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Comportamiento a compresión de non-crimp fabrics impregnados

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Abstract

Muchas industrias, como la del automovil están haciendo un gran esfuerzo para reducir costes y aumentar la productividad de los procesos de fabricación de composites. Aunque todas estas tecnologías aún están emergiendo, parece que los procesos de Moldeo de Compuestos por Vía Líquida (LCM) en los que hay una fase de compresión, como el Moldeo de impregnación por Compresión (WCM) o el Moldeo por Transferencia de Resina de Compresión (CRTM), son los mejor posicionados. En estos casos, dado que la preforma de fibra impregnada se comprime durante el proceso, es imprescindible conocer el comportamiento de compresión de estos materiales para seleccionar y optimizar el proceso de fabricación mediante herramientas de simulación.

Cuando se trata del proceso de compresión, se ha considerado que las preformas presentan un comportamiento elástico-lineal. Sin embargo, las últimas publicaciones han demostrado que este comportamiento es principalmente viscoelástico.

En este trabajo se ha caracterizado la relajación de un *Non-Crimp Fabric* (NCF) impregnado de 50k, bajo presión, para 3 velocidades de compresión diferentes. Para ello, el comportamiento viscoelástico se ha descrito mediante modelos fraccionarios, que en comparación con los modelos clásicos exponenciales, son capaces de reproducir correctamente la relajación del material durante la fase de máxima compresión

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1 Introduction

Vehicles lightweight is one of the most important topics considered in the automotive industry. In this sense, composite materials are an efficient alternative to metals, and therefore, the automotive industry is making a great effort in order to reduce costs and increase productivity for the manufacturing process of these materials.

The use of Non-Crimp Fabrics (NCF), in which the unidirectional (UD) fibres with several orientations are transversally stitched, facilitates the automation of manufacturing processes by increasing their productivity [1]. Furthermore, the probability of fibre orientation errors is reduced, together with the better in plane properties compared with woven fabrics (there is no fibre crimps) and better interlaminar prop- erties (the layers are stitched together).

Due to the high manufacturing rates and reduced manufacturing cost margin needed, the best positioned manufacturing methods are the LCM processes in which there is a compression phase, such as WCM or CRTM [2,

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9]. In such cases, the dry fibre preform is compressed during the process, so it is essential to know the material compression behaviour in order to select and optimise the manufacturing process by means of numerical process simulation techniques.

The force acting on the mould surface is the sum of the pressure generated by the resin and the reaction generated by the preform compaction. The relative importance of each of these contributions depends on the viscosity of the resin, preform (type of fibre, roving, fabric, fibre volume), the dimensions and geometry of the part and the compression parameters. Even if the viscosity of the resin has been the subject of numerous studies, the mechanical response of the preforms has received less attention. In such cases, the most common material response has been considered as linear elastic behaviour. Nevertheless, most of the publications in recent years have shown that this behaviour is viscoelastic [3, 4].

The objective of this study is to model the stress relaxation of 50k wet carbon fibre reinforced NCFs while subjected to maximum compaction in function of the compression velocity. To do so, based on the experience of previous works [5, 10], a fractional viscoelastic model is used for 3 different compression velocities.

2 Materials and experimental setup

A 0/90 oriented 50k and 610 g/m^2 density carbon fibre NCF with 150 140 mm^2 dimensions has been used to obtain the preforms. The tests have been performed in an Instron universal test machine with a 100 kN load cell. In order to compress the preform in an homogeneous way, an aluminium plate with dimensions 151×140×3 mm^3 is placed over the preforms, so that a 300 Pa pressure is applied which permits a similar initial deformation of the samples. To measure the deformation induced in the samples, the aluminium plate displacement is measured in two different locations by using 2 laser sensors, as it can be seen in the setup shown in Fig. 1.

Figure 1. Experiment configuration.

In the initial stage of the test, due to the weight of the aluminium plate, the preform has a initial thickness e_0 of 7 mm. Then, the preform is compacted until the maximum thickness of compaction is reached. The level of maximum compaction is maintained for some fixed t_c time. In this study, 3 different compaction velocities levels have been analysed, corresponding to 1 m/min, 5 m/min and 10 m/min.

In Fig. 2 the thickness and load profiles are shown. As stated before, in this study only the phase of maximum compression is studied, where the force decreases due to the material relaxation.

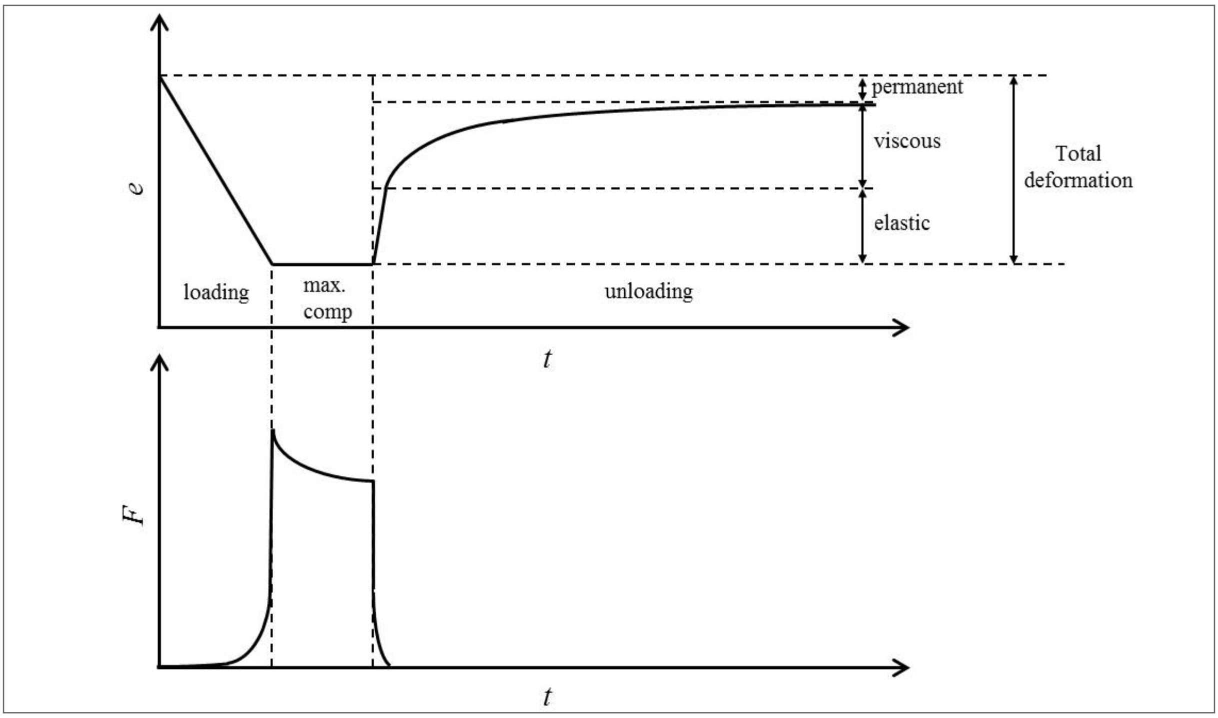

Figure 2. Theoretical test curves. Thickness vs.Time and Force vs. Time.

3 Fractional viscoelastic model

In order to characterise the viscoelastic material behaviour of a preform submitted to a constant compaction level, fractional models have been used [5–7, 10]. These models generalise the classical models based on elastic elements (linear springs) and viscous elements (linear dashpots), which model the elastic and pure viscous character, respectively, by the use of Scott-Blair elements of α order. For $\alpha = 0$ and $\alpha = 1$, perfectly elastic an viscous elements are obtained, respectively. Thus, extending the method used for classical mechanical models, based on springs and dashpots, the following fractional standard linear solid (FSLS) model is used to establish the relationship between the force in time $F(t)$ with the thickness in time $e(t)$:

$$F(t) + \tau^{\alpha} D^{\alpha} F(t) = k_{\infty} e(t) + k_0 D^{\alpha} e(t) \qquad (1)$$

where τ, k_0, k_∞ are material parameters and D_α is the fractional derivative operator of order α with respect to time [8]. The relaxation force $F_{rel}(t)$ corresponding to a constant maximum compaction thickness $e_0(t)$, imposed at $t = 0$ is obtained by integrating Eq. 1, which yields:

$$F_{rel}(t) = F_{\infty} + (F_0 - F_{\infty}) E_{\alpha} \left[- \left(\frac{t}{\tau} \right)^{\alpha} \right], \quad t \geq 0 \qquad (2)$$

where τ is the material relaxation time and E_α is the α-order Mittag-Leffler function, which is defined as [8]:

$$E_\alpha(z)=\sum_{k=0}^{\infty}\frac{z^k}{\Gamma(1+\alpha k)} \tag{3}$$

For the particular case where $\alpha = 1$, Eq. 2 yields the exponential classical relaxation response:

$$F_{rel}(t) = F_\infty + (F_0 - F_\infty)e^{-t/\tau}, \quad t \geq 0 \tag{4}$$

4 Numerical experimental correlation

In Fig. 3, the experimetal curves corresponding to the compression tests for 3 different compression velocities are shown. For all these tests, the maximum compression has been maintained until Force is stabilised.

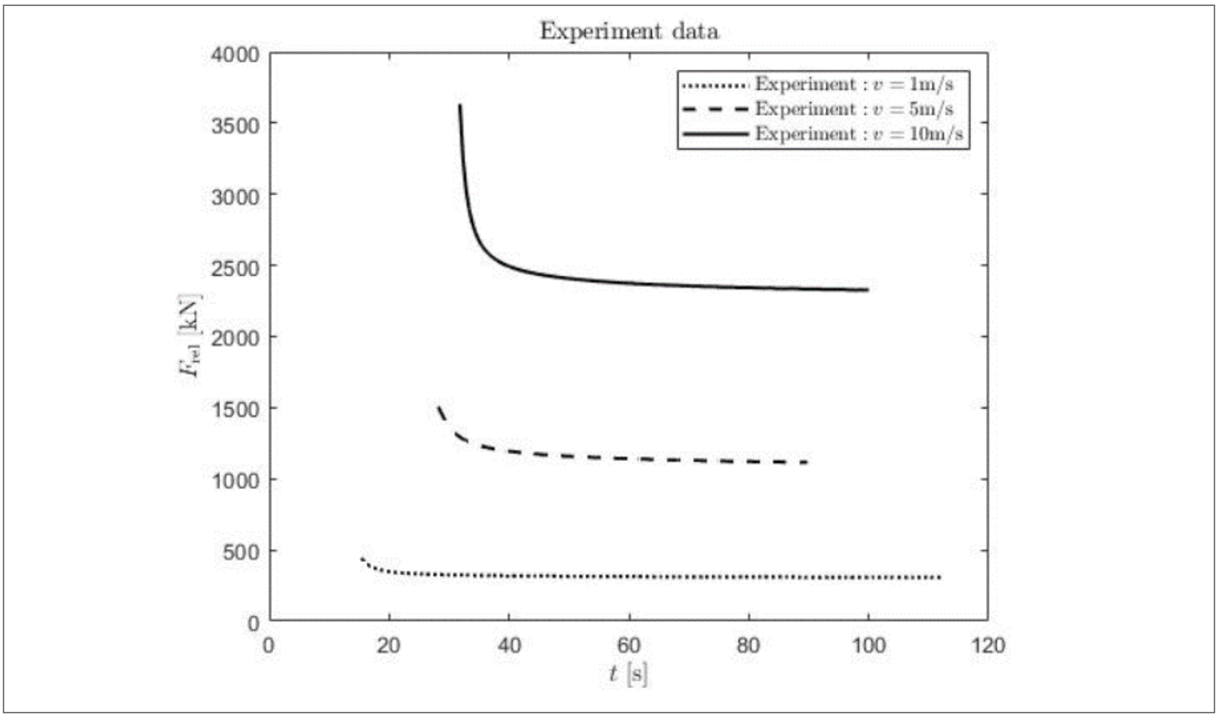

Figure 3. Experimental relaxation forces.

Figs. 4-6 show the experimental-numerical correlation for the 3 different compaction velocities, until the force is stabilised. The force relaxation levels are 35%, 34% and 39% for preforms compression velocites of 1 m/min, 5 m/min and 10 m/min, respectively.

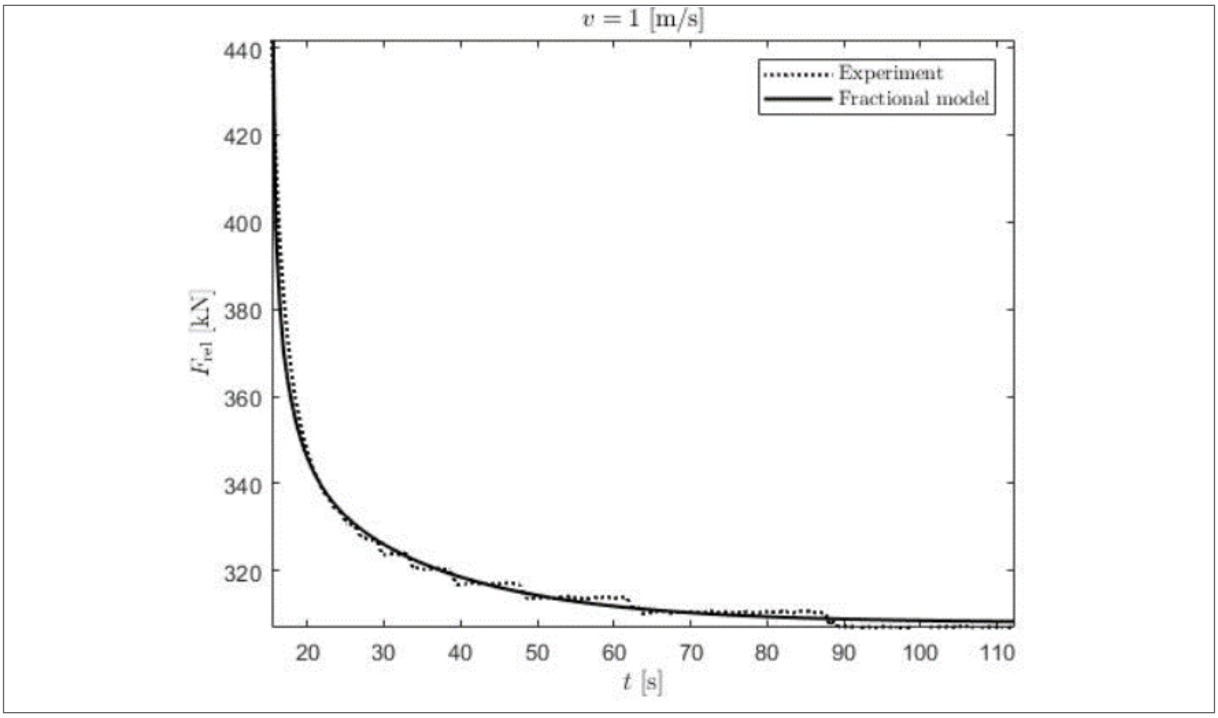

Figure 4. Experimental-numerical correlation for *v* = 1 m/min.

As it has been previously stated, fractional models are able to model relaxation phenomena in a more accurate way than classical exponential models [10].

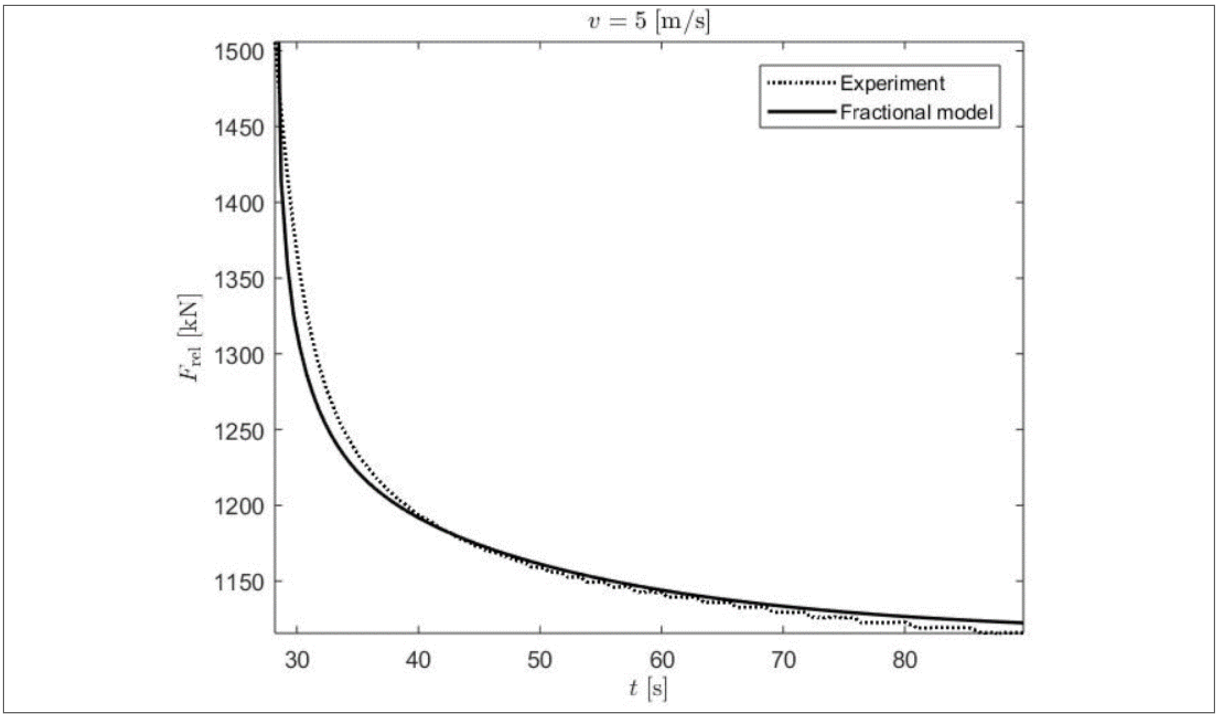

Figure 5. Experimental-numerical correlation for v = 5 m/min.

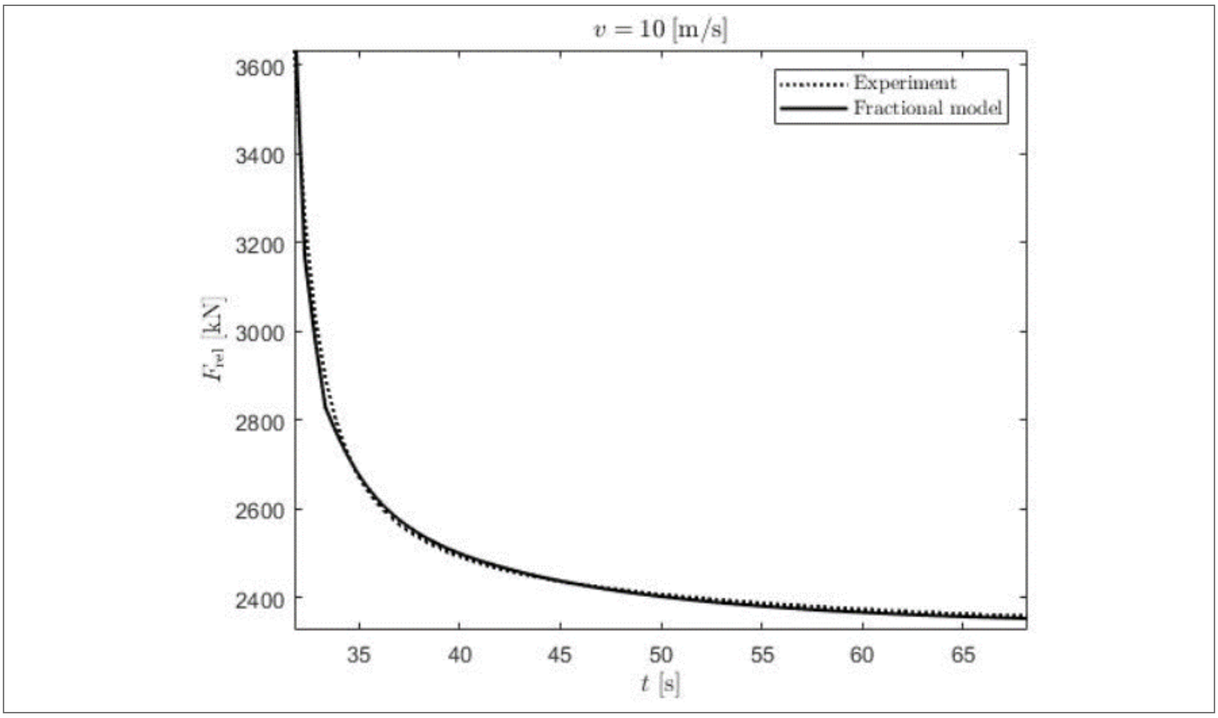

Figure 6. Experimental-numerical correlation for v = 10 m/min.

Table 1 gathers the fractional models parameters after identification from the experimental tests for different vf fibre volumes and né number of fabric layers. The model’s parameters, F_0 and F_∞ represent the compression force at the beginning and end of the maximum compression stage, respectively. The relaxation time τ indicates the way in which the force decreases due to material's relaxation. In this sense, it can be observed that the relaxation time remains constant for all the compression velocities. Finally, the derivative order α remains constant for the smallest compression velocities and increases for the bigest compaction velocity, which suggests that the derivation order is not an intrinsic material parameter and thus depends on the strain rate.

Table 1. Model Parameters

Test number	v [m/min]	F_0 [N]	F_∞ [s]	τ [s]	α
T1	1	469.11	300.94	1.5	0.53
T2	5	1652.93	1087.98	1.5	0.53
T3	10	3730.84	2291.92	1.5	0.65

5 Conclusion

In this work, the relaxation of a wet 50k carbon fibre reinforced NCF has been modelled by fractional models while it is subjected to maximum compaction for 3 different compression velocities.

For all the cases, compared with classical exponential models, the fractional model is able to correctly predict the material relaxation. Concerning the model's parameters, the relaxation times remain constant for all the compression velocities. However, the fractional derivative order remains constant for the smallest compression velocities and increases as the compression velocity is increased, which suggests the fractional derivative order dependence on the compression velocity and therefore is not an intrinsic material parameter as has been found in previous works of the authors.

As a future work, based on the ability of fractional models to predict correctly the material relaxation during the preform compression process, a model for the material's thickness recovery after the unloading stage will be developed, in order to optimise the manufacturing of LCM processes.

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