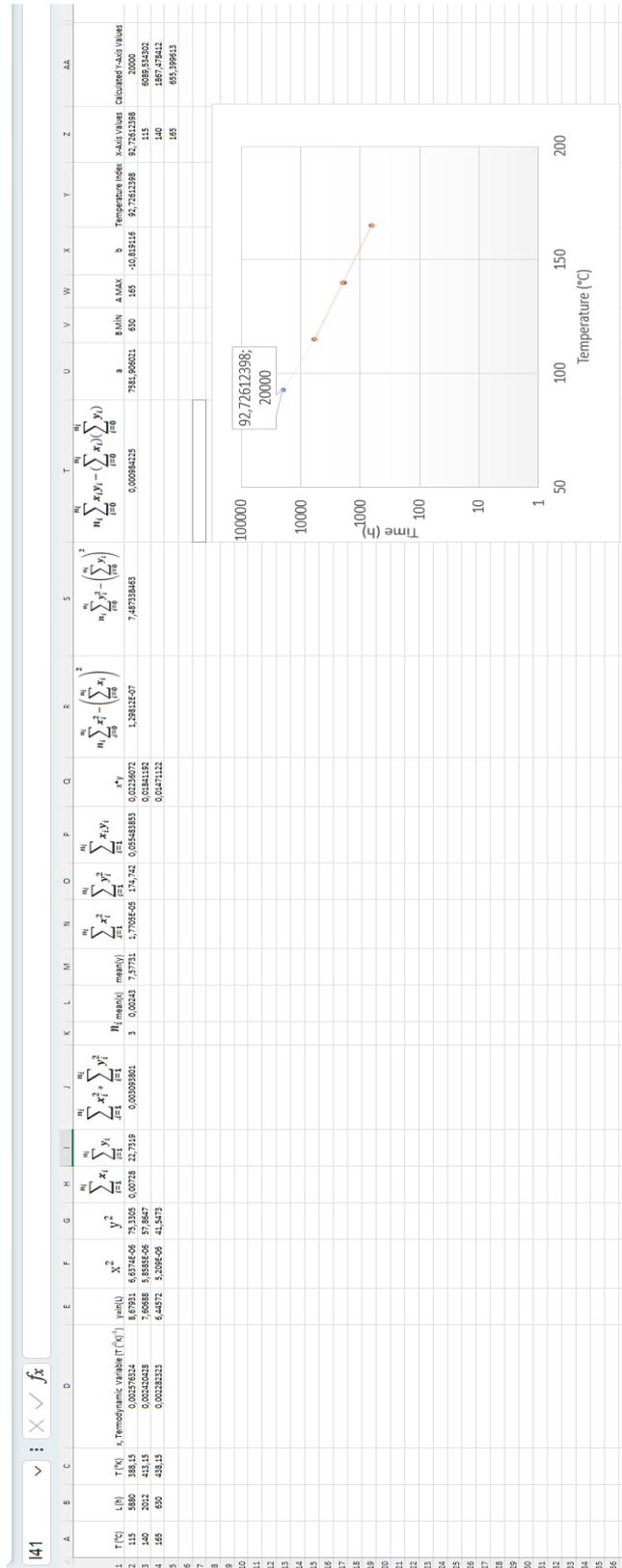
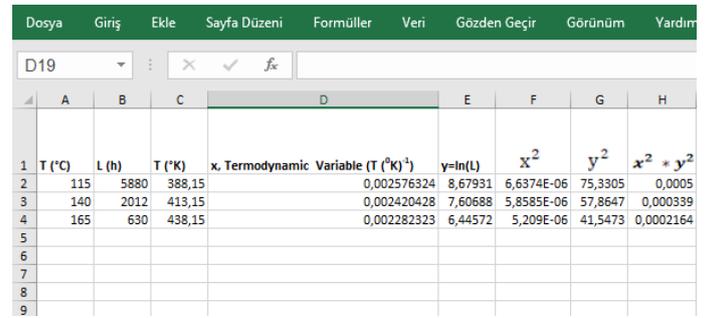
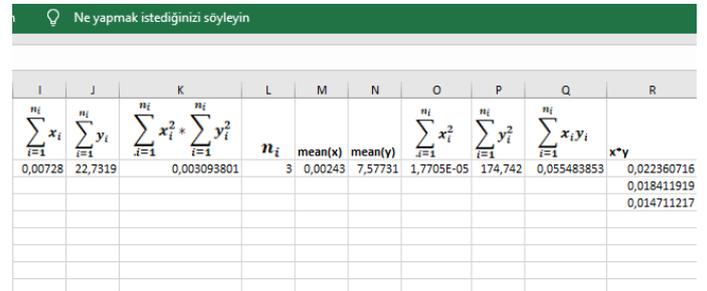


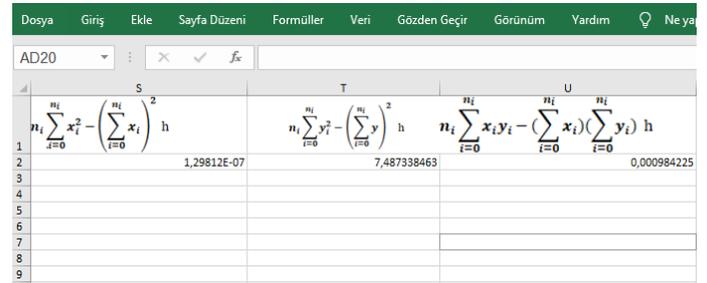
Figure 10. The appearance of the Spreadsheet prepared (Rotated to the left by 90 degrees for space consideration).



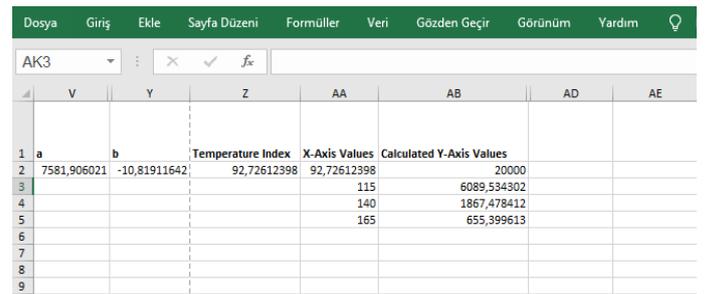
(a)



(b)



(c)



(d)

Figure 11. The zoomed sections (a, b, c, and d) of the prepared Excel Spreadsheet.

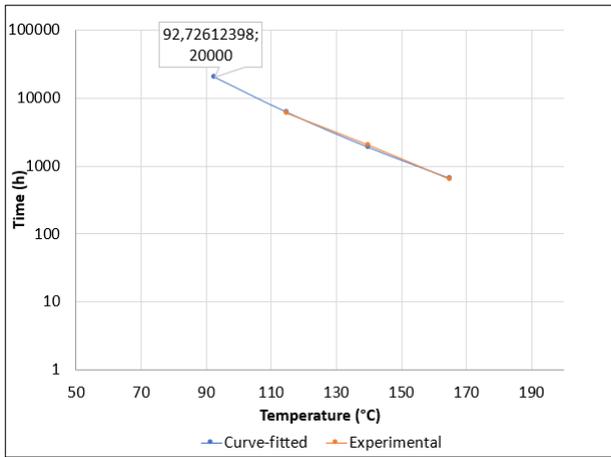


Figure 12. Thermal Endurance plot of the EPR material.

4. Conclusions

Thermal endurance tests are required for the cables made to estimate their life. In this study, the properties monitored in the thermal endurance test are the elongation at break up to an elongation of at least 50% according to IEC 60216-2. The exposure temperatures and their duration are decided according to standard IEC 60216-1. Ethylene propylene rubber is used in the experiments. The parameters of the thermal endurance test are calculated with a curve-fitting method. It takes time to use the least squares method by hand. The process needs to be automatized. In this paper, we have suggested using an Excel spreadsheet as a cheap solution for the automatization of the test results since it is already available in almost every company. Excel's Microsoft Office 365 2023 version has been used in this paper. The user should be careful not to use an earlier Excel version since it can cause unexpected errors. Creating spreadsheets in Excel is a highly flexible and functional process since Excel allows you to organize data, perform calculations, and visualize it with various graphs. This study aimed to swiftly and accurately conduct complex and time-consuming calculations related to a thermal endurance test using Excel spreadsheets. Excel's extensive range of formulas enables the needed calculations between cells, from simple operations like addition, subtraction, multiplication, division to complex mathematical formulas in an efficient way and a short time. The data provided from the thermal endurance test of the cable material examined is entered into the Excel spreadsheet, the necessary calculations is performed, and the thermal endurance plot of the tested material is visualized using graphs. The spreadsheet takes the time to end point criteria and exposure temperature as inputs, performs the curve-fitting, calculates the temperature index for a life of 20000 hours, and gives the plot of the material life versus the operation temperature. The calculations of Excel spreadsheet match well with that of Matlab. Although Matlab plots are more aesthetic, Matlab is unfortunately more expensive than Excel and harder to reach for company engineers. The Excel spreadsheet which is a simple and cost-effective solution for the preparation of the thermal endurance test is made downloadable for the cable companies and the researchers through the link given in [26]. Also, the spreadsheets can be easily used to make a database

for the thermal endurance test results of the insulation materials [27].

Author Contribution

Formal analysis –Reşat Mutlu (RM), Rabia Korkmaz Tan (RKT); Investigation – RM, RKT; Experiments – Kaan Önder (KÖ), Fatih Yerişenoglu (FY), Processing – RKT, RM, KÖ, FY.; Literature review – RM; Writing – RM, RKT; Review and editing – RM, RKT, KÖ, FY;

Declaration of Competing Interest

The authors declared no conflicts of interest concerning the research, authorship, and/or publication of this article.

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