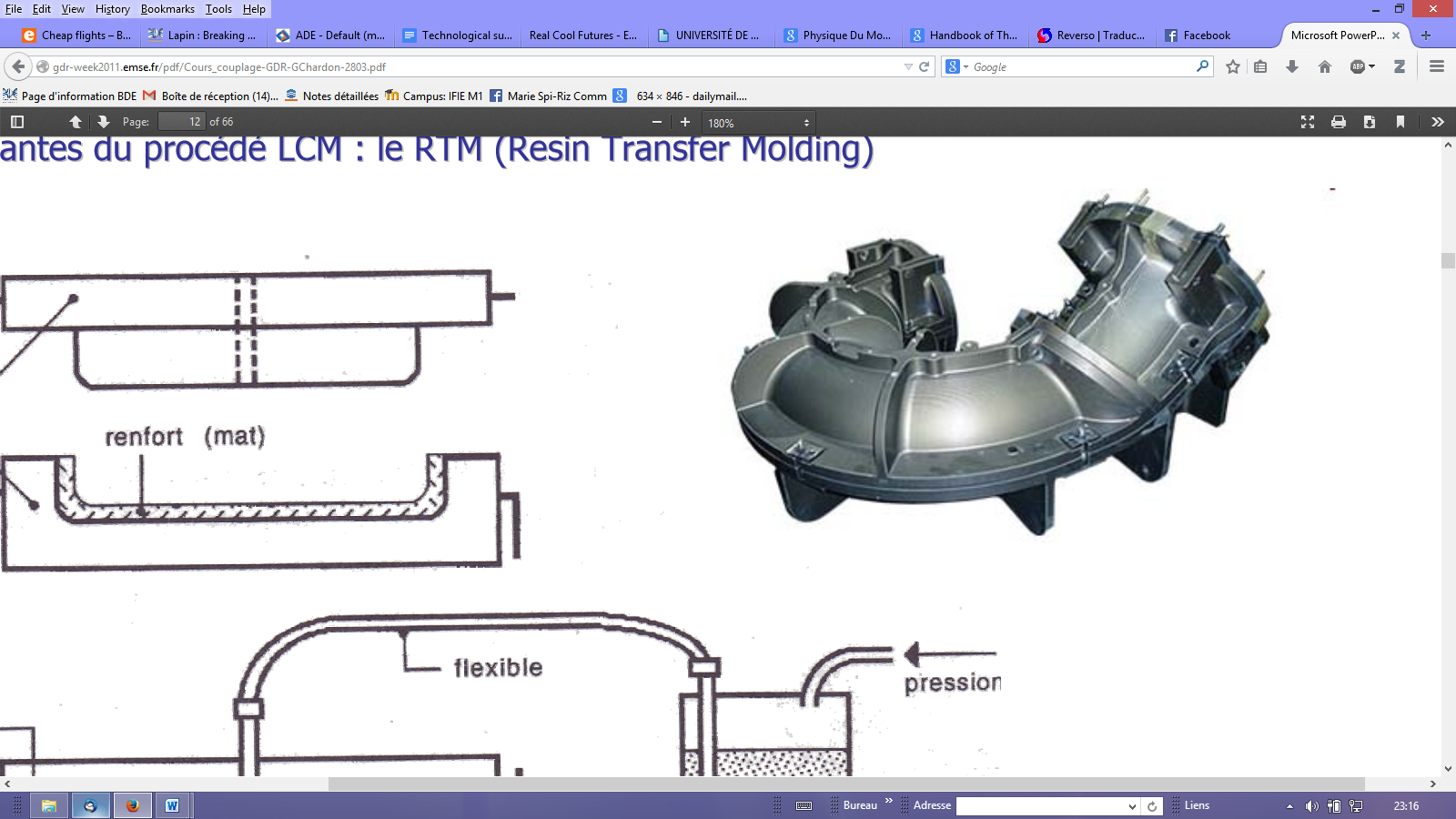


**2014**



**Diego BRITEZ**

**Marie JOLLY**

**Ahmad-Muheeb MOHAMMAD**

Technological survey: Filling and polymerization monitoring-Process control of LCM

# Introduction

Final properties of a composite part depend strongly on the chemical, mechanical, rheologic and thermal characteristics of its implementation. From this point of view, the control of process and the quality control thus become two important tools for the engineer to guarantee the capacity of production, the attributes, and the conformity with the standards, the durability, the esthetics, the reliability, the performance and the reputation of composite product made by any manufacturing process.

# Contents

[Introduction 1](#_Toc399963095)

[Contents 2](#_Toc399963096)

[I. Process and strategy of control for LCM family 3](#_Toc399963097)

[A. Various techniques of process linked to the product 3](#_Toc399963098)

[B. General presentation of control tools 3](#_Toc399963099)

[II. Description of techniques for LCM process monitoring and control 5](#_Toc399963100)

[A. Progression of flow 5](#_Toc399963101)

[1. Factors of influence 5](#_Toc399963102)

[2. Control of the parameters 5](#_Toc399963103)

[3. Comparison of control methods 8](#_Toc399963104)

[4. Industrial uses 8](#_Toc399963105)

[B. Curing of resin Diego 9](#_Toc399963106)

[1. Factors of influence 9](#_Toc399963107)

[2. Way to control them 9](#_Toc399963108)

[3. Comparison 9](#_Toc399963109)

[4. possibility of automation+industrial datas 9](#_Toc399963110)

[C. Porosity (depend on how much information we will find) Muheeb 9](#_Toc399963111)

[1. Factors of influence 9](#_Toc399963112)

[2. Way to control them 9](#_Toc399963113)

[3. comparison 9](#_Toc399963114)

[4. possibility of automation+industrial datas 9](#_Toc399963115)

[General Conclusion 11](#_Toc399963116)

[Table of figures 12](#_Toc399963117)

[Glossary 13](#_Toc399963118)

[Bibliography 14](#_Toc399963119)

# Process and strategy of control for LCM family

## Various techniques of process linked to the product

Among the manufacturing processes used for these materials, the processes of molding by transfer of resin said " Liquid Composite Molding " ( LCM) becomes more and more popular, because they present an excellent potential for the production to big volume. The process LCM includes, by this generic name, a family of processes of shaping of composites, in which a dry reinforcement or a preshape are placed on the bottom of a mold, which is then closed and in which a resin revives liquid is injected under the influence of a gradient of pressure. Secondly, the thermodurcissable resin reticules in the mold under the influence of the rise of the temperature to form the matrix. At the end of the cooking, the part can be turned out. The infiltration of resin by injection and that by infusion are two big families subdividing the range of the processes LCM :

* In the first family, we find the moulding by transfer of resin (" Resin Transfer Molding " or RTM), the moulding by transfer of resin " light " (" Resin Transfer Molding Light " or RTM-Light), the moulding by transfer of resin under vacuum (" Vacuum Assisted Resin Transfer Molding " or VARTM) and the moulding by compression (" Compression Resin Transfer Molding " or CRTM) there. The RTM and its by-products use the gravity, the movement of a piston or the differential of pressure created by a pump "to push" the resin in the cavity via the port(bearing) of injection.
* In the second family of processes, we make the space in the cavity of the mould and the resin is infused in the part under the influence of the atmospheric pressure (" Vacuum Assisted Resin Infusion " or VARI). The infusion can be also assisted by a network of preferential canals activated at distance (" FAST Remotely Actuated Channeling " or FASTRAC), by the use of an middle draining (" Liquid Resin Infusion " or LRI), often called SCRIMP (" Seemann Composites Resin Infusion Molding Process ") in the nautical domain and by the infusion of resin arranged in films inserted between the layers of the reinforcement ("Resin Film Infusion" or RFI).

## General presentation of control tools

There are several categories of sensors with or without thread who are currently in the course of development or already available on the market. These last ones can be installed one  
Grind LCM and\or a dissimilar composite part, so supplying for the operator all the information needed for studying the progress of several variables of state such as the temperature, the stream of heat, the pressure, the debit and the degree of curing. Thus, it becomes possible to manipulate directly or indirectly these variables of the process and, after all, to intervene on the material microstructure, phases separation. In order to monitoring the process, the industrial groups use nowadays several types of sensors or computing methods on samples before getting the right process configuration.

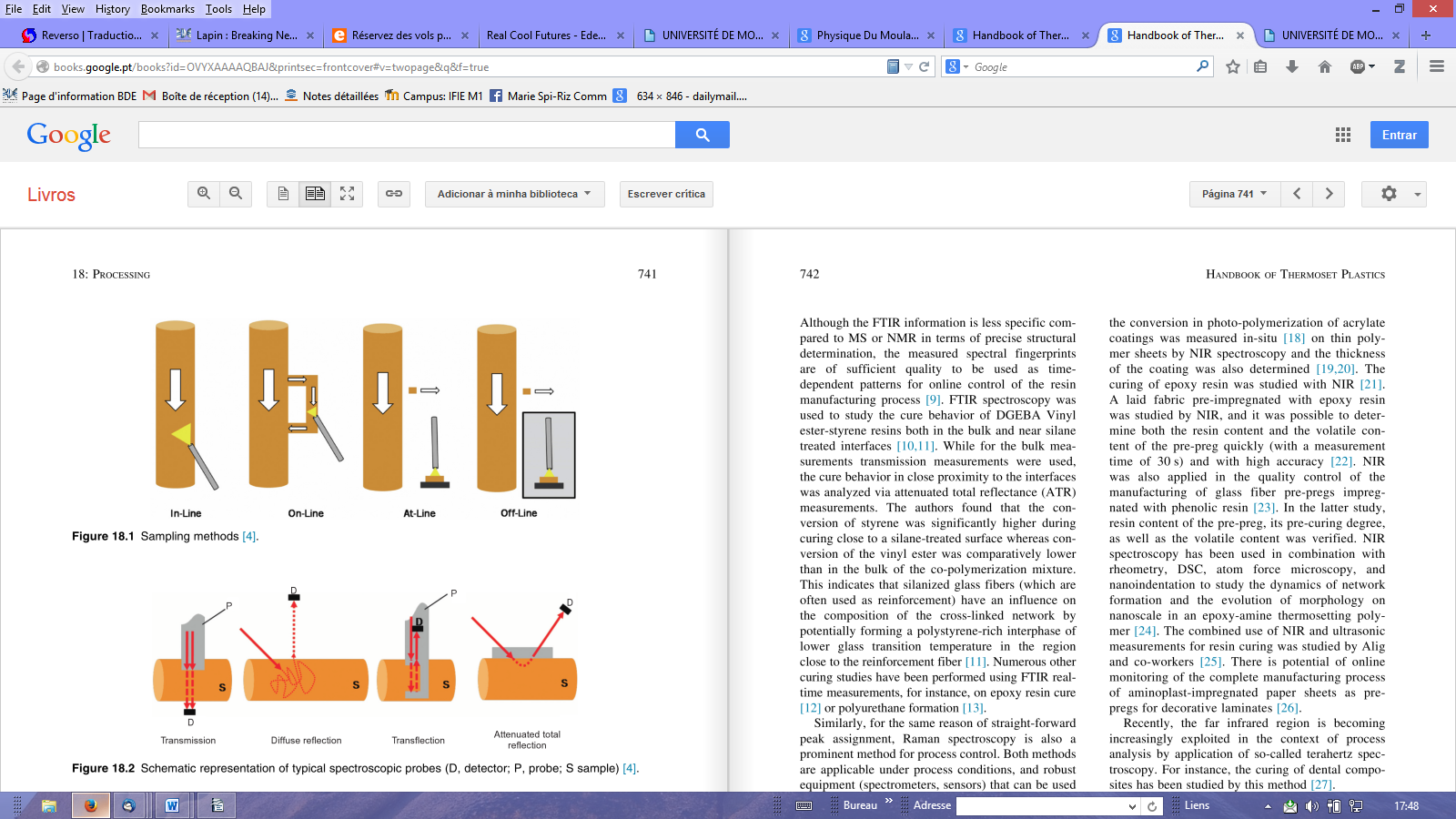


Figure : Sampling methods

Any chemical or physical information made accessible by sensors can be used for online monitoring of resin formation, resin location in the mold and resin cure. Generally these parameters are recorded as functions of the reaction time that the resin synthesis lasts. The thermoset resin can be analyzed either by an in-line, on-line, at-line, or off-line sampling strategy. The first two allows a quicker response in the feedback loop.

Nowadays, most of common control and monitoring techniques includes different types of sensors :

* **Point-wise detection sensors:** Collect information at specific locations of the mold. Most of the available sensors are of this type. To increase the spatial resolution using these sensors it is necessary to have more measuring locations. The amount of measuring points is upper limited by the disturbing influence of the sensors on the manufacturing process. Hence, this fact limits the maximum resolution.
* **Large area covering sensors:** Collect information of all or at least big areas of the mold. Most of them (like digital camera systems) allow obtaining the desired information without disturbing the process, but they are limited when large complex structures are monitored. That is because sometimes is not possible to have some parts of interest in the mold transparent, or the complexity of the structure limit the accessibility of the camera.

# Description of techniques for LCM process monitoring and control

Especially as the processes of putting After studying the different processes of composites fabrication, we are going to turn now on a specific identifications of control parameters for the Liquid composite Molding process. According to our researches, we identified three main parameters to control during the process.

## Progression of flow

### Factors of influence

As we have seen before, the flow of the resin inside the mold could be characterized by the Darcy’s law. The use of Darcy’s law requires information about the material modeling. That is a reason why a major aspect to model is the perform textile permeability that characterizes the resistance offered by the porous medium to fluid flow.

However, access to the right simulations of resin behavior about speed and way of diffusion is difficult due to the dependence on a multitude of parameters which are not easy to qualify such as:

* Preform architecture
* Fiber volume fraction
* Emplacements of vent and inlets
* Variations of inside temperature
* Pressure of injection which is applied

### Control of the parameters

#### Physical control : sensors

The most common way to control the flow resin direction and speed is based on flow sensors. It also the most used tool to follow the flow of resin nowadays. The following ones could also be used in order to control the curing or the porosity.

Acoustic sensor: The acoustic sensors work according to the principle that any physical change in the environment surrounding a sensor is going to echo as a local variation of the acoustic impedance. Thus, the passage of a fluid such as the resin can be captured by the distribution of an acoustic signal along the mold.

Pressure sensor: This instrument of measure is generally established constituted by a diaphragm provided with an extensometric capacity which can associate a deformation with a pressure. These sensors can be settled in the mold of a way not intrusive. Several striking facts during the manufacturing of a composite part can be found by the pressure sensors : the arrival of the resin to the vent or the beginning of the withdrawal. By looking on the datas which are recorded, it is possible to avoid racetracking effects.

Digital cameras: it is possible to make the follow-up of the progress of the front of resin in the fibrous reinforcement with the help of cameras and of algorithms of pictures analysis.   
 This method is rather adapted well to the industrial processes LCM using molds semi translucent or transparent, using transparent vacuous covers such as the processes LRI, VARI and SCRIMP.  
Furthermore, this strategy of visual follow-up by digital cameras can be useful for experimental studies of the flows and future progress.

SMARTweave sensor :The SMARTweave sensor was developed in 1993 for measuring the progression of the resin front and controlling the flow parameters for mainly LCM processes.The use of this sensor is based on a set of electrically conductive wires that are placed crosswises the fabric layers of the preform. When resin flows across the mold and reach a certain position of the grid of wires, an electrical circuit is closed at this position and an external voltage indicates that the resin has reached this point.

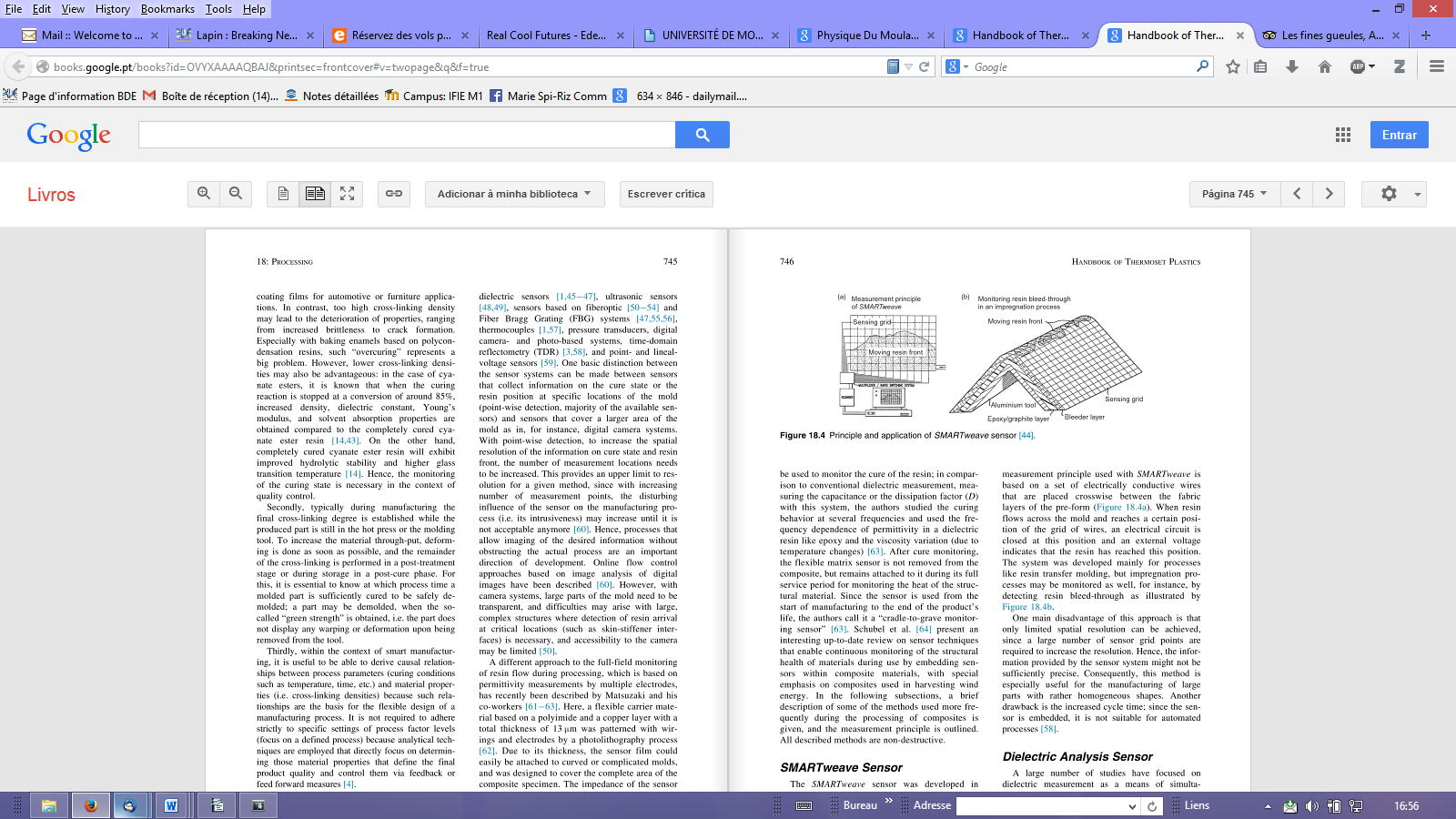


Figure 2 : Principle and application of SMARTweave sensor

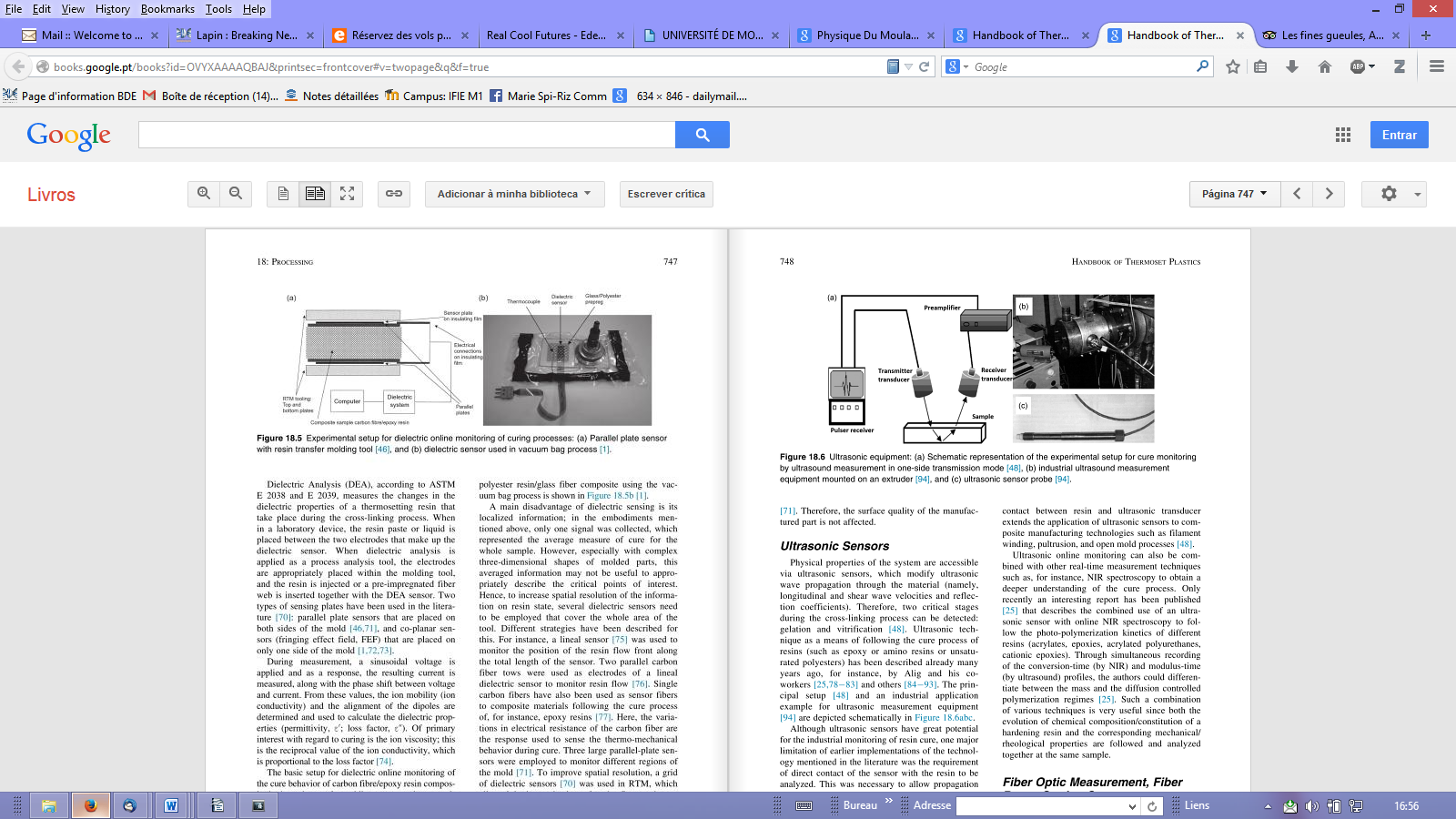
Dielectric analysis sensor :A large number of studies have focused on dieletric measurement as a means of determining resin flow and cure at the same time. This kind of system measures the changes of dielectric properties of the resin which progress during the cross-inking process. A sinusoidal voltage is applied and as a response, the resulting current is measured. From these values, the ion mobility is determined and used to calculate the dielectric properties. 

Figure 3 : Experimental setup for dielectric online monitoring

#### Simulation with virtual molding

This method is generally based on the construction of a meshed model which is going to calculate the progression of the flow about one control parameter. Then, a comparison between the model and the real progression is made for adapting the eventual differences.

In order to obtain a computational framework that can be used for these intend in on-line control systems, it is proposed a novel technique based on configuration spaces. The application of these spaces in LCM processes is called Flow Pattern Configuration Space (FPCS). This technique allows to represent the actual filling process in terms of configuration parameters. In this works, the camera is defined as a grid of customary sensors used in RTM where the pixels acts as a punctual sensors. The global sensor frame can be considered as a matrix of nodes that produces a space discretization.

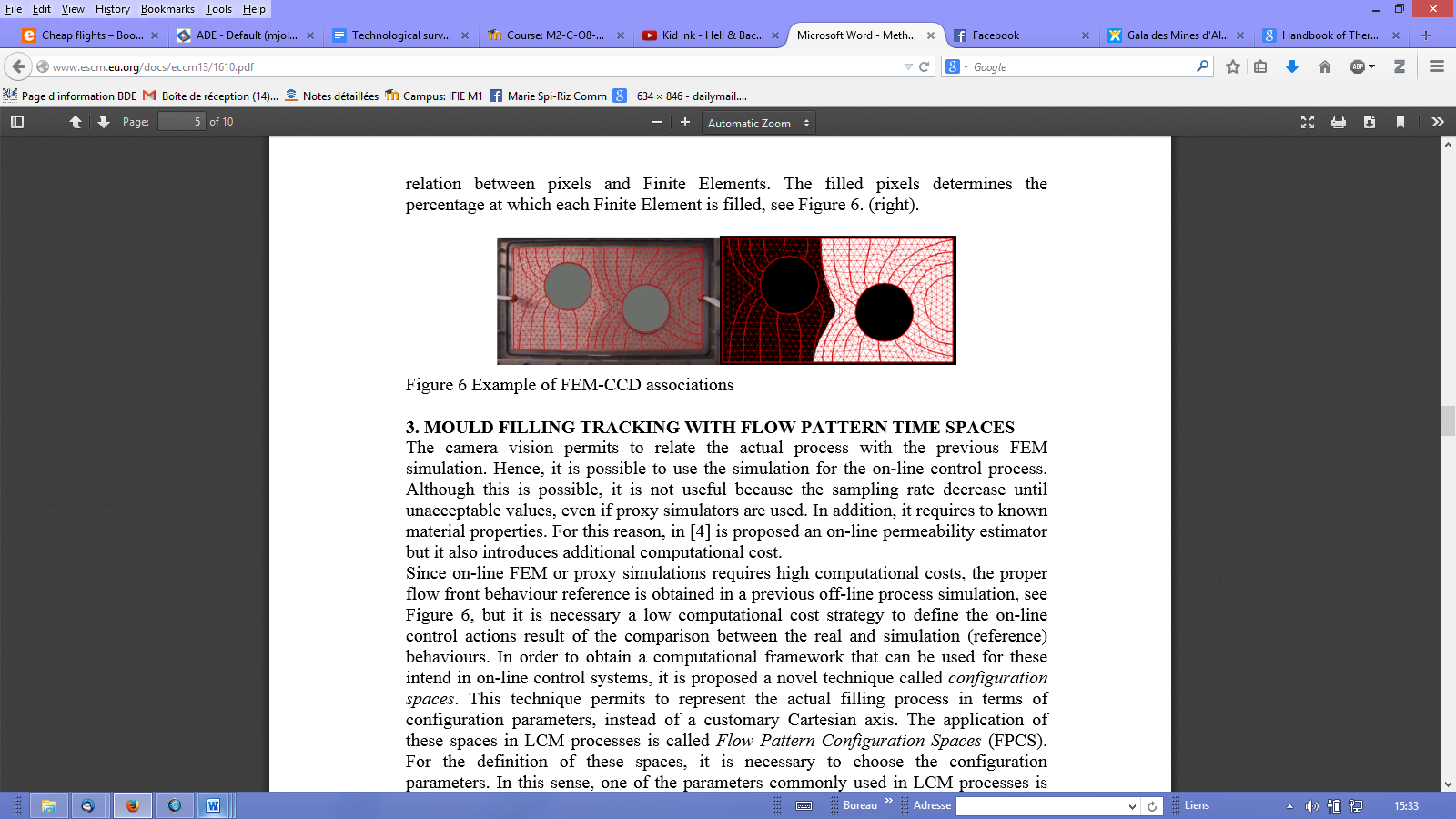


Figure 4 : Example of finite elements simulation

For the definition of these spaces, it is necessary to choose the configuration parameters. In this sense, one of the parameters commonly used in LCM processes for the front progression is the filling time.

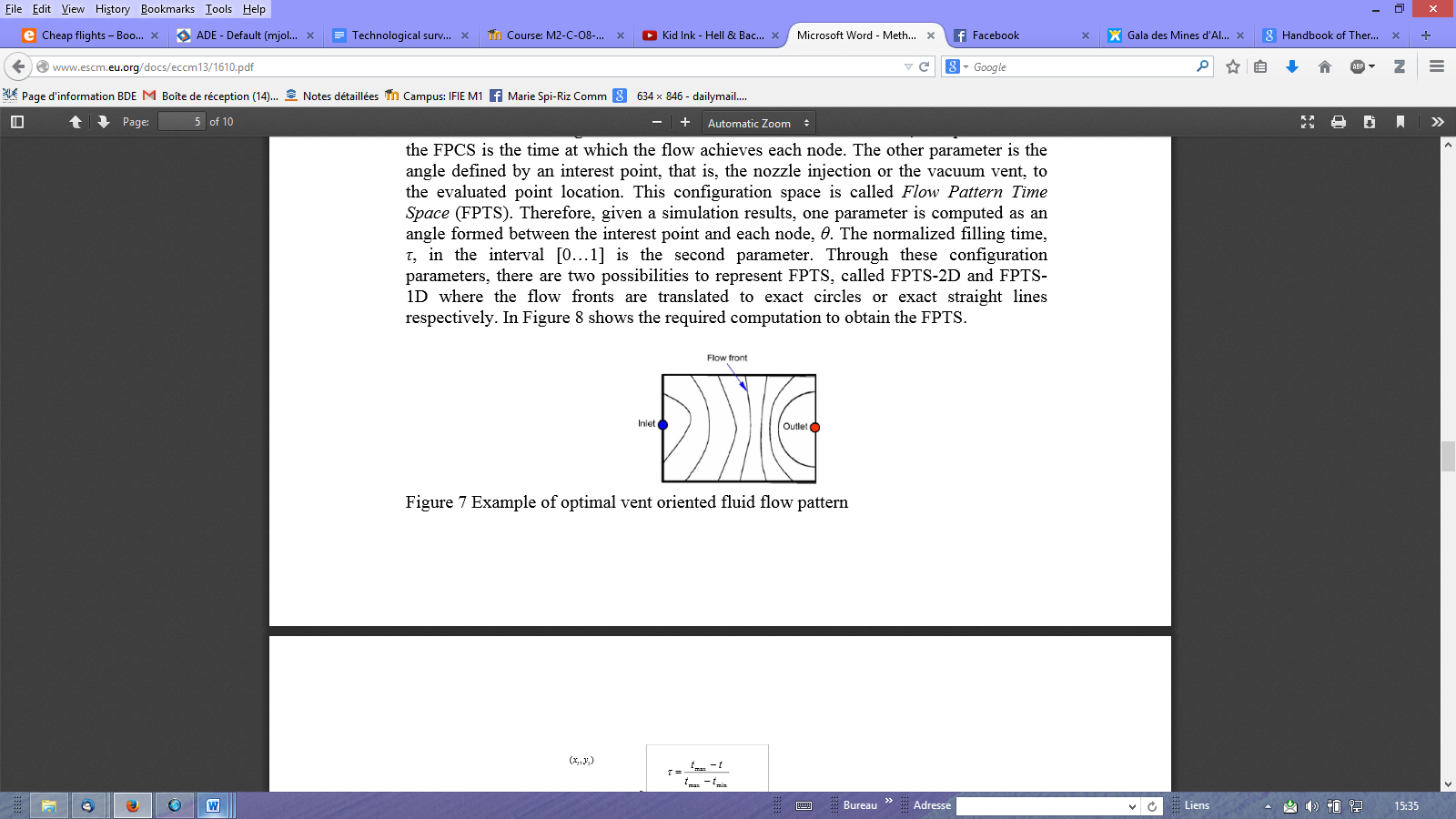


Figure 5 : Example of optimal vent oriented fluid flow pattern

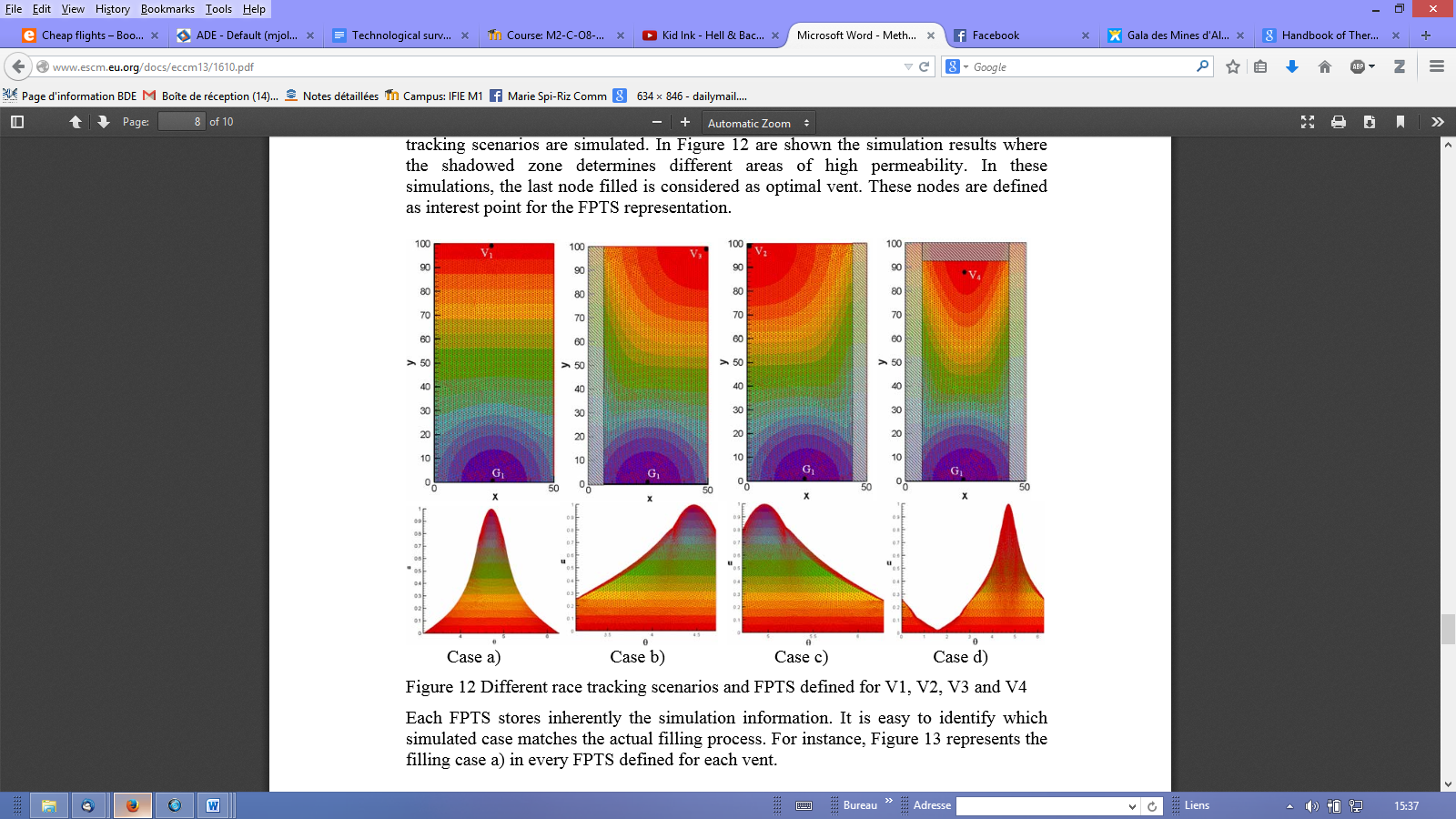


Figure 6 : Different race tracking scenarios and FPCS

### Comparison of control methods

According to the configuration or the size of the composite part to produce, the control methods present several advantages or bad points. The following table summarizes the pros and cons of each one.

|  |  |  |
| --- | --- | --- |
| Control methods | Pros | Cons |
| Pressure sensor | * This sensor can be used for several parameters of control * High signal to noise ratio * Low user intervention | * Expensive * Intrusive technology, required the mold to be machined * Localized sensing |
| Cameras | * relatively little expensive approach in terms of cost of equipment * non-intrusive * ease of real timing facing * possible flow sensing over a large area | * Less appropriate for the processes LCM requiring stiff molds such as the process RTM. Indeed, the industrial molds used in the processes RTM, SRIM, CRTM and ACRTM is especially made of stiff materials |
| SMARTweave sensor | * Possible cure monitoring | * Low realibility * Low signal-to-noise ratio due to electromagnetic interference * Needed to be careful about no connections touching each others |
| Dielectric sensor | * Small size | * Intrusive technology * Localized sensing |
| Simulation FPCS | * Very good knowledge of the front behavior * not limited for the type of process (VARI, VARTM and RTM) * not limited for the dimensionality of the mold and the complexity of gates and vents | * Hard to let in place * requires to known material properties * introduces additional computational cost |
| Acoustic sensor | * Compact Economic possess * A good resistance in high temperatures and in wear * An insensitivity in front of magnetic electro interferences | This type of sensor is only capable of positioning the front of resin during the filling of the mold, according to the surface proportion of the sensor covered by this polymer. It is thus about a strictly local and directional measure of the progress of this front in the mold. |

### Industrial uses

Analytical treatment of the flowing evolution and using electricalc variation is difficult except for a few simple geometries. Therefore, numerical methodologies for flow simulation were developed in past decades for RTM and extended to other processes more recently. Nonetheless, this control is still on a research step in order to adapt it to the mass production.

Generally speaking, the industry is nowadays in favor of pressure sensor for their low cost, their durability but also for the fact that they can be used to control other critical parameters such as thermic variations.

## Curing of resin Diego

### Factors of influence

### Way to control them

### Comparison

### possibility of automation+industrial datas

## Porosity (depend on how much information we will find) Muheeb

### Factors of influence

### Way to control them

### comparison

### possibility of automation+industrial datas

# General Conclusion

# Table of figures

[Figure 1 : Sampling methods 3](file:///C:\Users\MarieJ\Desktop\Technological%20survey.docx#_Toc399962823)

[Figure 2 : Principle and application of SMARTweave sensor 6](#_Toc399962824)

[Figure 3 : Experimental setup for dielectric online monitoring 6](#_Toc399962825)

[Figure 4 : Example of finite elements simulation 7](file:///C:\Users\MarieJ\Desktop\Technological%20survey.docx#_Toc399962826)

[Figure 5 : Example of optimal vent oriented fluid flow pattern 7](file:///C:\Users\MarieJ\Desktop\Technological%20survey.docx#_Toc399962827)

# Bibliography

LEBEL FRANÇOIS, Contrôle de la fabrication des composites par injection sur renforts, Université de Montréal, 2012, 437p.

<http://www.escm.eu.org/docs/eccm13/1610.pdf>

<http://books.google.fr/books?id=0cKqeUjoWz8C&pg=PP2&dq=lcm+process+controle&hl=fr&sa=X&ei=BBAoVMqXD8neaKz4gfAM&ved=0CCsQ6AEwAA#v=onepage&q=lcm%20process%20controle&f=false>