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PROCESS-MECHANICAL PROPERTIES RELATIONSHIP FOR AN AIRCRAFT WING SPAR: COMPARISON OF PREPREG, LRI AND RFI TECHNIQUES

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SUMMARY: An aircraft wing spar made of carbon fibres and epoxy resin has been manufactured using different industrial techniques: Preg: considered as the reference, this process is also the most expensive, and this justifies the development of alternative low cost processes. LRI: Liquid Resin Infusion, this is a promising technique because it requires little equipment to obtain an acceptable quality, two different pressures were examined. RFI: Resin Film Infusion aims to combine both the advantages of using the same resin as the one used for prepreg and low cost manufacturing facilities. This study constitutes an important database for the evaluation of the mechanical properties obtained from different industrial processes. A set of tensile, bending, impact and damage tests has been conducted. Some particularities are highlighted, like the effect of the waviness defect of one side of the laminate which affects the bending strength, especially for processes from dry fabrics. Preg is a reference for all the mechanical properties but remains expensive; It justifies the emergence of alternative techniques which require lighter facilities and shorter lay-up durations like the LRI process. For the RFI process, it seems that the conditions for good manufacturing are not optimized.

KEYWORDS: Composite manufacturing, LRI, RFI, bending, shear, damage, impact

INTRODUCTION

The industrial development of composite structures requires manufacturing at a reasonable cost, so many processes can be candidates for producing a given part. In this context, an aircraft manufacturing company proposed a technico-economic study of processes for building an aeronautical composite structure. In order to perform this study a wing spar from an aerial acrobatics aircraft has been manufactured using four different candidate techniques : carbon-epoxy prepreg lamination cured at 160°C considered as the reference (Preg), liquid resin infusion of dry carbon fabrics by an epoxy resin under vacuum, and cured at 160°C with or without an additional pressure of 2,2 bar (LRI ATM and LRI 2,2) and the resin film infusion of dry carbon fabrics by an alternated stacking sequence of resin layers, cured under vacuum with an additional pressure of 2,2 bar at 160°C (RFI). These techniques do not require the use of an autoclave, and can be used without heavy equipment. Some of these processes are still under development, and are of interest for all the composite industrial domains. Indeed, shipyards use similar techniques at room temperature, but this requires resins with a satisfactory viscosity in order to impregnate the fabrics correctly.

The wing spar is made up of flanges loaded in tension or compression by the bending moment, and of a web loaded in shear by the transverse force. A different stacking sequence for each portion allowed us to cut relevant samples for characterizing the mechanical behaviour of the four wing spars manufactured by different techniques. Characteristics such as morphology (geometrical defects, volume fraction), elasticity, damage, impact resistance and failure have been measured by means of the coupons cut in appropriate areas of the structures. Analysis of the results provides a quantitative comparison of the four processes [1], [2].

MANUFACTURING OF THE WING SPARS

The four manufacturing routes are based upon a curing process under vacuum at 160°C. The full analysis of the processes would require presentation of a large quantity of details which come from a specific know-how. This will not be done here, and only the general details of the processes will be evoked.

The Processes

Each process presented here is at present employed in industry with a greater or lesser degree of development:

<u>L.R.I. ATM. (Liquid Resin Infusion under vacuum)</u>:
The resin impregnates the fabrics by flowing through the preform. The internal pressure (under the impermeable membrane of the mould) is established at 5 millibars, while only the

atmospheric pressure is loading the outside. The polymérisation is assured by maintaining temperature at 160°C.

L.R.I. 2.2 bars:
This is the same process as the precedent with addition of a pressure generated by a bladder inflated at 2.2 bars after the end of the infusion.

R.F.I. 2,2 bars (Resin Film Infusion):
Stacking sequence of dry fabrics and resin films put down alternately in the mould, which is put under vacuum by using a membrane. An additional pressure of 2.2 bars is obtained by a bladder at 160°C.

Preg (prepreg fabrics):
Well known process consisting of draping fabrics already filled with resin in the mould, applying vacuum by means of a membrane, then placing the part in an autoclave at 160°C under additional pressure of 2.2 bars with a bladder.

The Tool

It is a steel female mould able to resist the pressure of a bladder so that an additional load can be applied to the composite part to be manufactured. The mould and the process steps are presented in Fig. 1.

Fig. 1 Mould and manufacturing steps.

The Parts

The wing spars are designed with a U shape. The upper and lower parts carry the bending moment, and the vertical part carries the shear force. Coupons for mechanical testing are taken from different areas (Fig. 2). Stacking sequences are detailed in Table 1. The initial objective of the study was essentially to assess the process, so only the central part of the structures has been manufactured because a longer length would not have brought any additional information. Moreover, design has been simplified and the number of plies is not relevant for strength considerations.

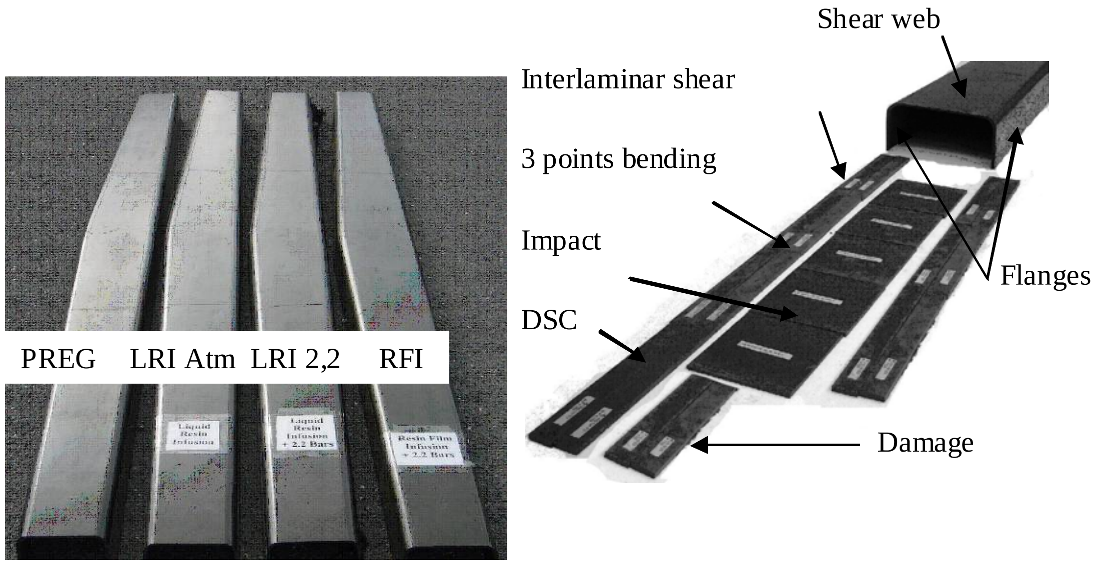


Fig. 2 Wing spars and sample coupon machining for mechanical testing.

Coupons have been cut from the flanges and the centre of the four wing spars in order to quantify the strength of the material. In addition, a measurement was made of the surface profile located on the side of the vacuum membrane (Fig. 3).

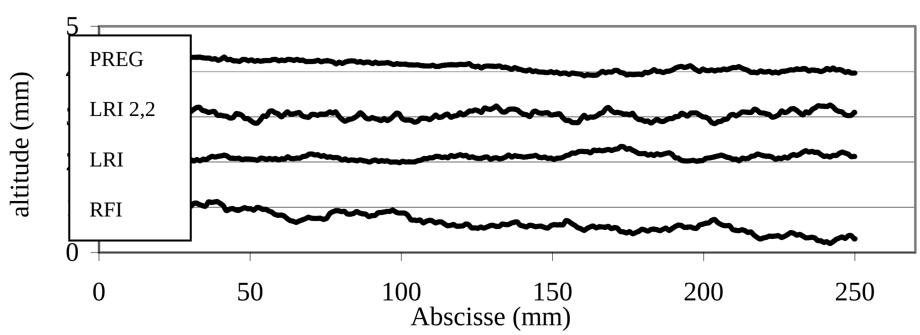


Fig. 3 Geometrical measurement of the spar profiles.

A similar waviness is observed for the three processes using dry fabrics. This typical defect shape is characterized by the average period of the wave and the corresponding average depth. This defect is not the roughness. Table 1 below lists the geometrical properties of the four wing spars.

Table 1 Microstructure and geometrical data for the four wing spar laminates

Process Stacking sequence	Thickness (mm)		Fibre volume fraction (%)	Tg (°C)	Waviness W (mm)	
	Flange	Web			Depth	Period
Preg $[\pm45,[\pm45_2,0]_5,0,[0,\pm45_2]_5,\pm45]$	8.03	5.41	68,2	141	0,04	32,8
LRI Atm $[[\pm45_2,0]_4]_S$	6.90	4.68	57,6	173	0,18	23
LRi 2,2 $[[\pm45_2,0]_4]_S$	6.52	4.40	60,4	179	0,16	24,2
RFI $[[\pm45_2,0]_4]_S$	6.84	4.51	60,5	154	0,18	25,5

Related to the average thickness of a laminate measured with a calliper, the thickness of a ply has to be defined for each process. Yet, regarding the defect in Figure 3, a mismatch of 2.5% appears between a classical measurement including the top of the waves and another one including the bottom on laminates manufactured from dry fabrics.

This will not affect the tests analysis, but it should be kept in mind when the bending test results are interpreted. A higher fiber content is noticed for the Preg wing spar, because it is exclusively laminated with unidirectional fabrics.

The materials used are recalled below:

- Preg; Carbon unidirectional fabrics HR Structil 268g/m² with epoxy resin Structil 1053A with no shrinkage.
- LRI and LRI 2,2: Dry carbon fabrics HR with epoxy resin RTM ST 1157. LRI 2.2 part has a higher density due to the additional pressure of 2.2 bars.
- RFI 2,2 ; Same fabrics as LRI and same resin as Preg.

For all the processes, micrographs showed very low levels of voids in all parts.

MECHANICAL PROPERTIES

In order to compare the mechanical performance of structures produced by the four processes, several tests have been conducted (table 2). This selection aims to cover the relevant loading cases on coupons able to qualify such structural parts. Each time, a set of 3, 4 or 5 samples have been taken in order to provide an overview of scatter. It will not systematically be reported if it does not explain differences among the processes. Each test result is discussed below.

Three-Point Bending

The focus is put on which side is loaded in compression: the one from the mould or the opposite side. Significant differences are noted which can reach 18% (Table 2). This means that the smooth side of the laminate has to be identified and its location during the tests has to be mentioned in order not to provide confused test results.

Interlaminar Shear

This test is of doubtful value on account of hypotheses involved in its interpretation and the presence of such a concentrated loading in composite parts. However, it is so simple that it has become widespread for characterizing interlaminar strength. Surprising results are noted, with a particularly weak value for the RFI laminate (Table 3).

Impact on Square Plate

This test applies a damaging impact across the width of the laminate during bending and shear of a square plate (140 x140)mm^2 simply supported on a circle below the coupon. The interest in such tests is increasing for the qualification loop of materials and structures. The impactor is spherical. The test report only indicates the surface of the damaged area, obtained from C-Scan control. One can notice that the RFI specimens present a wider damaged area compared to LRI, with the same impact energy levels (Table 4). It is not possible to compare these values to the ones from the Preg process, because those samples are much thicker.

Damage and Plasticity under Inplane Shear

This test recalls a damage identification procedure at the scale of the elementary ply [3]. It consists of measuring the tensile load and the corresponding longitudinal and transverse strains, and in applying load-unload quasi-static cycles on a $[\pm 45]_S$ laminate. The results are the coefficients of the damage and the plasticity master curves (Table 5) which simulate the non-linear response of the ply in shear. The three processes using dry fabrics present similar damage properties (Fig.4), while Preg has higher damage strength. It is the same tendency for plasticity properties, except for RFI which plasticizes faster than the others.

Table 2 Bending strength - Mould side in Tension or in Compression

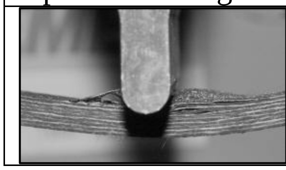
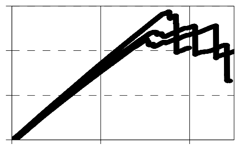
3 points bending	Load-displacement		C (MPa)	T (MPa)	Bias (%)
		Preg	713	681	4
		LRI	696	588	16
		LRI 2,2	763	629	18
		RFI	616	541	12

Table 3 Interlaminar shear

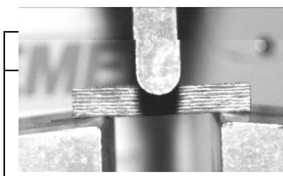
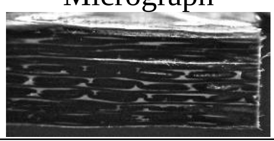
	3 points bending		Average (MPa)	COV (%)
	Micrograph 	Preg	62	1.5
		LRI	55	1.5
		LRI 2,2	50	3.1
		RFI	40	3.4

Table 4 Impact strength

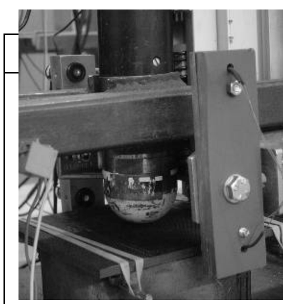
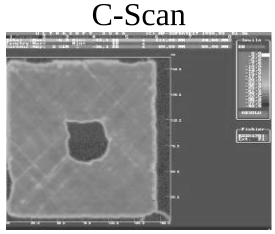
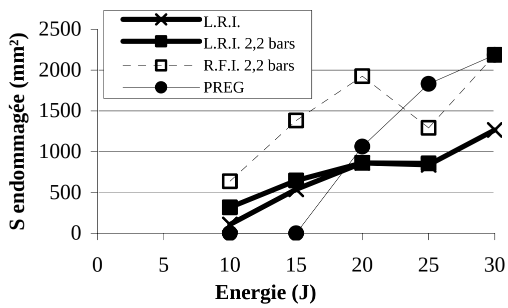
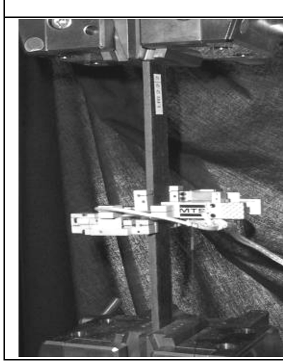
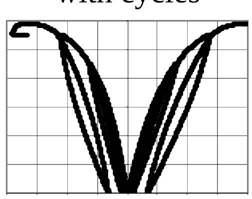
	t on plate	Damaged area – Impact energy
	C-Scan 	

Table 5 Damage and plasticity in shear

Tension [±45] with biaxial extensometer			Threshold $(Y_0)^{1/2}$	slope $(Y_C)^{1/2}$	Plasticity R (MPa)
	Stress-strain curve with cycles 	Preg	0.126	1.23	1520
		LRI	0.154	1.00	1340
		LRI 2,2	0.157	0.99	1310
		RFI	0.25	0.88	1250

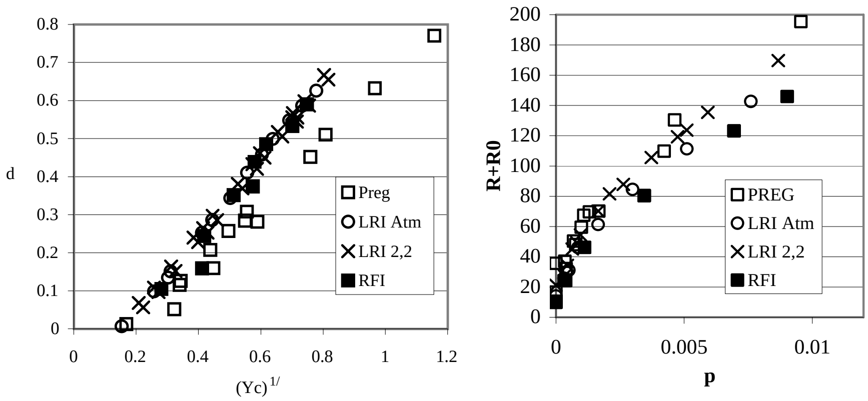


Fig. 4 Damage and plasticity master curves

CONCLUSION

This study constitutes an important database for the evaluation of the mechanical properties obtained from different industrial processes. A set of tensile, bending, impact and damage tests has been conducted. From there, some particularities are highlighted, like the effect of the waviness defect of one side of the laminate which affects the bending strength, especially for processes from dry fabrics. Despite differences in the stacking sequence, Preg is a reference for all the mechanical properties. However, this process remains very expensive and this justifies the emergence of alternative techniques which require lighter facilities and shorter lay-up durations. Following this logic, the LRI process is competitive because it solves the drawbacks mentioned above. Adding a pressure of 2.2 bars in this process increases the mechanical properties slightly. For the RFI process, it seems that the conditions for good manufacturing are not optimized. Indeed, the interlaminar shear strength is insufficient and it would be necessary to apply a higher additional pressure (around 4 bars). This would require the use of an autoclave, increasing significantly the cost of the process.

REFERENCES

1. Casari P., Choqueuse D., Davies P., Stervinou B., Léost L., Raymond L., 2006, "Caractérisation mécanique de quatre longerons carbone-époxy réalisés par différents procédés d’infusion", *JST AMAC ONERA* - Mise en forme des matériaux composites.

2. B. Stervinou, P. Casari, P. Davies, D. Choqueuse, "Relation process-propriétés mécaniques pour un longeron d'aile d'avion : Comparaison des techniques préimprégné, LRI et RFI", *15èmes Journées Nationales sur les Composites* - JNC 15 Marseille 6-8 juin 2007.

3. Ladevèze P., Le Dantec E., 1992 “Damage Modeling of the Elementary Ply for Laminated Composites”, *Composite Science and Technology*, 43, 257-267.