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Question SC-B2-PS2-Q9
Based on the thermal ageing data what is the expected life (in years) of an ACCC conductor at 160 °C operating temperature? What is the expected end of life (in years) of ACCC at 180 °C ?

Contribution
While conductors with a carbon fiber composite core have been in use for two decades now, this is a relevant question concerning the expected life time of these types of conductors. ACCC is one such conductor, but there are others, for example ACFR (Aluminum Conductor Fiber Reinforced) and we have used our testing of this conductor's core to share some light on the question from a general perspective and propose a testing method to predict this.
A method which can be used for life time prediction is using the Arrhenius Equation below, which basically is a formula for the reaction time's dependence on temperature for many chemical reactions:

$$k = A \times e^{-\frac{\Delta E}{RT}}$$

Here k is the reaction rate, A is the pre-exponential factor, ΔE is the activation energy needed for the reaction, R is the gas constant and T is the absolute temperature in Kelvin.

This speed rate constant k affects the element's molecule breaking (pyrolysis) speed in the composite core that links to the degradation of the tensile strength. As it can be seen, this time-temperature relationship is exponential in nature. For example, just as a rule of thumb, for some materials around 10 °C temperature rise will double the reaction rates.

The polymer matrix used in a composite core, which function is to contain and hold the carbon fibers, is a unique custom design and will have a speed rate constant specifically representing this composition. Thus, the thermal ageing tests and the associated life-time prediction, using the Arrhenius equation, should be performed on each composite core design type.

The method is described in IEC 60216-1, covering electrical insulation material. Samples of the composite core are aged at different temperatures & durations, and subject to tensile testing to prepare for the plot. The thermal ageing results are plotted on a semi-log graph: the tensile strength as a function of the ageing time (Fig. 1). Then using the natural logarithm the test time and test temperature can be plotted (linear) on the semi-log graph and the Arrhenius Equation can be solved (Fig. 2). The expected time at a certain temperature, or the maximum operating temperature at given specified life-time, can be calculated.

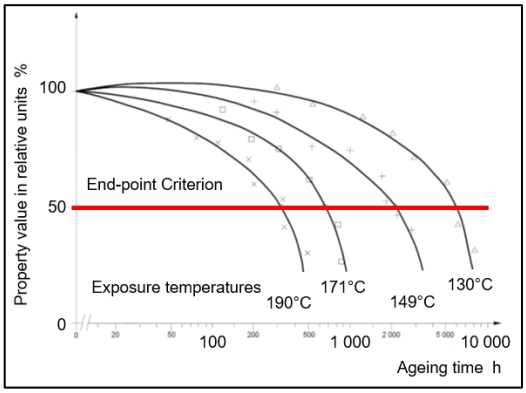

Figure 1: Ageing test results (example from IEC 60216-1)

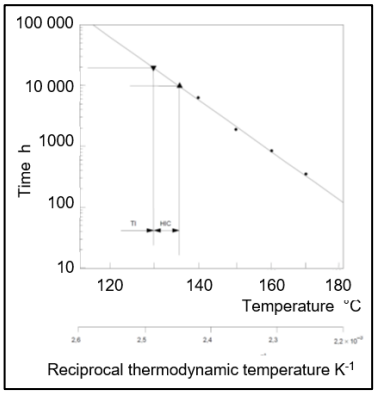

Figure 2: Arrhenius Plot (example from IEC 60216-1)

It should be noted that maintaining a high tensile strength is more important for the overhead conductor core application than for insulating material and we are usually working with 90% or 95% of rated tensile strength instead of the lower strengths described in IEC 60216-1. This "end-point" criteria will of course greatly affect the time and temperature limits of the carbon fiber composite core.

Below figure 3 represents an actual test for a CFCC core for ACFR conductor where the end-point criteria was agreed with the customer to be 90% of rated tensile strength.

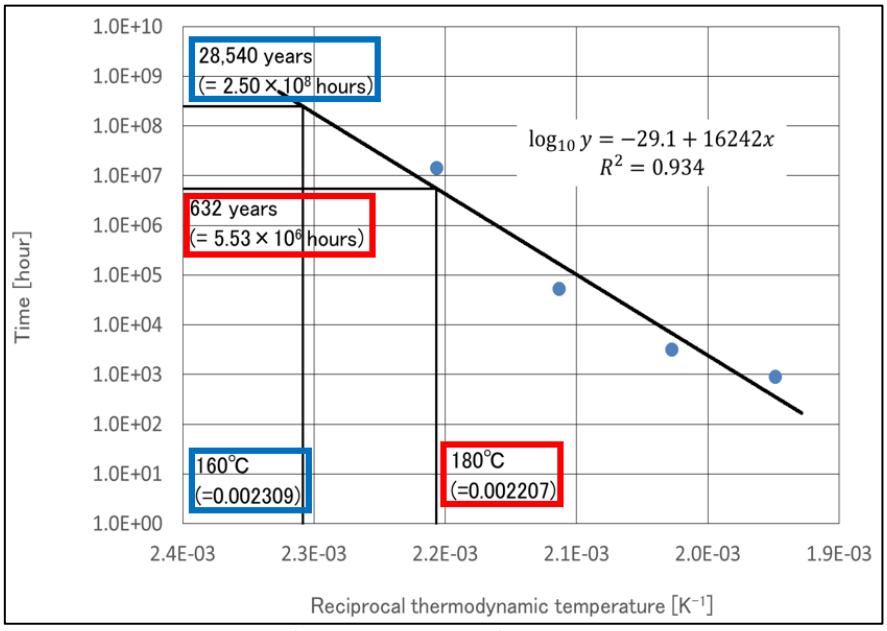

Figure 3: Ageing test results for a CFCC core used for ACFR conductor

For this particular test, we can answer the referenced question:
This carbon fiber composite core will have an expected life time operating continuously at 160 °C of 28,540 years. If it is operating continuously at 180 °C, the life time is 632 years.

By the 4 data points, it can be seen that the lowest test temperature here was 180 °C followed by 200, 220 and 240 °C as the highest temperature. It is recommend that tests are conducted at minimum 3 temperatures. It should be noted that the rating for this composite core is 180 °C continuous operation, and 200 °C for emergency. Thus the 180 °C continuous

operating temperature is conservative. However, as the curve indicates which is the nature of the exponential reaction, the ageing progresses quite fast when the temperature is above 200 °C.
The expected life time for 200 °C operation is just above 10 year and therefore there is a set restriction for maximum 1000 hours at emergency.

The Arrhenius thermal ageing test, which can be used for carbon fiber composite cores, are currently being discussed and drafted in IEC TS 62818, where the method will be described in greater detail.