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Luc Amedewovo, Arthur Levy, Laurent Orgeas, Basile de Parscau Du Plessix, Steven Le Corre. Development of a lab scale in-situ characterization bench for deconsolidation of high temperature thermoplastic composites. International Conference on Manufacturing of Advanced Composites 2022, Sep 2022, Sheffield, United Kingdom. hal-03782217

HAL Id: hal-03782217

<https://hal.science/hal-03782217>

Submitted on 21 Sep 2022

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Development of a lab scale in-situ characterization bench for deconsolidation of high temperature thermoplastic composites..

Luc Amedewovo¹, Arthur Levy¹, Laurent Orgeas², Basile De Parscau Du Plessix¹, Steven Le Corre¹

1 : Nantes Université, IRT Jules Verne, CNRS, Laboratoire de thermique et énergie de Nantes, LTeN, UMR 6607, F-44000 Nantes, France.

(E-mail: luc.amedewovo@univ-nantes.fr, arthur.levy@univ-nantes.fr, basile.de-parscau@irt-jules-verne.fr, steven.le-corre@univ-nantes.fr)

2 : CNRS, Université Grenoble Alpes, Laboratoire 3SR, 38000 Grenoble, France

(E-mail: laurent.orgeas@3sr-grenoble.fr)

Keywords: Thermoplastic matrix, laminates, deconsolidation, thermal cycle, thickness monitoring.

I Introduction

Thermoplastic composites (TPC) offer the possibility to manufacture complex structures. In TPC manufacturing processes, after the composite laminate has been consolidated, it experiences a subsequent heating step. This is the case, for instance, of welding, thermostamping or overmoulding. Such a subsequent heating usually occurs without consolidation counterpressure and results in deconsolidation of the laminate [1,2]. This deconsolidation takes the form of porosities nucleation and growth or delamination. These are detrimental to the final quality of the parts [3]. A better understanding and control of this deconsolidation phenomena is thus of first importance to ensure a good final quality structure.

Several studies aimed at identifying the physical phenomena leading to deconsolidation: moisture or volatile release [4], fibre-bed relaxation [2], or even degradation are identified as key effects. Thus, the deconsolidation depends on the initial laminate consolidation state (residual stresses, absorbed moisture etc), and also on the deconsolidation conditions (heating rate, temperature, counterpressure etc). Attempts to characterize the deconsolidation are sparse and limited to (i) post mortem analysis or (ii) in-situ observations but usually not representative of the manufacturing process. On the one hand, thermo mechanical analysis laboratory setup are limited to small geometries. On the other hand, Brzeski and Mitschang [5] did a first attempt on measuring thickness evolution of a laminate experiencing deconsolidation in hot press. Nonetheless, the versatility (in terms of high temperature) and thermomechanical control of their setup is limited.

In this work, **a specific lab scale deconsolidation characterization bench (CODEC) was developed**. It permits to deconsolidate a characteristic thermoplastic composite laminate of up to 10cm by 10cm under temperature and pressure characteristic of industrial processes. The CODEC bench was then used to characterize deconsolidation of carbon-PEKK aerospace grade thermoplastic composite laminates. The experimental setup proves efficient at investigating dynamical deconsolidation effect.

II Development of the CODEC bench

A chamber contains a heating plate allowing the layup of a 100mmx100mm composite laminate (figure 1). A standard vacuum bagging can be positioned on the hot plate. The controlled heating plate can reproduce industrial cycles representative of aerospace grade thermoplastics: a vacuum bag consolidation cycle with a dwell of up to 450°C. The setup is positioned in a chamber which allows to apply compaction pressure of up to 10 bars to mimic autoclave counterpressure. The laminate thickness is continuously measured from the top, thanks to a contactless laser sensor, through a glass window.

The setup was tested with a reference material (Aluminum) and shows a thickness measurement sensitivity smaller than 40 microns over the whole temperature cycles.

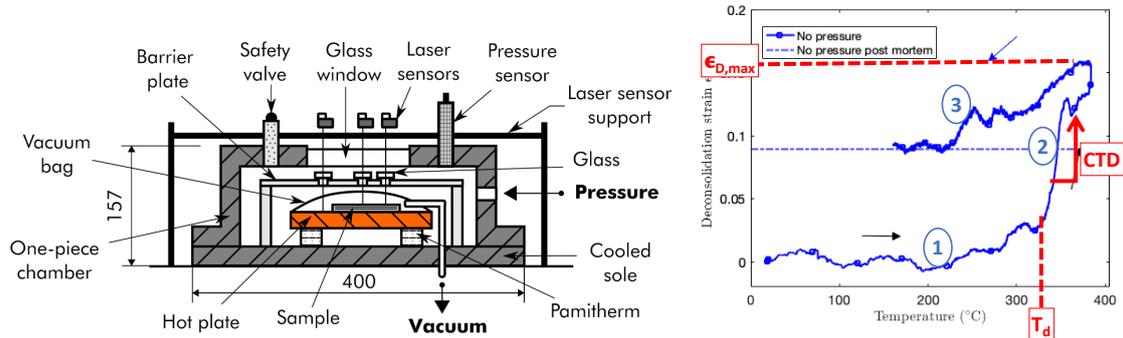


Figure 1. CODEC bench schematic (left). The bench allows thermoplastic composite laminate deconsolidation under controlled temperature and counterpressure. Contactless laser sensors track the laminate thickness continuously and in-situ. **Deconsolidation graph (right)** obtained from laminate thickness evolution during a temperature cycle for the test #1. The deconsolidation phase 2 is a dynamic phenomenon.

III Application to a Carbon PEKK laminate

1 - Procedure

Then, the setup was tested with an industrial continuous unidirectional carbon/PEKK system (size 125mmx25mmx2.90mm). Nine different conditions were tested. Several preconsolidation were used: Hot Press (HP) or vacuum bag consolidation (VBO). Except for the last laminate stored at ambient conditions, the others were dried for 72 hours at 180°C. The deconsolidation parameters in CODEC were also varied according to test matrix shown in Table 1. The counterpressure was varied from 0 to 5 bars and the heating conditions were tested according to Table 1. A dwell at 380°C for 5 minute follows the heating ramp and cooling is natural.

Thickness evolution is plotted versus temperature in Figure 2. During ramp up and down the evolution is representative of the transverse thermal expansion and thermal and crystallization shrinkage. Additionally, deconsolidation occurred quickly (in less than 30s) around melting temperature. The CODEC bench is able to track this dynamic phenomenon. Additionally, during the deconsolidation phase 2, characteristic magnitudes including deconsolidation temperature onset, coefficient of thermal deconsolidation (slope) and maximum deconsolidation strain can be obtained. This information, specific of the deconsolidation dynamics, would not have been accessible with usual post-mortem analysis.

	Initial laminate		Deconsolidation	
	Process	Conditioning	Counterpressure	Heating rate
1	HP	Dried (DS)	No pressure	10° C/min
2	HP	Dried (DS)	1 bar	10° C/min
3	HP	Dried (DS)	5 bars	10° C/min
4	VBO	Dried (DS)	No pressure	10° C/min
5	VBO	Dried (DS)	1 bar	10° C/min
6	VBO	Dried (DS)	5 bars	10° C/min
7	HP	Dried (DS)	No pressure	60° C/min
8	VBO	Dried (DS)	No pressure	60° C/min
9	HP	Ambiant (AS)	No pressure	60° C/min

Table 1. Test matrix. The initial laminate consolidation and storing conditions were varied as well as the deconsolidation conditions in the CODEC bench.

2- Parametric study

The results of the parametric study (Figure 3) shed light on several industrial results.

1 – 1 bar is sufficient to prevent deconsolidation in the case of vacuum bag consolidated laminates but not for press consolidated laminates. The press consolidation probably results in a higher internal stress release during heating. The counterpressure still delays the deconsolidation which starts at higher temperature. 5 bars counterpressure is sufficient to prevent deconsolidation in all cases.

2 - For laminates consolidated in hot press, the higher the heating ramp during subsequent process, the higher the deconsolidation. We suspect that heating slower results in giving more ability to the matrix for stress relaxation before deconsolidation.

3 – Preconditioning the laminate seems not to change the final deconsolidated thickness (around 11%). Nonetheless, the deconsolidation at high temperature differs highly with a much higher maximum deconsolidation for the laminate stored at ambient conditions.

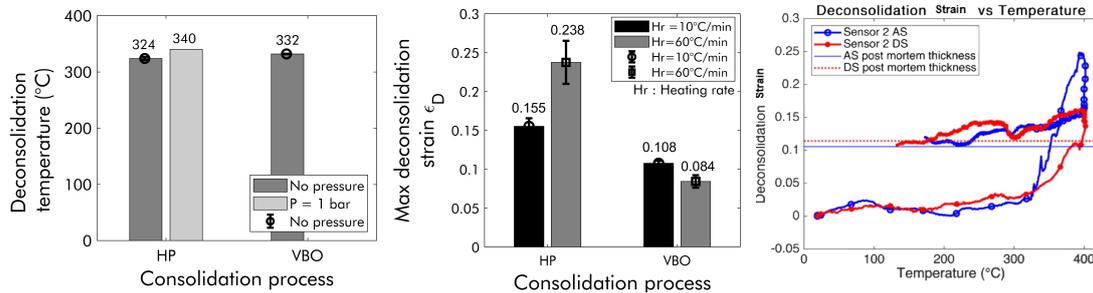


Figure 3. Parametric study. Effect of counter pressure (left) heating rate (middle) and preconditioning (right).

IV Conclusion

The CODEC bench was developed and fabricated to characterize deconsolidation of high temperature thermoplastic matrix composite laminates. It enables to track the deconsolidation in-situ and continuously during a cycle representative, in terms of pressure and temperature, of various manufacturing processes. The bench was used to investigate the effect of consolidation conditions and moisture of the initial laminate as well as deconsolidation heating ramp and counterpressure. The deconsolidation is confirmed to be a dynamic phenomenon.

Acknowledgment: The authors would like to acknowledge the funding of PERFORM project led by IRT Jules Verne. Authors wish to associate the industrial partners of PERFORM project: Airbus, Safran, Latecoere, Stelia Aerospace, Clayens NP, Naval Group and Faurecia.

The authors would like to thank two colleagues. Arnaud Arrive helped with the design and manufacturing and Julien Aubril helped with the acquisition and control of the bench.

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