Study Committee B2

Overhead lines

11142_2022

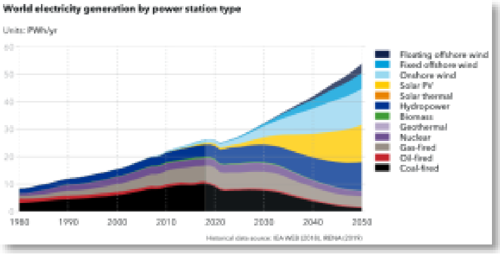
TOWARDS A PREDICTIVE MODEL FOR THE RESIDUAL STRENGTH OF POLYMER MATRIX COMPOSITE CORE IN HTLS CONDUCTORS

Baptiste Gary, Maeva Chambaud, José Portoles, Haithem Bel Haj Frej, Xavier Colin

Epsilon Composite Cable, ENSAM

Motivation

- Because of global warming, **generation mix are changing** having important consequences on the transmission grids. Uprating lines by changing standard conductors limited to 90°C by **HTLS conductor using carbon fiber composite core is ideal**. This technology being quite recent, there is still a **lack of consensus on the maximum operating temperature**.

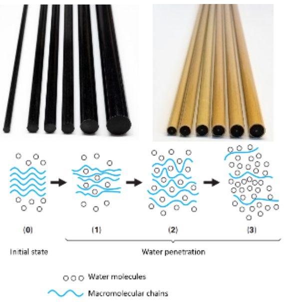


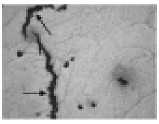
Method/Approach

- **Composite materials** : Two organic matrix reinforced with carbon or carbon/glass (HVCRC®) fibers with an average fiber volume fraction of about 70%.

- **Hydrothermal ageing** : When polymers are exposed to humid environment, the diffusion of water molecules into the polymer network results in a decrease in the glass transition temperature which can be reversible or irreversible.

- **Thermal ageing** : Chemical ageing, which modifies the structure of the macromolecular skeleton and alter the thermomechanical properties. It includes thermolysis and thermo-oxidation.





Objects of investigation

- **Explain the different ageing processes** as thermolysis, thermo-oxidation, water absorption, hydrolysis, plasticization and their consequences on the microstructure and mechanical properties of the composite core.
- Combined physico-chemical and empirical models to **predict the residual performances depending on the use of the conductor**.

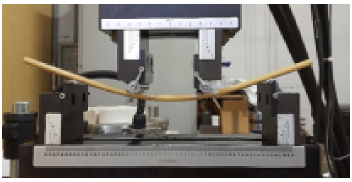
Experimental setup & test results

- **Tests methods :**

Dynamic Mechanical Analysis (DMA Q800, TA Instruments)

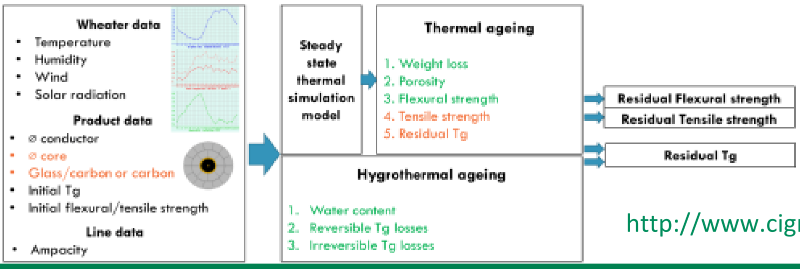
4-point flexural test on an MTS machine

Weight measurement



Conclusion

- Humid ageing tests revealed a drop of T_g which is partially reversible. Given that **composite rods will operate at high T°, this lead to fully drying the material, preserving its physico-chemical properties.**
- Thermal ageing tests revealed that thermolysis is the main degradation phenomena. TTSP was successfully applied to flexural properties. **Extrapolated data to 160 °C revealed the good thermal stability of composite rods**.
- Tg and tensile results after thermal ageing will be published in another paper. **End of life criteria definition for each property (tensile, Tg and flexural) is a critical topic to reach trustable expected end of life based on models.**



http://www.cigre.org

Study Committee B2

Overhead lines

11142_2022

TOWARDS A PREDICTIVE MODEL FOR THE RESIDUAL STRENGTH OF POLYMER MATRIX COMPOSITE CORE IN HTLS CONDUCTORS

continued

Hydrothermal ageing

Neat resin and hybrid rods samples are aged in demineralized water.

The ageing temperatures selected for this study were: 30, 50, 70 and 90°C. Tg and weight measurement to assess water content are performed after ageing.

A simplified relationship between the glass transition temperature of the wet (Tg) and dry (Tg0) polymer can be written as follows :

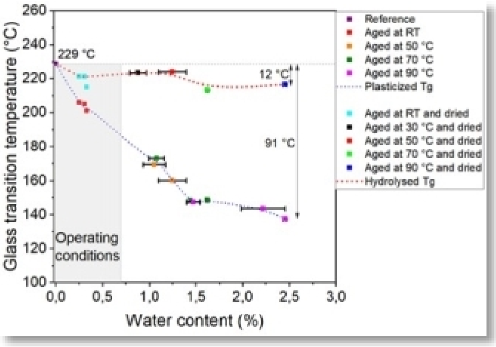
$$\frac{1}{T_g} = \frac{1}{T_{g0}} + A_p v$$

A_p : linked to the water Tg (~120 °K)
v : the water mass fraction

Results on neat epoxy fits the plasticization theory (figure available in the paper).

Figure here show the evolution of Tg for CFRP samples. After a first rapid drop of about 10 °C, the Tg of hydrolysed samples seems to be constant over time and water content.

Immersion in water at high temperatures, represent harsh conditions that accelerate ageing phenomena. **During in-service life, the maximum water content will not exceed 0.7 % as tested in following conditions : 70 °C and 85% RH.**



Thermal ageing :

Thermal ageing was applied to hybrid rods at 4 different temperatures: 180, 200, 210 and 220 °C.

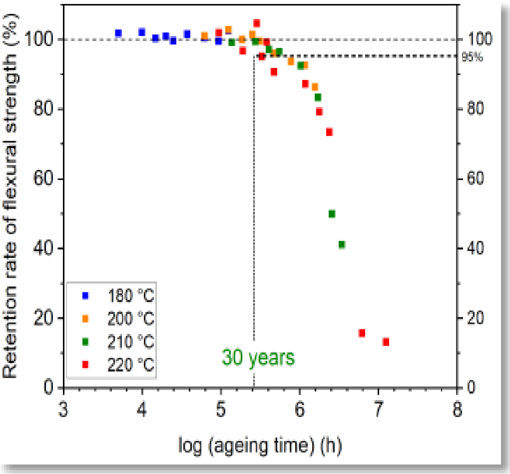
100% carbon rods were aged only at 220 °C.

Time-Temperature Superposition Principle (TTSP) was applied to experimental data at different ageing temperatures. The **TTSP is based on the theory that increasing the temperature is equivalent to shortening the time of the response of the material.**

160 °C was considered as reference temperature and properties at 200, 210, 200 and 180 °C were shifted horizontally to build the master curve at 160 °C. The empirical relationship between temperature and time effect on weight loss is then formulated in an Arrhenius law as follows:

$$\log(a_T) = \frac{\Delta H}{2.303R}\left(\frac{1}{T} - \frac{1}{T_0}\right)$$

a_T : horizontal shift factor
ΔH : activation energy (kJ/mol)
R : universal gas constant
T : exposure temperature
T_0: reference temperature



Extrapolated master curves of flexural strength to 160 °C are shown here. **It's clear that after 30 years of exposure at 160 °C, the residual flexural strength is higher than 95 % of the original value**. Based on figure 9 in the paper, for the same void fraction evolution induced by thermolysis, flexural and tensile results are very different leading to a real need to define properly the end of life criteria.