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VISCOELASTIC ANALYSIS OF FIBROUS REINFORCEMENTS IN LIQUID COMPOSITE MOULDING PROCESSES

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SUMMARY: Liquid composites moulding processes have now a high penetration ratio in the aerospace and aeronautic industries and are more and more used in the automobile sector. From the industrial point of view, the optimisation of the process parameters is necessary. This work presents an experimental study and a theoretical modelling of the compressibility and the relaxation of the reinforcements in the LCM processes. In the first part, experimental compressibility tests of the fibrous reinforcements were carried out on various types of fabrics (mat, twill, taffeta, unidirectional) while varying the compression parameters such as the number of plies, compression rate, the architecture of the reinforcements and their impregnation. For each case compressibility and relaxation curves have been obtained. In the second part, a viscoelastic approach and an elastic nonlinear modelling of the fibrous reinforcements are presented. The nonlinear elastic approach is based on the equation of continuity, Darcy's law and that of Terzhagui. In the rheological approach the models of Zener, Burger and Maxwell are used. The results, experimental and theoretical, show a good agreement for reinforcement ratio less than 50%, which constitute a good result regarding the reinforcements ratio usually used in LCM. For the rheological approach, the software Gnuplot which employs Levenberg-Marguadt method has been used. The best results, particularly concerning the relaxation time, are obtained with the model of Maxwell. The relaxation time decreases with the impregnation and increases with the grammage.

KEYWORDS: Liquid Composite Moulding (LCM), compressibility, relaxation, rheology.

INTRODUCTION

The liquid composite moulding is a manufacturing method largely used in the advanced technology industries and has a great potential of application. From a practical point of view, LCM processes have a more or less long phase of compression of the reinforcement. This step influences the compression rate of reinforcement and consequently the process of filling of the mould. This has a direct impact on the performances of the parts obtained. This work on the compressibility of the reinforcements presents a modelling using a micromechanical and rheological approaches. The first model of compressibility is that of Chen [1] represented by a power law between the stress and the volume fraction of fibres written as follows:

$$\sigma = A\, V_f^{\,B} \tag{1}$$

Parameters *A* and *B* allow fitting the above model to experiments. Several authors underlined the large dispersion of the results obtained for these two parameters and some modifications of this model has been proposed [2, 3] in order to better fit the experimental results. Chen et al. [4] proposed a model using physical parameters. These models applies only to the phase of compression and do not allow to describe the phase of relaxation. Gutovski et al. [5] proposed a model based on the beams theory. This model, in spite of his micromechanical aspect, does not permit to model the phenomena observed in the experiments. Several authors used the rheological models and the phases of compression and of relaxation are described separately [6, 7]. These models give a good result thanks to the use of the coefficients of adjustment. For the experimental part, several authors were interested in the study of the compressibility of the reinforcements. An abundant literature exists on this aspect in particular the study of the effect of the type of reinforcement, the rate of compression, the number of plies or the impregnation [8-10]. The experimental studies highlight at the same time the phase of compression and the phase of relaxation which are represented on the same figures [11]. Kelly [12] proposed interesting approach inspired from the work of Saunders [13], which treats simultaneously the phases of compression and relaxation.

The objective of this work is to propose an experimental study and two models of compressibility. The experimental curves present simultaneously the phase of compression and of relaxation. The effects of the process parameters have been studied. The results obtained are compared to the experimental curves obtained within our laboratory.

EXPERIMENTAL PROCEDURE

Dry and saturated reinforcements are used in the experiments. The testing machine used is a universal press of a maximum capacity of 50 kN controllable in displacement. The software of the driving machine allows the tracing of the curves representing the evolution of the force or the compressive stress according to time. The reinforcements in the form of rectangular plates of dimensions 150*100 mm^2 are compressed between two rigid plates up to a given level of strain as shown in Fig. 1. Then a constant level of strain is maintained and the stress relaxation is recorded. The tests made it possible to study the effects of the architecture of the reinforcement, the rate of compression and the impregnation of the reinforcements. Table 1 presents the properties of the various samples used for the present study:

Table 1 Characteristics of the fibrous reinforcements

	Mats		Fabrics		
	Mat 450	Mat 624	Unidirec-tional	Taffetas	Twill
Superficial weight (g/m^2)	*450*	*624*	*689*	*606*	*423*
Number of plies	*10, 15 20*	*10*	*10*	*10*	*10*
Compression rate (mm/min)	*1,5 ; 2 ; 2,5 3*	*3*	*3*	*3*	*3*

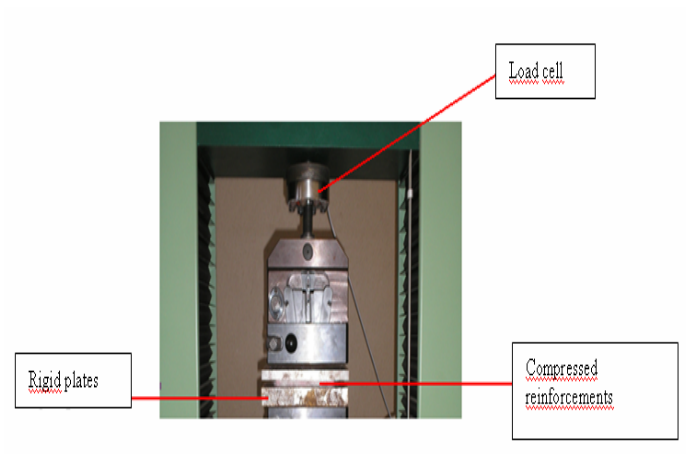

Fig. 1 Overall picture of the testing machine EM550.

Results on the Compression of Dry Reinforcements

Effect of the number of plies

Fig. 2 presents the results obtained for the various studied parameters. The increase in the number of plies allows higher rigidity of the reinforcement and the relaxation intensity.

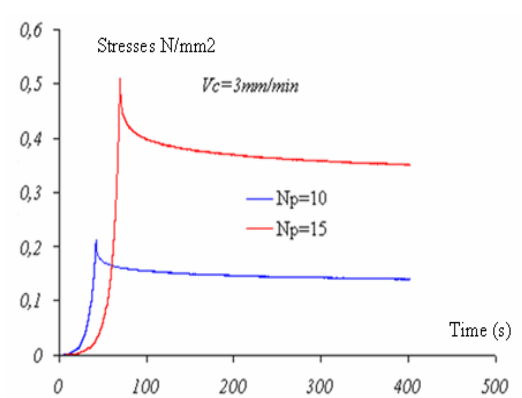

Fig. 2 : Effect of the number of plies for a mat 450.

Effect of the compression rate

The reinforcements are compressed at various speeds 1,5, 2 and 3 mm/min. Fig. 3 makes it possible to identify the rate of compression as an important parameter influencing the viscoelastic response of fibrous reinforcements. It is noted that more the speed of compression is high, the relaxation time is short. The maximum constraint increases with the speed of compression. Lastly, the intensity of the relaxation increases with the speed of compression.

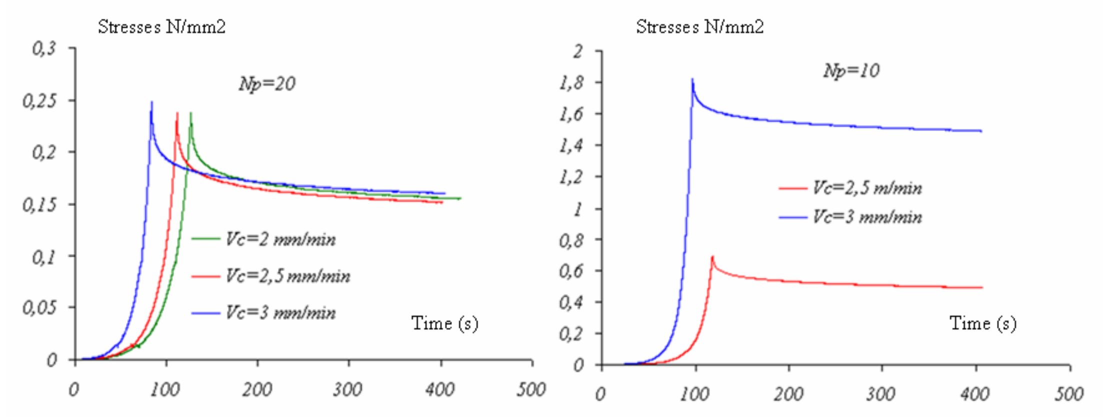

Fig. 3 Effect of the compression rate for mats 450 and 624.

Effect of the architecture of the reinforcements

Fig. 4 presents the effect of architecture on the behaviour of the fibrous reinforcements and shows that the rigidity of a mat reinforcement is related to the aerial weight. The results obtained on various woven architectures show that the rigidity decreases respectively in the order: the twill one, the unidirectional one and then taffetas.

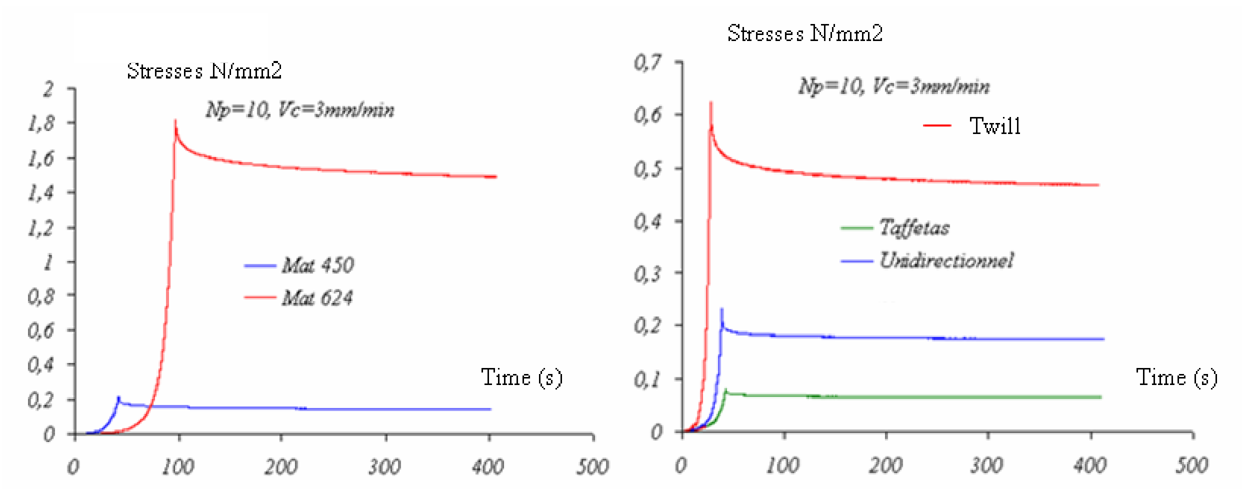

Fig. 4 Effect of the material (mats 450 and 624) and of the reinforcement architecture.

Compression Results for Wet Reinforcements

The tests of the wet reinforcements consist of compressing the reinforcements that are saturated by glycerin and diluted to give a resin viscosity of 0,105 and of 0,165 Pa.s (Fig. 5). The results show that the impregnated reinforcements oppose less resistance to the deformation than dry reinforcements. The effect of lubrication could not consequently be neglected. However, this influence is more or less marked according to the viscosity of the glycerin.

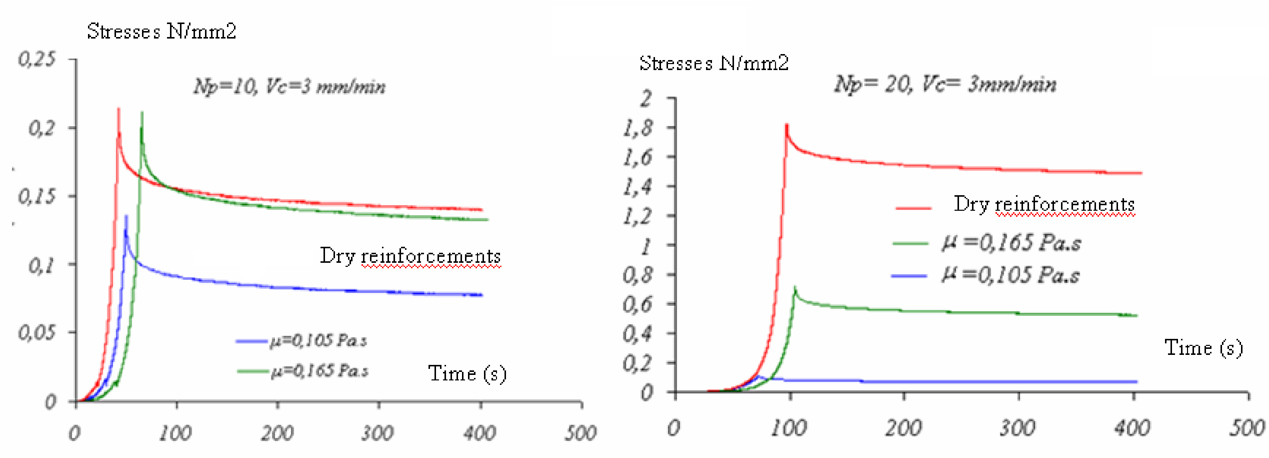

Fig. 5 Effect of resin impregnation for mats 450 and 624.

RESULTS

Micromechanical Model

Fig. 6 respectively presents the compression of a random mat 624 and twill reinforcements at 3 mm/min and impregnated by a glyceryn of viscosity 0,105 Pa.s. The approach by the equation of continuity and Darcy's law associated to the model of Chen et Chou [5] gives results that agree with the experimental data for a fiber volume fraction of fibres lower than 45% for the mat and lower than 55% for a twill. Knowing that the fiber volume fraction of a typical LCM fibrous reinforcement is about 50%, the predictions are thus in agreement with the experimental results.

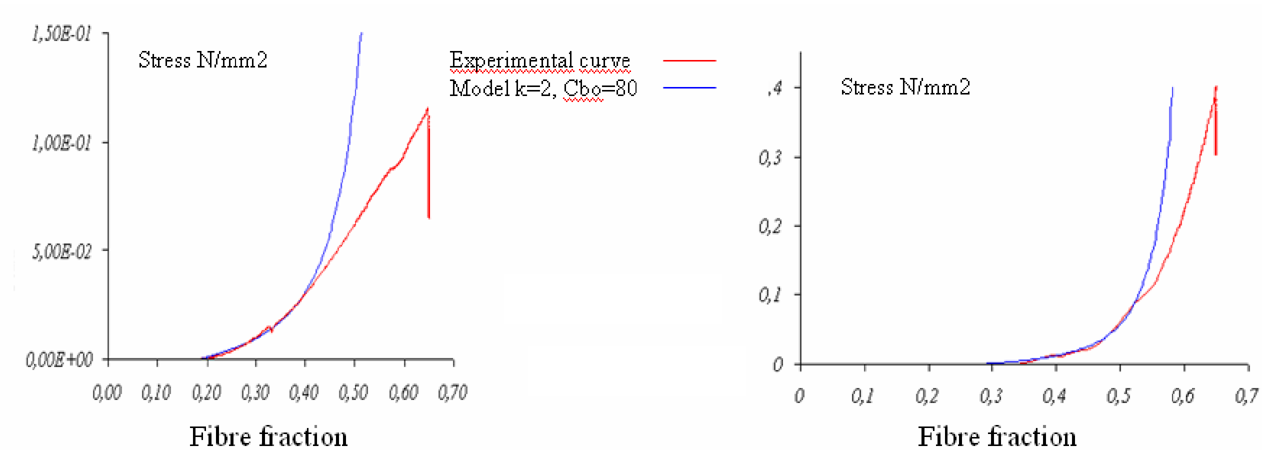

Fig. 6 Validation of the model based on the equation of continuity and Darcy's law for a mat 624 and a twill.

Rheological Models

The studied rheological models can be classified in two categories: the Zener model that has one relaxation time and Burger and Maxwell models with two relaxation times. The results obtained are presented respectively for the three models in Fig. 7. For the rheological approach, the software Gnuplot which employs Levenberg-Marguadt method has been used [14]. The best result, particulary concerning the relaxation time, is obtained with the model of Maxwell. The relaxation time decreases with the impregnation and increases with the grammage.

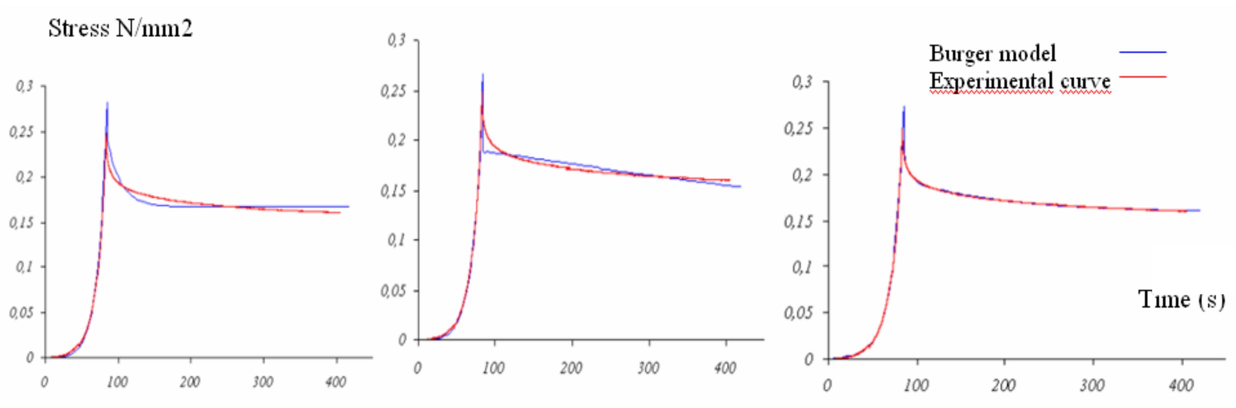

Fig. 7 Validation of the rheological model of Zener, Burger and Maxwell in the case of 20 plies of a mat 450.

CONCLUSION

In this work, we used two approaches for the modelling of the compressibily. The first one is based on the equation of continuity, the Darcy's law and that of Terzhagi. The second is a rheological approach where the models of Zener, Burger and Maxwell are studied. For the tests of compressibility, results show a good agreement for fiber volume fraction less than 50%. Which is very acceptable considering the fiber volume fraction usually practised in the LCM processes. For the approach by the rheological models, the Maxwell model gives the best results in particular concerning the relaxation time which decreases with the impregnation and increases with the grammage.

REFERENCES

1. Van Wyk, C. M, "Notes on the Compressibility of Wool", *Journal of textile Inst.*, 37.T285-292, 1946.

2. F. Robitaille and R. Gauvin, "Compaction of Textile Reinforcements for Composites Manufacturing I: Review of Experimental Results". *Polymer Composites*, 19(2), pp. 198-216, 1998.

3. F. Robitaille and R. Gauvin, "Compaction of Textile Reinforcements for Composites Manufacturing. 3: Reorganization of the Fiber Network". *Polymer Composites*, 20(1), pp. 48-61, 1999.

4. B. Chen and T. Chou, "Compaction of Woven-Fabric Preforms in Liquid Composite Moulding Processes: Nesting and Multi-Layer Deformation", *Composites Science and Technology, Vol.* 60 (12-13), pp. 2223-2231, September 2000.

5. Gutowski, T.G., T. Morigaki, and Z. Cai. "The Consolidation of Laminate Composites," *Journal of Composite Materials*, Vol. 21,pp. 172-188, February 1987.

6. B. Chen, A. H-D Leng and T-W Chou, "A Non Linear Compaction Model for Fibrous Performs", *Composites Part A*, 32(5), pp. 701-707, 2001.

7. R. A. Saunders, C. Lekakou and M.G. Bader, "Compression in Processing of Polymer Composites 2. Modelling of the Viscoelastic Compression of Resin-Impregnated Fibre Networks", *Composites Science and Technology*, 59(10), pp. 1483-1494, 1999.

8. F. Robitaille and R. Gauvin, "Compaction of Textile Reinforcements for Composites Manufacturing. III: Reorganization of the Fiber Network", *Polymer Composites*, 20(1), pp. 48-61, 1999.

9. R. A. Saunders, C. Lekakou, M. G. Bader, "Compression and Microstructure of Fibre Plain Woven Cloths in the Processing of Polymer Composites", *Composites Part A: Applied Science and Manufacturing*, 29(4), pp.443-454, 1998.

10. B. W. Grimsley, P. Hubert, X. Song, R. J. Cano, A. C. Loos and R. B. Pipes, "Flow and Compaction during the Vacuum Assisted Resin Transfer Moulding Process", *Proceedings of the 33rd International SAMPE Technical Conference – Advancing Affordable Materials Technology*, Vol. 33, Seattle, WA, November 5 – 8, 2001, SAMPE, Covina, CA, 2001, pp. 140 - 153.

11. S. Bickerton, M. J. Buntain and A. A. Somashekar, "The Viscoelastic Compression Behaviour of Liquid Composite Moulding Performs", *Composites Part A: Applied Science and Manufacturing*, 34(5), pp. 431-444, 2003.

12. P. A. Kelly, R. Umer and S. Bickerton, "Viscoelastic Response of Dry and Wet Fibrous Materials During Infusion Processes", *Composites Part A: Applied Science and Manufacturing*, 37 (6), pp. 868-873, 2006.

13. R. A. Saunders, C. Lekakou and M. G. Bader, "Compression in Processing of Polymer Composites 2. Modelling of the Viscoelastic Compression of Resin-Impregnated Fibre Networks", *Composites Science and Technology*, 59(10), pp. 1483-1494, 1999.

14. Gnuplot,www.traduc.org/doc-vf/gazette inux/html/2005/115/lg115-Ahtml.