MODELING OF CREEP BEHAVIOUR OF A COMPOSITE MATERIAL

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Introduction

Various structures in composite are dimensioned by considering that these materials have a linear behaviour until their threshold of elasticity, while knowing that their properties may deteriorate in the long term under the influence of various external effects such as temperature **[1].** Thus during their normal duration of life, the behavior of the structures manufactured by this material is deteriorated by parameters related to the environment like the temperature and the degree of hygroscopy. Generally, the characteristics of polymer matrices reinforced with glass fibre fall in a hostile climate **[2]** and that is why these materials using in various applications, like the transport of the fluids or the manufacture of several products such as the bulk storage tanks of water or other chemicals, the bumpers for cars, give place to many applications for which one seeks a good behaviour, with a high durability under mechanical requests and under a severe climatic environment. It is thus a question of establishing relations stress-strains utilizing couplings between the mechanical properties and physical properties.

One identifies the laws of behavior of material starting from the varying creep tests in traction under temperatures of 45°C and 50°C.

Experimental

Materials

The studied composite material is the SMC (sheet moulding compound) containing resin unsaturated polyester and reinforced with randomly oriented type C glass fibers about 50mm of length with surface mass concentration 450g/m². This material is manufactured by the dry process using the moulding compounds that are pre-impregnate for the manufacture of composite major releases: fabrics, roving, but mostly cut fiber.

Apparatus and Procedures

The creep tests in traction were carried out on a machine of creep in traction. This apparatus is provided with an isothermic enclosure in which the test-bar creeps under 2 temperatures (45°C and 50°C). Lengthenings are recorded by a comparator except for the 1/100 mm.

Results and analysis

The experimental results for the three loads are grouped for each temperature in the same graph, (figures 1, and 2)

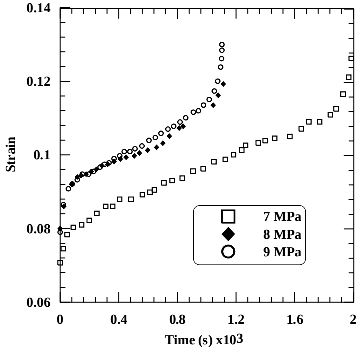

Figure 1. Evolution of creep ε subjected to the influence of the stress for a temperature θ=45°C

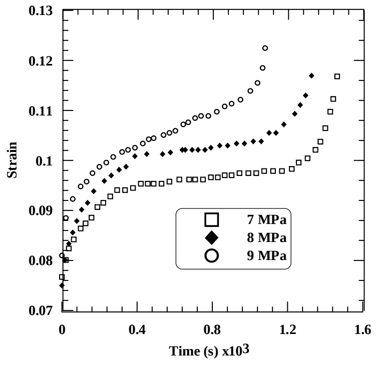

Figure 2. Evolution of creep ε subjected to the influence of the stress for a temperature θ =50°C

The response of our material is in overall in conformity with the curves of traditional creep, where one observes a very fast decrease in the speed of deformation from the very start of the test. This zone, rather short, which one can associate to the primary creep counts for an average of 8% of the totality of the test. Primary creep is followed by a secondary zone of creep where the deformation increases slightly. This zone of creep has a long duration since it constitutes the major part of creep and determines the lifespan of the structure.

Note a remarkable modification of the law of evolution of creep from θ = 45°C, where one may observe the appearance of a threshold of transition suggesting a qualitative change in the law of behavior ε. This threshold results in the appearance of the tertiary creep being characterized by a break of slope and ending ineluctably in a rupture.

Modelling of primary and secondary creep

On the basis work by GHORBAL and al **[3]** completed on the époxy/verre, an empirical law of behaviour of creep ε as function of time t(s) was proposed, it is show in the following form:

$$\varepsilon = \varepsilon_0 + B\sigma^m t^k \qquad (1)$$

We adapt this one to our experimental curves and we seek to adjust the phenomenological parameters, namely B m and K according to the temperature.

A specific programme to the method mentioned above allowed us to determine the coefficients B, m and k under different loading conditions, by injecting into it the experimental values of each test and the results are shown in figures 3, 4, 5, and 6 which represent a comparison between our experimental results and the simulations model results. Notice the good agreement between the experiment and the digital simulation model.

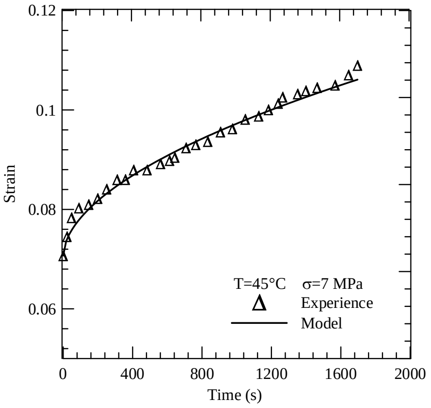

Figure 3 Comparison of the evolution of primary and secondary creep estimated by the experience and the numerical solution under temperature of 45°C and 7 MPa

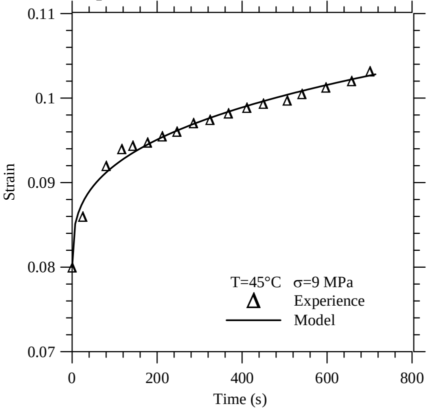

Figure 4. Comparison of the evolution of primary and secondary creep estimated by the experience and the numerical solution under a temperature of 45° C and 9 MPa

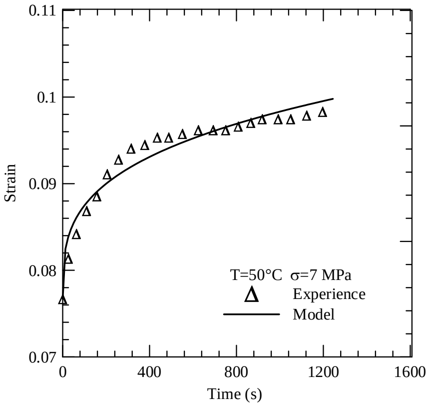

Figure 5. Comparison of the evolution of primary and secondary creep estimated by the experience and the numerical solution under a temperature of 50°C and 7 MPa

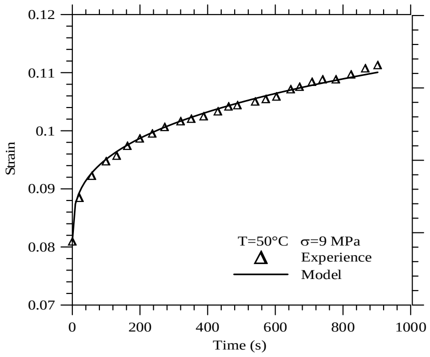

Figure 6. Comparison of the evolution of primary and secondary creep estimated by the experience and the numerical solution under a temperature of 50° C and 9 MPa

Modelling of tertiary creep

At this stage, it is observed an acceleration of the rate of deformation which finishes with the rupture of the material that corresponds to a singularity in law of power as given below **[4]**: $\frac{de}{dt} \approx \frac{1}{(t_r - t)^p}$, (2)

p = critical exponent, t_{rc}: rupture critical time for the failure of the material.

This modelling corresponds to a viscoelastic fibers beam model with nonlinear viscosity based on the work of Eyring **[5]** who concludes that the macroscopic deformation of polymer would be related to a macromolecular chains segments movement and of the potential barrier. This type of mode was applied to model the fracture mechanical behaviour of similar composites to our material based on polymer fibres **[6]**.

The model is represented by a nonlinear shock absorber of viscosity in parallel with an elastic element of rigidity E.

The deformation of the element of Eyring is governed by the equations:

$$\frac{de}{dt} = K\sinh(\beta s_1), \qquad (3)$$

s'= Ee, and $S = s_1 + s'_1 = \frac{s}{(1-P(e))}$,

$$\frac{de}{dt} = K\sinh(\beta(S - s'_1) = K\sinh\left[\beta\left(\frac{s}{(1-P(e))} - Ee\right)\right], \qquad (4)$$

$$\frac{de}{dt} = K\sinh(\beta(S - s'_1) = K\sinh\left[\beta\left(\frac{s(e+e_{02})^\mu}{e_{01}^\mu} - Ee\right)\right]. \qquad (5)$$

For the tertiary creep leading to the rupture, the approximate analytical solution (5) is obtained by neglecting the term e_{02} compared to e **[6].**

Near the rupture, and for large *e*, the term *Ee* is small compared to:

$s_2 = \frac{s}{e_{01}^\mu}(e+e_{02})^\mu$. This leads to the equation:

$$\frac{de}{dt} \approx \frac{K}{2}\exp\left[\frac{\beta s e^\mu}{e_{01}^\mu}\right]. \qquad (6)$$

Including the solution is: $e(t) = A[-\ln(t_c - t)]^{\frac{1}{\mu}}$ (7)

$$\frac{de}{dt} = \frac{A}{\mu}[-\ln(t_c - t)]^{\frac{1}{\mu}-1}\frac{1}{t_c - t}, \qquad (8)$$

with $A = e_{01}(\beta s)^{-1/\mu}$.

The numerical solutions of this equation (8) are represented by figures 7 and 8 respectively under 45°C and 50°C.

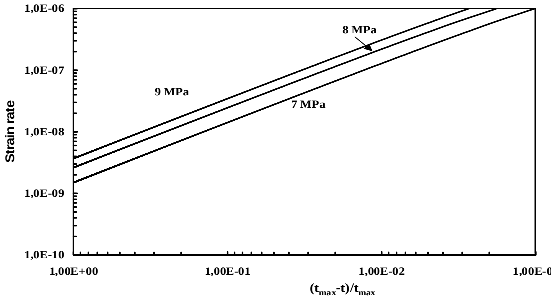

Figure 7. Numerical Solution showing acceleration in law power rate of strain before the break at T=45°C

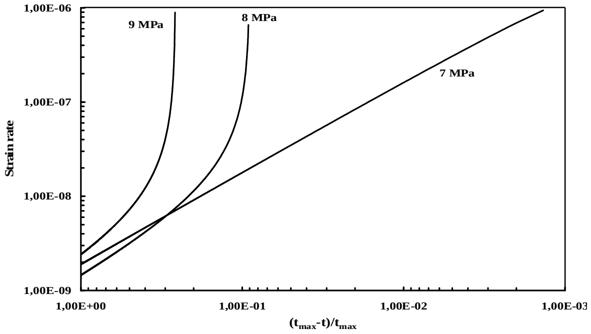

Figure 8. Numerical Solution showing acceleration in law power rate of strain before the break at T=50°C

Conclusion

This study shows that the mixed model (empirical approach-rheological model) that we have proposed can be used in order to simulate the creep behaviour of a composite material. In particular, our tests revealed a better behavior at low temperatures which can be extended to higher temperatures but with less significant loads. This indicates the need of innermost knowledge of the material behavior evolution in a precise field of use. The model for empirical approach is consistent with our experimental results for the primary and secondary creep thus underscoring the variation creep parameters of this model as a function of temperature and stress. The Eyring model for the tertiary creep reflects the acceleration of law in power of the rate of deformation in the creep and the influence of temperature. Mixed modelling that we have proposed seems to be confirmed by a good fit between the experimental results and the simulations.

References

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