Feedback Control of Liquid Composite Molding Processes

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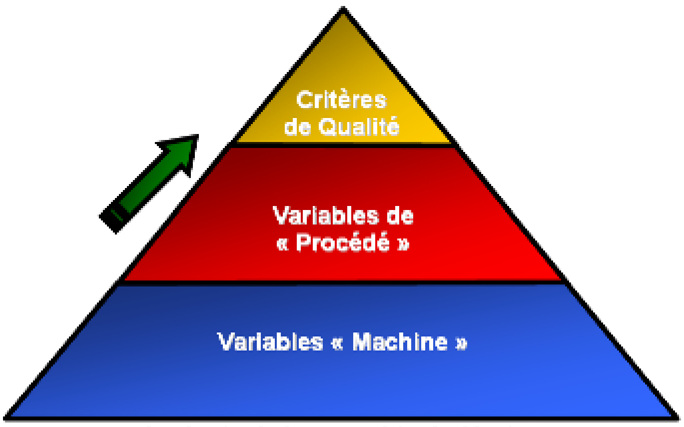
1. INTRODUCTION

In the beginning employed mainly in the military field, thermosetting polymer-matrix composite materials are found now in a growing number of industrial applications. Their popularity knows a considerable growth in the fields of aerospace, transportation, medicine and the leisure. This is explained by their excellent mechanical performance in term of specific rigidity, their good soundproofing and electric properties, as well as a remarkable resistance to fatigue and corrosion. The principal obstacle with a generalization of their employment in many sectors remains the manufacturing costs, which remain prohibitive. However the high performance composite manufacturing by liquid composite moulding processes succeed in reducing much the manufacturing costs of these materials as opposed to more traditional manufacturing methods like autoclave curing.

In order to control composite manufacturing by resin transfer moulding, a better knowledge on modeling and control of manufacturing processes is necessary. In particular, the real time quality control of composite parts, improvement of manufacturing reproducibility and reject minimization constitute as many industrial issues and challenges to meet.

The goal of this project is to answer the three following fundamental questions:

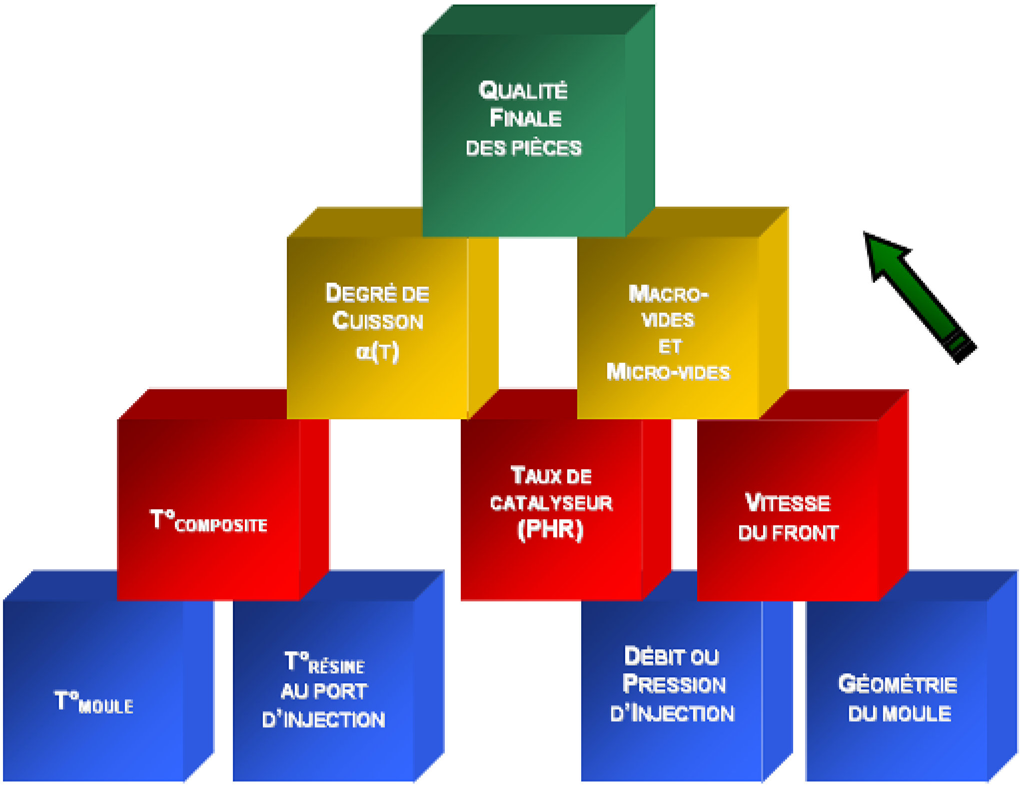
- Why is it necessary to control liquid composite moulding processes (LCM)?
- Could they be controlled?
- Lastly, in the case of an affirmative answer to the preceding question, how could one be able to control them in an industrial production context?



Analogie de la pyramide de *Maslow*

The main objective of manufacturing process control is to produce parts at the higher standard of practicable productivity, according to quality standards established beforehand.

However, these quality standards are occasionally accessible or controllable directly via an unspecified metrology.



To control quality of produced parts, firstly "Machine Variables" and then "Process Variables" must be controlled well. Within the framework of Liquid Composite Moulding processes, these “Quality Criteria”, "Machine Variables" and "Process Variables" are presented hereof.

2. INTELLIGENT CONTROL SYSTEM

The injection system used is composed of:

- 2 tensile testing machines:
    - Precision-built DC servomotors
    - DOLI digital controllers
    - Cross-head speed and position control
- Single or double-acting piston (pump):
    - Heavy-duty
    - Could be used to inject filled or unfilled resin
    - Could be used to inject catalyst and initiator
    - Could be thermally controlled
- Tanks and supply lines
    - Could be thermally controlled
- Computer workstation
    - Equipped with a touch screen

3. COMPUTERIZED INJECTION

In anticipation of safety and a robustness, pneumatic valves are used to automate the manufacturing process steps which are:

- Resin and catalyst recirculation
- Mould opening and closing
- Catalyzed resin injection
- Mixer flushing with acetone

These valves could be used as:

- Pneumatic grippers:

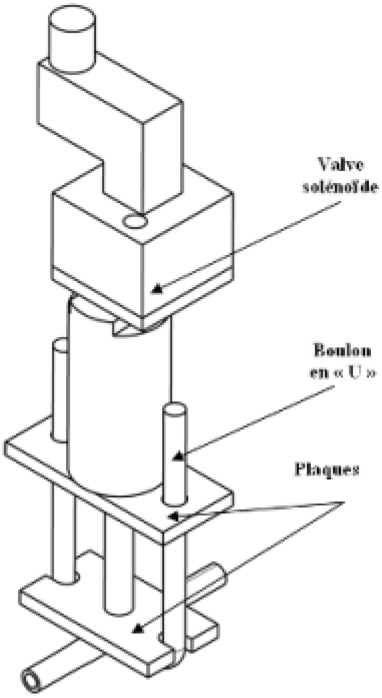
That can be used as mould gates and vents

- Autosprue:

To flush static mixer with solvent and reject not properly mixed resin.

- Pneumatic injection guns:

To inject resin and catalyst as well as recirculate both reactive fluids.



4. INJECTION CONTROL

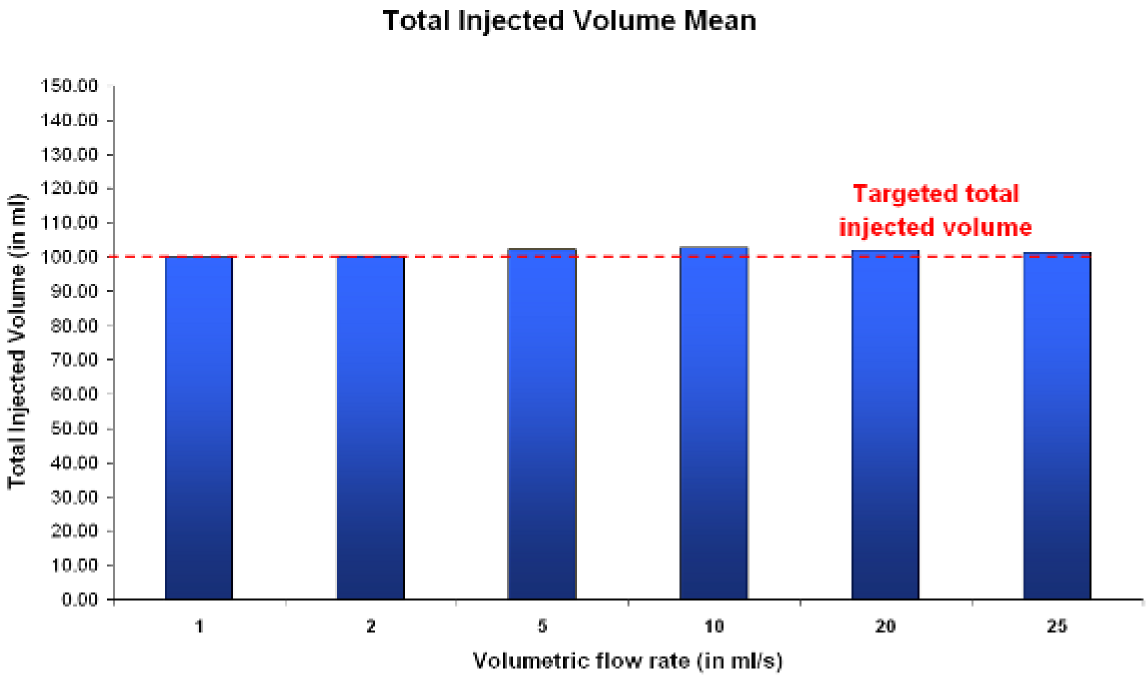
Since the two pistons are assembled on two independent tensile testing machines, it is possible to impose with a high degree of accuracy:

- A volume to inject into a mould
- An injection flow rate
- A catalyst ratio (variable as may be required)

Moreover, the supply lines of the two pistons are equipped with:

- Pressure transducers
- Flowmeters
- Thermocouples
- Heat flow sensors

It becomes possible to control injection pressure via a computer workstation and specific feedback algorithms.



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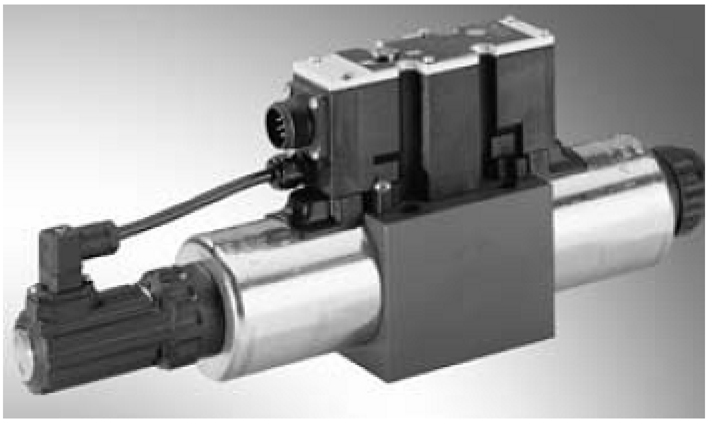
5. COMPACTION CONTROL

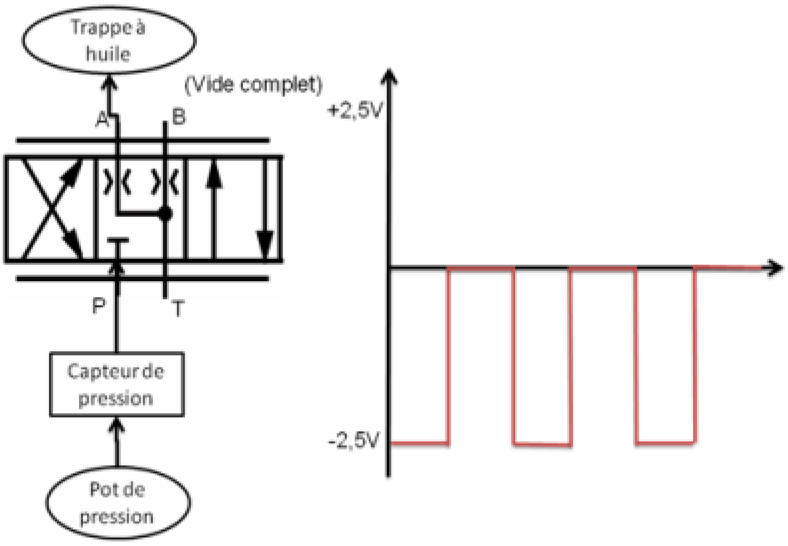
In the flexible injection process using a double-cavity mold ("Polyflex"), there are two additional manufacturing steps:

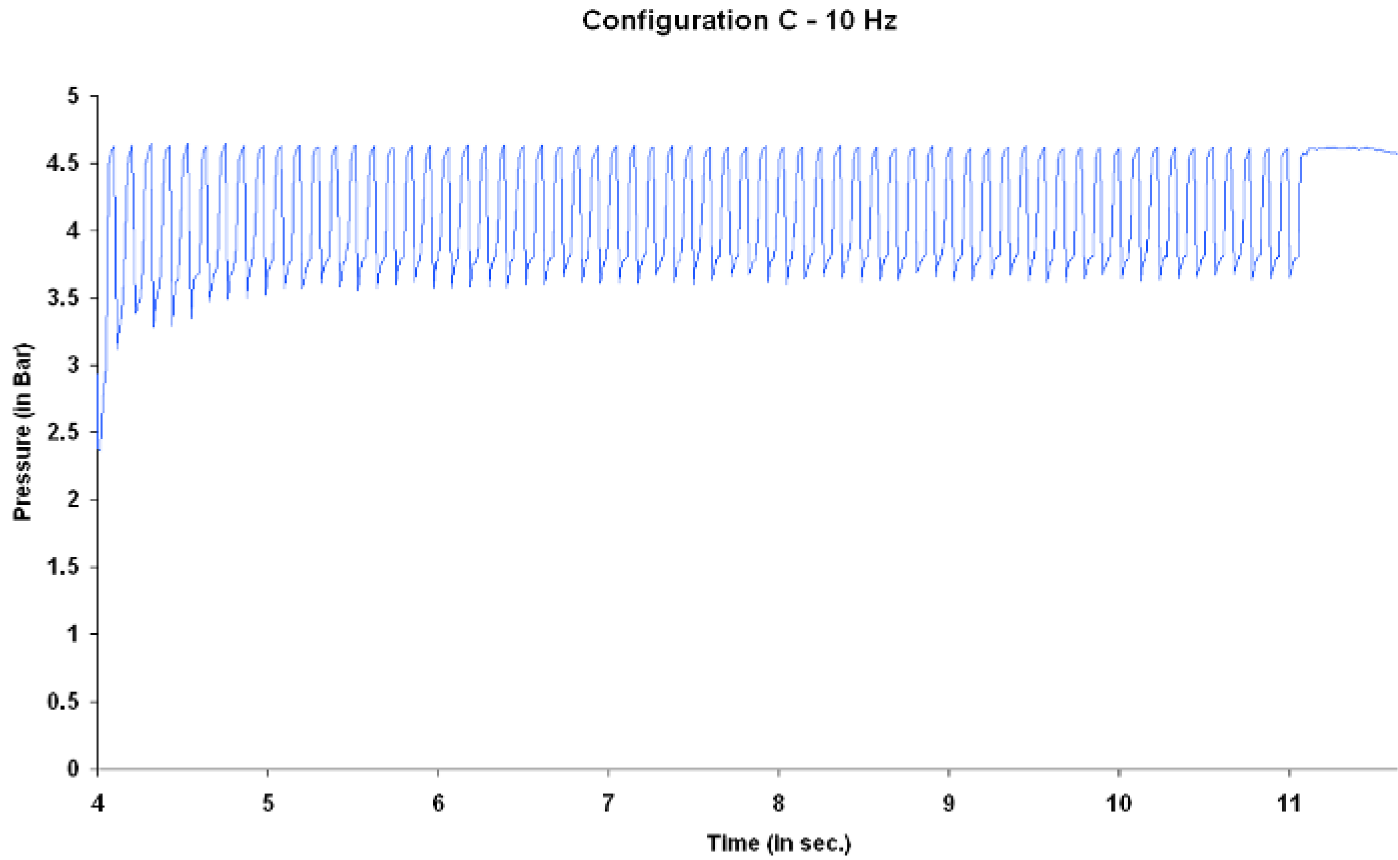
- Cyclic compaction or not
- Cyclic or hydrostatic consolidation

High frequency pressure cycling, using a <u>proportional directional valve</u>, will:

- Improve reinforcement impregnation
- Improve thickness homogeneity of the manufactured parts

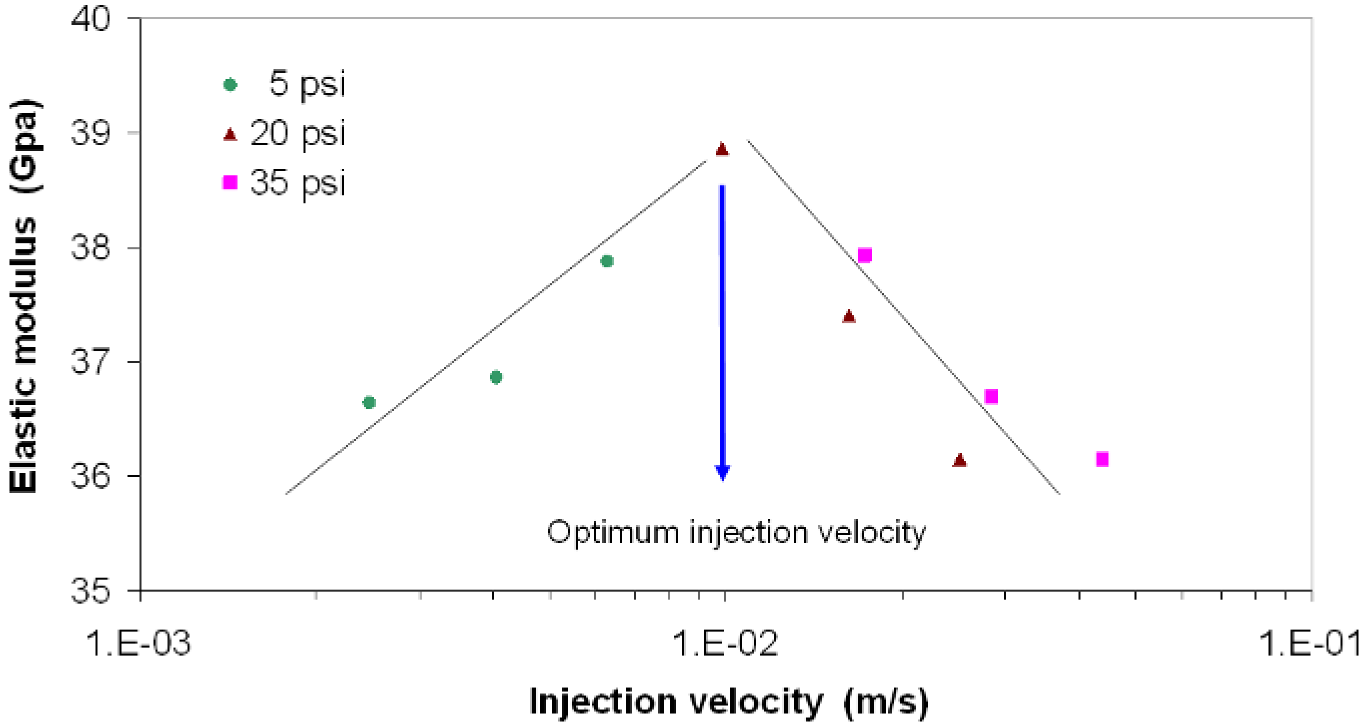






6. CONCLUSION

- First manufacturing tests under a cyclic compaction :
Significant improvement for thickness homogeneity of the parts.
- More designs of experiments on this subject and on the impacts of <u>flow rate control</u> during injection and <u>cyclic compaction</u> on <u>void content</u> will come soon.
- Impact of void content in a composite part :
Reduction of mechanical properties such as the elasticity modulus.
- Catalyst ratio (PHR) control during injection:
Control of final degree of cure of the manufactured parts because, just like void content, this composite property influences its mechanical performances in service.



	Fibre de carbone		Fibre de verre	
	Épaisseur (µm)	Écart type (µm)	Épaisseur (µm)	Écart type (µm)
Compaction simple	3537	93	2598	143
Compaction cyclique	3941	58	2485	80
Différence	**+11%**	**-38%**	**-4%**	**-44%**