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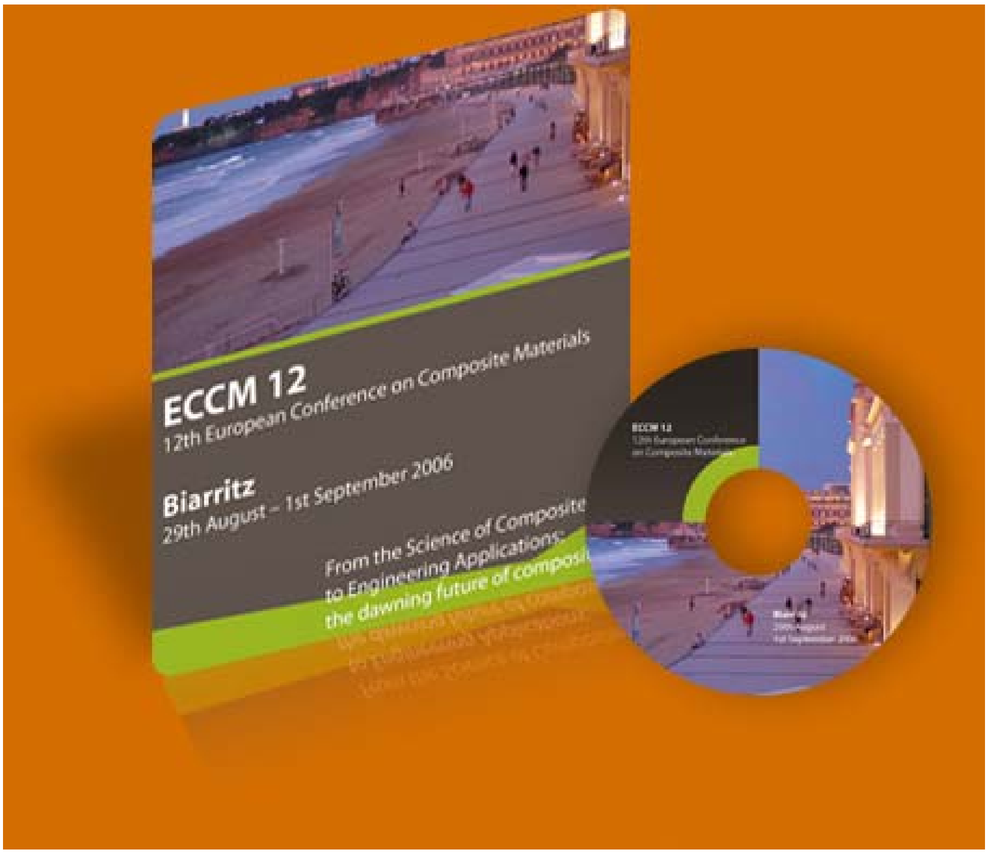

EXPERIMENTAL DAMAGE STUDIES OF 2.5D INTERLOCK CFRP UNDER UNI –AXIAL LOADING

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ABSTRACT

In this paper, five types of woven fabric interlock 2.5D are presented. Two parameters, the number of interlacing and the rate of fiber with respect to yarn direction, differenced one from each other. A results of uni-axial tests accompanied with acoustic emission are also presented and discussed. Damages and failure mechanisms are identified by microscopic observation and compared by their identification attributed to stages of amplitude. This analysis make possible to describe the failure scenario. A three-dimensional analytical model through the application of failure criterion 3D of Tsai-Wu, is applied to the REV of these composites, to predict the rupture of yarns, by taking into account their structural parameters. The results from these modeling are compared with experimental results.

Keywords**:** Interlock- Acoustic emission- Damage- Microscopic studies- Failure

1. INTRODUCTION

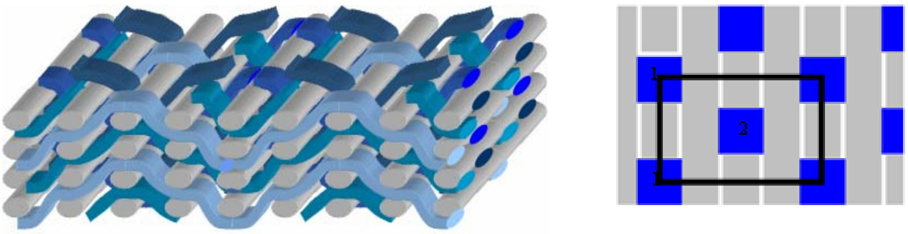
The development of weaving techniques allowed, these ten last years, the development of new architectures of three-dimensional reinforcements. Thus was born a new generation of composite materials whose elastic and failure performances in third direction are increased considerably. Moreover the reinforcement in the third direction allows a clear improvement of the interlaminar resistance which remains one of the main concerns with respect to the laminated composite materials.

Nevertheless, an incomplete understanding of the mechanical behavior associated to the complex fiber architecture, limits the optimal using of these materials. The few works undertaken by certain authors [1,2,3] on this subject does not make it possible to cover the problems. Acquired knowledge remains insufficient compared the conventional materials 2D.

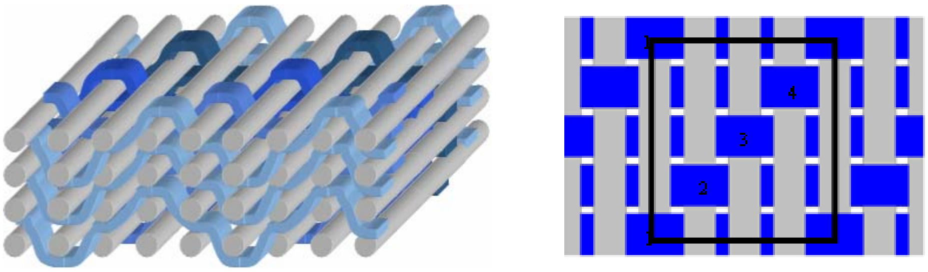
This study constitutes a contribution to the comprehension of the damage mechanisms in this kind of composite materials. It concerns more particularly the damage generated following a uni-axial tensile test of weaving angle interlock 2.5D carbon fiber composite

2. MATERIAL PRESENTATION

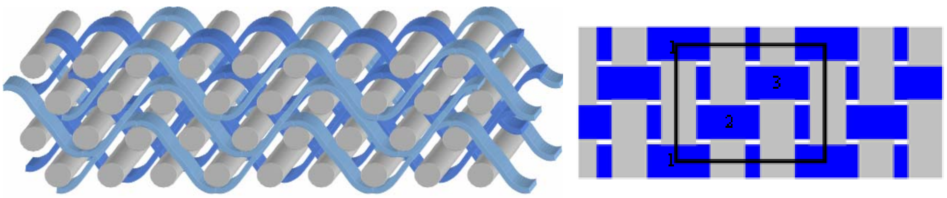
This work concerns five types of composite materials reinforced with T300 carbon woven fabric interlock 2.5D. These materials are obtained by the resin transfer molding process. The resin used is an RTM6.
The internal geometrical design of each type is visualized in figure 1 (the unit cells REV are framed by rectangles). The variable parameters between each type are the number of interlacing of warp yarn through the fill yarn as well as the proportion of fiber in yarns. The geometric characteristics of weaving are presented in table 1.



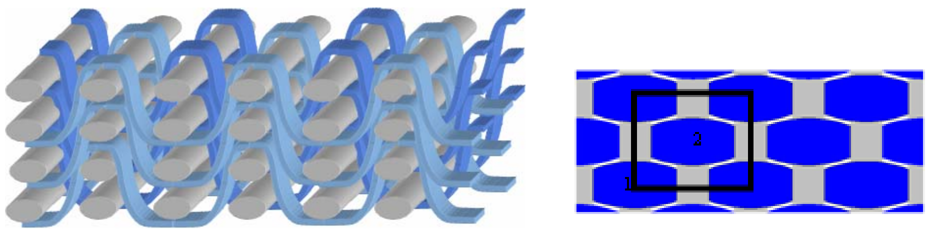
a-Weaving type 1



b-Weaving type 2 and 3



c-Weaving type 4



d-Weaving type 5

Figure 1: The five internal design of angle interlock 2.5D fabric

	Type of woven fabric				
	1	2	3	4	5
Number of vertical plan layer in REV	2	4	4	3	2
Number of vertical interlacing	3	3	3	3	3
Number of horizontal interlacing	3	3	3	2	1
Number of filaments in yarns	6k	48k	48k	12k	48k
Fiber proportion in warp yarn	35%	70%	50%	50%	70%
Fiber proportion in fill yarn	65%	30%	50%	50%	30%

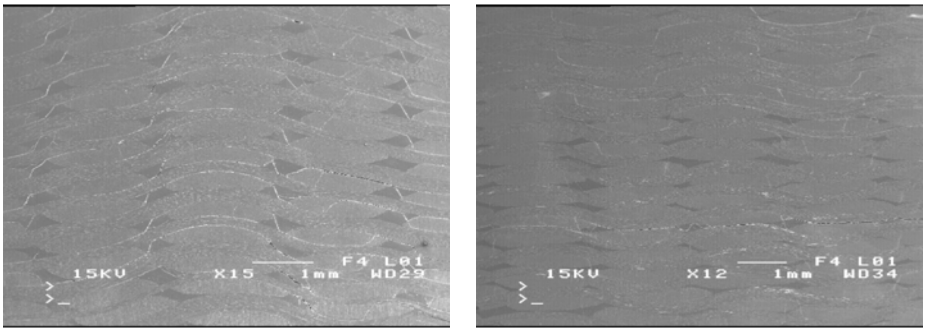
Table 1: Characteristic of type of woven fabric interlock 2.5D

3. Damage and rupture process

The behavior of materials was investigated under a uni-axial tensile loading in the warp and weft directions. The tests are instrumented by a bidirectional strain gages which make possible to follow the evolution of the strength according to the deformation. The damage and the failure mechanisms were identified by microscope observations. The evolution of the damage is followed by the acoustic emission (EA). The detection of signals are assumed by a piezoelectric sensor with wide band (20 kHz -1 MHz.

3.1- Microscopic studies

The sequence of damage is carried out by microscopic studies under an electronic microscope (MEB: JOEL - JSM 6100 Scanning Microscope). Figure 2 shows an example of microscopic observations of damage under uni-axial tension loading. This analysis make possible to describe the failure scenario. It's summarized by five stages for each loading direction (figure 4 and 5): 1- Release and propagation of rupture in the position on stress concentration. 2- Propagation of rupture through the trajectories of interface warp/fill yarn, followed by shearing rupture of resin blocks. 3- Interface rupture of warp or fill yarn/resin by surrounding yarns in perpendicular position to load, followed by transversal shearing in these same yarns. 4- Longitudinal damage of yarns which have the load direction, in the position of high slop. 5- Multiplication of transversal shearing of yarns perpendicular to load. In all steps, we signal the multiplication of micro-cracks of block resin. The final failure of material is carried out when the yarns in direction of load is failed transversally.



-a- -b-

Figure 2: Damage of interlock under uni-axial tension. a: in warp direction . b:in weft direction. Weaving type 1

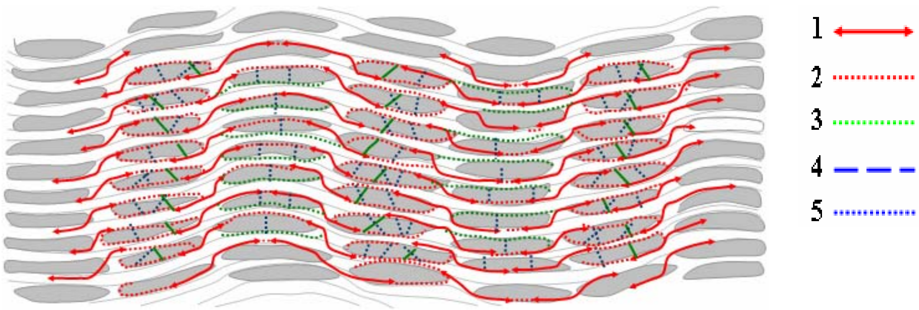


Figure 4: Mechanism of damage under uni-axial tension load in warp direction

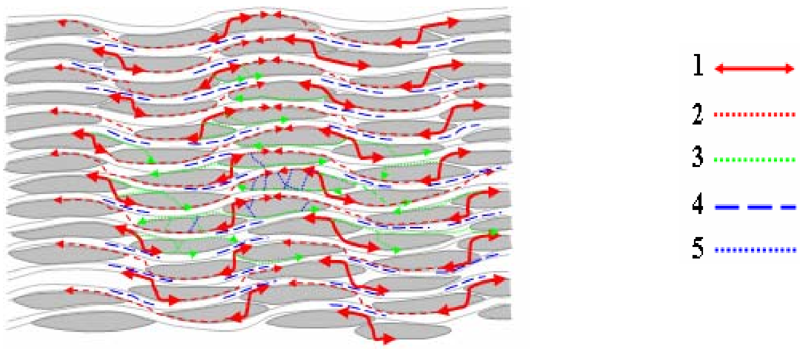


Figure 5: Mechanism of damage under uni-axial tension load in the weft direction

3.2- Acoustic emission studies

The identification of the damages is carried out in agreement with the attribution of the range of amplitudes of AE to the various damages establishes by Barre & al [4] (figure 6).

The analysis of results is based on the correlation of the evolution of the load and the cumulative acoustic emission (AE) represented by the distribution the number of events for each stage identified previously. We presented in this study only the stage of amplitude [82-100] dB whose corresponding to fiber failure.

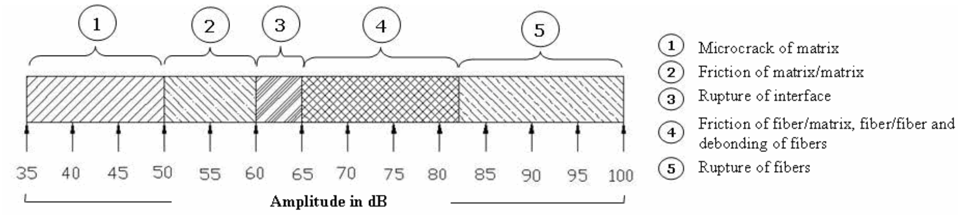


Figure 6: Attributed amplitude stages to different types of damage established by [4]

For all the results, the EA studies are presented in terms of number of events. In the same diagram, the red curve is the tension test load/time, the black curve is the cumulus of number of events whose the amplitude is between 82-100 dB. The bleu dots group presents the distribution of number of event in the same range of amplitude. The particular level of stress is indicated for the comparative studies with analytical model developed previously [ref]. For the weaving type 1, the figures 7 and 8, present a correlation between microscopic studies and the AE, under uni-axial tension, respectively in warp and weft direction. Even if the proportion of fiber is 35% in warp direction and 65% in weft direction, the shape of acoustic emission curves seems be the same. On the other hand, the first significant fiber ruptures earlier appear in the case of warp direction testing.

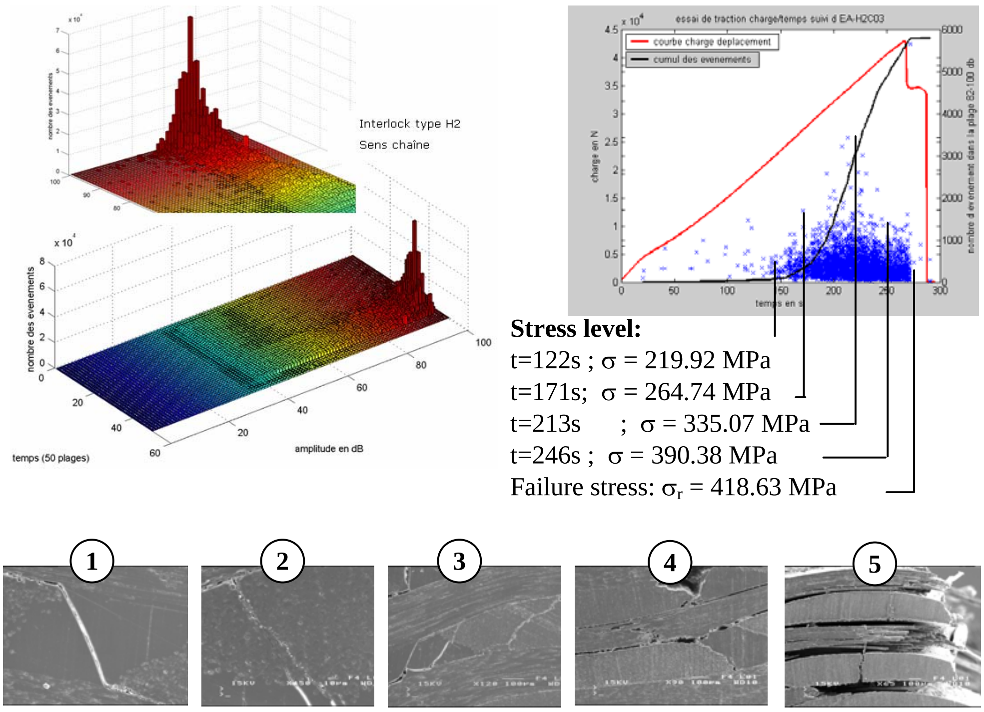


Figure 7: Microscopic studies and acoustic emission results in terms of number of event for the weaving type 1, under uni-axial tension in warp direction

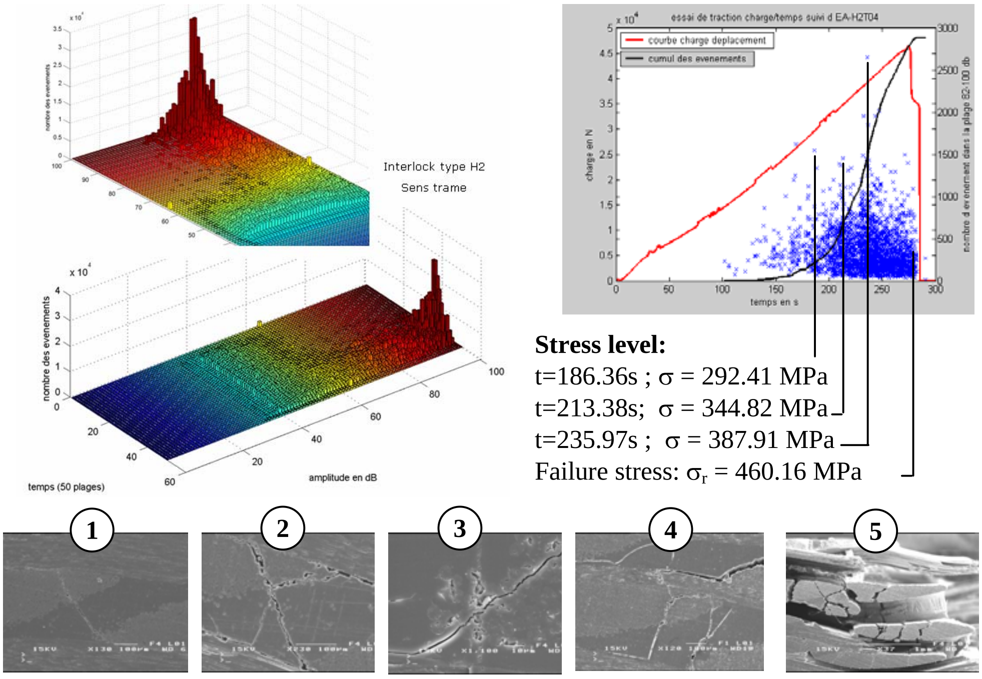
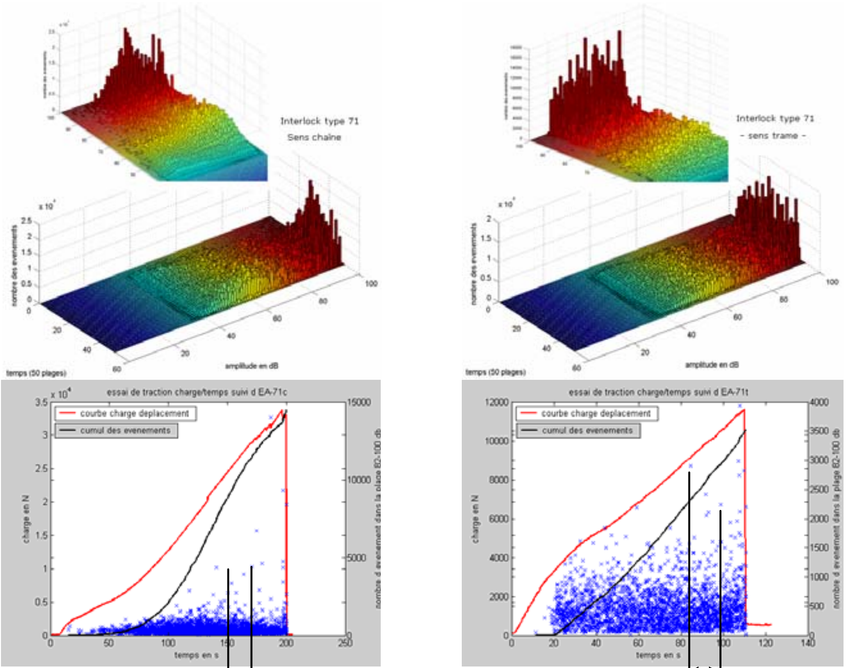


Figure 8: Microscopic and Acoustic emission results in terms of number of event for the weaving type 1, under uni-axial tension in weft direction

The weaving type 2 exhibits a monotone distribution of event in weft direction (figure 9) with earlier fiber failure comparatively to the type 1 weaving. Contrary to the previous material, the behavior on the warp direction and the weft one is very different. The ultimate stress is, roughly, 3 time higher in the warp direction than the weft one, with acoustic emission shape curve more linear in the weft direction. The result of weaving type 3 (uni axial tension in warp direction and of weaving type 4 and 5 (uni-axial tension in weft direction) are represented respectively in figure 10 and figure 11. The weaving type 4 presents an evolution of cumulated EA completely different from other materials. Indeed the shape indicates an early beginning of fiber rupture which continues in an intensive way throughout the test. This phenomenon explains the delamination failure of this type of weaving contrary to the other materials where the rupture is franker.



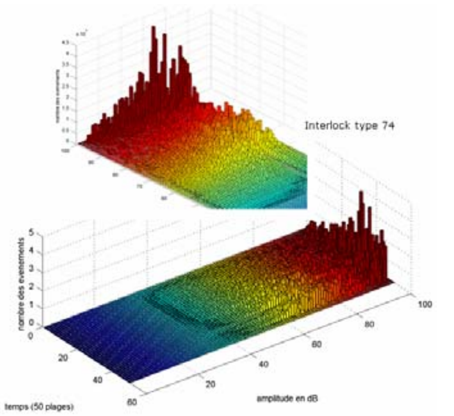
Stress level:
t∈[150-170]s ; σ ∈[515.41-543.66] MPa
Failure stress: σ_r = 672.99 MPa

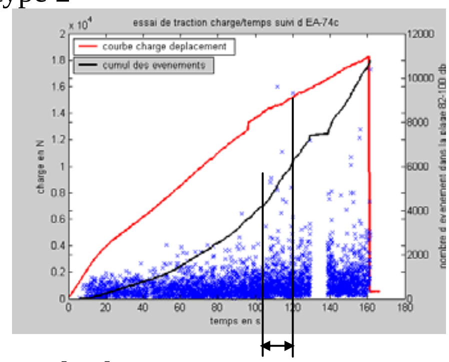
Stress level:
t∈[84.7-100]s ; σ ∈[181.95-211.91] MPa
Failure stress: σ_r = 238.19 MPa

a- uni-axial tension in warp direction

b-uni axial tension in weft direction

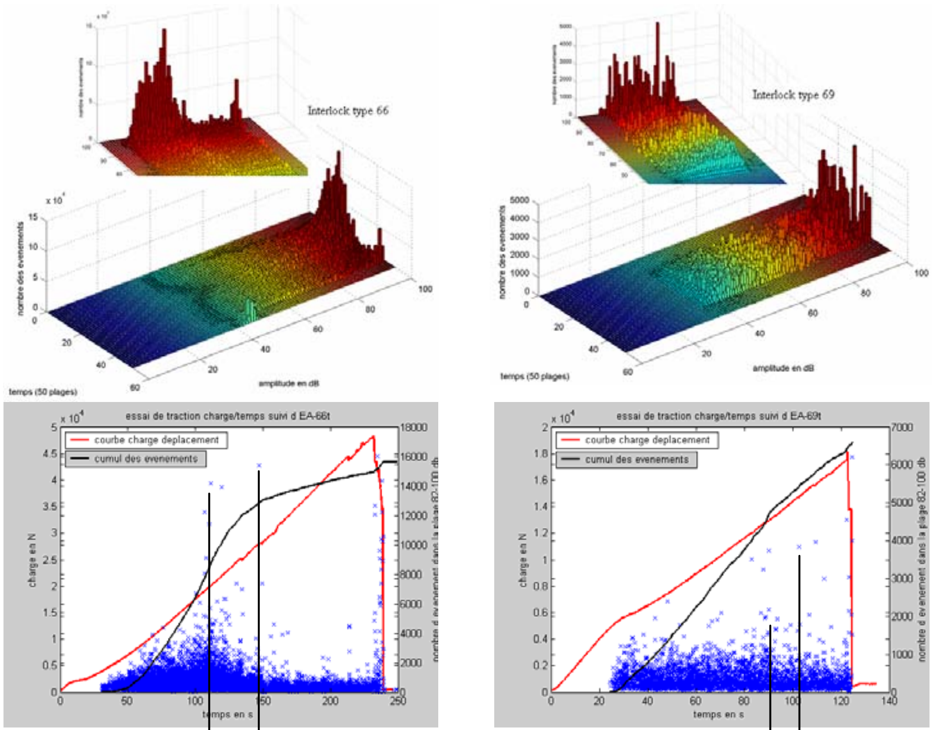
Figure 9: Acoustic emission results in terms of number of event for the weaving type 2





Stress level:
t∈[104.87-119.4]s ; σ ∈[269.8-288.72] MPa
Failure stress: σ_r = 349.45 MPa

Figure 10: Acoustic emission results in terms of number of event, under uni-axial tension, in warp direction for the weaving type 3



Stress level:
t∈[111.23-147]s ; σ ∈[442.93-615.23] MPa
Failure stresss: σ_r = 1072.52 MPa
a-weaving type 4

Stress level:
t∈[93.15-102.84]s ; σ ∈[279.97-308.63] MPa
Failure stress: σ_r = 380.54 MPa
b-weaving type 5

Figure 11: Acoustic emission results in terms of number of event, under uni-axial tension, in weft direction

4. RESULTS AND DISCUSSION

Except the weaving type 1, all the others types, cause fibers rupture in a advanced time of the test and the distribution of event are sensibly constant. The proportion of fiber influences on the beginning of the fiber rupture, an increase of proportion causes a delay. The number of horizontal interlacing does not influence much the distribution of the events. The table 2 present the result of yarns' failure by the application of a homogenization analytical model. This model is based on the average of the sum of the rigidity of each component of REV through the application of a rupture criterion 3D of Tsai-Wu and according to the methodology suggested by a study on orthogonal 3D textile composites [5-6]. The column 5 which present the analytical predicted stress ruptures of yarns perpendicular to the load are in a good agreement with the particular stress indicated for each type in AE for all types of weaving.

Type of woven fabric	Direction of uni-axial tension load	Experimental studies	Analytical model /interval	
		σ_r (MPa)	$\sigma_{r\ yarn\ //\ load}$ (MPa)	$\sigma_{r\ yarn\ \perp\ load}$ (MPa)
1	warp	418.63	[220-530]	380
	weft	460.16	750	[320-340]
2	warp	672.99	[580-670]	[520-540]
	weft	238.19	[430-440]	[190-210]
3	warp	349.45	[190-380]	[280-380]
4	weft	1072.52	[1110-1120]	[480-600]
5	weft	380.54	[510-520]	[280-300]

Table 2: Comparison of rupture stiffness of yarns

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