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TOWARDS ARTIFICIAL VISION AND PATTERN RECOGNITION TECHNIQUES FOR APPLICATION IN LIQUID COMPOSITE MOULDING PROCESSES

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Abstract. *This paper aims to use artificial technologies to measure flow variables and parameters for Resin Infusion (RI). In particular, in this paper are used visible cameras to sense the interesting aspects of study from the filling process stage. In [1], the CCD sensor was considered as a matrix of nodes that produces a space discretization. Then, it is possible to define a camera vision sensor as a space discretizer with Finite Elements. It produces a direct relationship between the FEM and the real process.*

This work pretends to explore novel ways for variables and parameters measurement relates to resin flow behavior onto the several fiber reinforcements by means of artificial vision techniques. These techniques could be useful in the industry for large composite parts for measurement, monitorization and control of resin infusion (RI) processes. Before use it, artificial vision system must be calibrated to allow online measurements that corresponds to real distances. In this paper, machine vision algorithms are developed which allow the applications below. First, computes the real flow front shape and position. Next, for the anisotropic fiber reinforcement case, the flow front has a particular shape, that is, an ellipse shape. It has a direct relationship with the permeability of the fiber reinforcement. Then, the machine vision makes a pattern recognition that measures the main and secondary axis of the ellipse in each instant of time during a filling mould.

Artificial vision techniques also allow measuring one of the main interesting topics in LCM processes, the non-saturated zone. This zone is defined between the wet and dry zone. The length of this zone has an important role in the final properties of manufacturing part because has a direct relationship with the void formation during the filling stage, [2]. Along this paper, some experimental results are shown.

1 INTRODUCTION

Liquid Composite Molding (LCM) is a group of manufacturing processes widely used in the industry. The techniques in LCM most commonly referred in the literature are RTM (Resin Transfer Molding), LRI (Liquid Resin Infusion), RI (Resin Infusion) or VI (Vacuum Infusion), VARTM (Vacuum Resin Transfer Molding). These processes are commonly used in aeronautics, automobile industry, water sports, civil engineering, and aeolian industry.

In Resin infusion RI process, one tool face is made of transparent flexible film. Resin infusion process can be utilized in low cost open molds with vacuum bags in nylon or silicone due to its low pressure conditions.

Currently several different research works treat the simulation of the manufacturing process so they effort regards to obtain characterization of materials (thermal kinematic of resin, permeability of reinforcement, compaction, rheology, etc). This information is obtained with different sensor technologies. In attention for it, we want doing in the first section a deep revision of the state of the art about the flow sensing. Moreover we will focus in the resin impregnation and void formation mechanisms in a given part.

In the second section, this paper reviews some fundamentals and does an interesting analysis related to the usefulness of visible and thermal (IR) spectrum digital cameras and artificial vision that can be used in LCM process. In this work it is developed useful experimental novel approaches to prove that artificial vision and last generation sensors help understanding and analyze the physical phenomenology in the porous media.

The third section presents an experimental approach based on AV for the filling mould stage in VI (Vacuum Infusion) process. The goals are first: to develop an experimental setup for AV which calibrating dimensions of real mold and CCD camera for monitoring the elliptical flow front shape. Second: experimental measurement approach of the principal axis of the ellipse that generates the flow evolution into the anisotropic fabrics. Third: the measurement of the unsaturated flow zone that is a gap between saturated and unsaturated resin flow front.

1.1 Resin impregnation studies at the flow front during injection

The quality of composite parts is strongly dependent on the percent of macro/micro-voids contained [3]. The micro-pores are defined as the interstitial spaces between the filaments in the fiber tows, while the macro-pores are the gaps between the tows [4]. As the resin impregnates a dual-scale porous media it will fill the empty spaces between the tightly packed fiber tows at a much faster rate than the empty spaces within the fiber tows. Consequently, the macroscopic resin front can be downstream, while the fiber tows are still continuing to saturate upstream [5]. Therefore, they do a well description of the flow regions corresponding to single and dual-scale mediums. For single- scale preforms there is only one flow region of length L_s, since every portion of the fabric is always fully saturated. Nevertheless, for dual-scale preforms there are two different flow regions: one is the fully-saturated zone of length L_s, and the other is partially-saturated zone of length L_{us}, in which the region between the tows may be fully saturated, but the fiber tows are only partially saturated. Manufacturing practice addresses the dual scale filling by allowing the resin to bleed out of the vent for sufficient amount of time, maximizing the chances of tow saturation [5].

In [2] presents the examination of the capillary number as evidence of a non-saturated zone, characterized by a critical length which was defined in [6] and redefined this length in [7]. At level of the flow front, due to the non-saturation of the reinforcement, it becomes imperative to take into account the contribution of the capillary pressure. Therefore, the analysis of the flow through a fibrous medium can be

done using the critical length, which evaluates the importance of the capillary effect during the wetting of the reinforcement. This effect depends on the capillary number and the type of reinforcement [2]. By increasing the inlet pressure or by increasing the radius of the inlet can be reduced the critical length [7]. Suggest it that these variations influences on the impregnation velocity rate at the unsaturated flow zone. Indeed, investigators have observed that the infiltration velocity influences the formation and location of the voids in the part [8]. This is well explained by the two types of forces that induce the motion of the fluid trough the dual-scale porous media: the viscous and the capillary forces. This means that the impregnation velocity at any time and position should ideally be the one that minimizes the micro-scopic and macro-scopic voids content [3].

In most recent times know us a interesting and research work that studies the impregnation and level saturation phenomena using cameras [9]. However, concludes between other things that the beginning assumptions for the impregnation model cannot be validated experimentally. Therefore, in order to understand the impregnation phenomena requires more research and scientific knowledge.

The other hand, in [10] formation of voids in woven fabrics is quite different then in mats or non-woven fabrics.

1.2 Flow-sensing technologies

In previous research works have been used several kind of sensors in order to flow monitoring and characterization of preforms. Usually two manufacturing stages concentrate the monitoring: filling mould and cure stages. In [11] is considered one of the concerns in RI process, especially when making large integrated co-cured structures with varying thickness, is the knowledge of the resin flow front location at all times. The critical aspect of a RI process is to ensure that the perform (fibers) is completely wetted by the resin. In addition during the infusion of a large and complex part where there are multiple resin and vacuum ports, an optimal infusion strategy can be adopted based on the feedback on the location of the resin front [12,13]. Sensing technologies for in-process monitoring for control of closed-mold techniques were presents in [14] as also on this same subject show the several applications of flow sensing [11,15]

Literature make mention of several flow sensing technologies for monitoring, sensing and controlling [16] the LCM process as well as is mentioned any sensors with constraints [17].

Pressure sensors [18,19] have high signal-to-noise ratio (SNR), but suffer with the problem of localized sensing and are intrusive. *Conductive sensors* [20]can address multi-location sensing but has low SNR due to electromagnetic interference. However, these sensors cannot be used in conductive medium, like carbon [11]. *Dielectric sensors* [21-23]are easy to implement but pose the problem of localized sensing and intrusiveness. *Time domain Reflectometry (TDR) sensors* [24,25] are very good for multiple location sensing but require costly instrumentation. By *ultrasonic sensors* [26] concludes that ultrasonic techniques are applicable to determine the flow front localization during injection as well as monitor the cure behavior of the resin. Micro-thermocouples [15] senses the flow front using heated resin previously to the injection. *Optical fibre* [27] or *fiber optic sensor* [11] based on Fresnel reflection is used to detect the resin flow front during a plate infusion process under industrial environment; in fact, this was a novel direct approach to detect resin front. Besides there exist other techniques to monitor and sense indirectly resin front and degree of cure, as for instance *LDC (Linear Direct Current)* method developed in [28]. *Digital cameras*, which is tackled below at the second section.

Therefore, a conformed intrusive network by punctual flow-sensors, it is able to provide useful information on the flow front location in function of the temperature or pressure local changes as well as acoustic, electrical or light level changes. For this sensor networks, resolution depends on how flow sensor there is per units of area. However, there is many concerns with the location of intrusive sensors since they can affect adaptive control and the resulting filling pattern and, therefore, the final quality of the part [29]. Normally, sensors are not involved for simulating the end mechanical properties as well as the implications of the intrusiveness in the quality of the finished part.

The overall analysis of the state of the art in sensing flow technologies above suggest that despite of many efforts to monitor, sensing and controlling as well as it be able to perform modifications at the flow front behavior during processing; there is no reliable system able of achieving the consistent production of high quality parts. Moreover, LCM manufacture process requires better understanding of the physical phenomena related to the flow front behavior on the fibrous means in order to develop effective industrial controls with feedback and predict the optimum processing parameters to manufacture high quality parts in a productive way. In [23] mentioned it issues.

2 ARTIFICIAL VISION TECHNOLOGIES AND DIGITAL CAMERAS

Currently, the use of artificial vision is growing in LCM process. In this sense, manufacturing process with the top half-mold semi-rigid or transparent as VARTM (Vacuum Assisted RTM) or VI (Vacuum Infusion), top half mold was rigid, (RTM), and it is cannot observe the flow moving through them. Then, this kind of camera sensor, focalized for visible spectrum has been introduced in LCM process with semi rigid mold recently [18,30,31]. In that research works, the camera was used as a flow presence sensor matrix. In [18,30], the artificial vision is used as a sensor of the on-line control system of flow front movement. In [30] determines an approximated correspondence between pixels and the mesh nodes used for the on-line simulation. In [31], two cameras calibrated previously were used for measuring the thickness variations that appears in the VI process due to the local pressure variations.

Digital cameras [32] have also been employed for the real time resin flow monitoring with suitable image processing techniques[11]. A combination between CCD and projector develops in [15] allow to assess the progress of the resin front by measuring the swelling (changes of thickness) of the perform during infusion. In this sense, [33] proposed an Artificial Vision Package (AVP) based on the laser scanner and spectrum visible and thermal CCD for accurately measuring the changes of the thickness and monitor the flow front progress during resin infusion for 2.5D parts. Other works has used this kind of sensing for instance in [18,30,31]. This work [9] treats using the brightness and light camera parameters to validate their studies about the impact of capillary pressure and air entrapment on fiber tow saturation during VI. They finished that work without quantitative results only qualitative.

However, literature reports as one of the reasons why sensing technology not is extended widely in laboratories; non-in industries due to its scheme require the mould to be transparent or accessible to the camera. So far, it has represented a difficult to use digital cameras for instance in large complex structures where resin arrival detection is necessary at critical location (e.g. skin –stiffener interface) inaccessible to the camera. Nevertheless, the mould complexity for real 2.5D resin infusion process can be easily solved including multiple cameras and calibrated them with stereovision techniques [33]. As result, a 2.5D mould mesh is obtained where the camera vision acts as Finite Element mesher and process sensor simultaneously.

Our previous works have aimed in order to achieve an artificial vision system to link the computational and real framework [33] which improves the approach proposed in [1]. Other works relates or make allusions to AV in LCM process has been presented such as [33,34]

From just above could be deduced that AV systems in LCM process would be sensing technologic contributions simply, if not offers it, substantial improvements in the understanding and the process analysis. Therefore, AV should be associated to techniques and algorithms of optimum computation that allows use the sensing information.

2.1 Multispectral Artificial Vision Systems

Cameras for using in Artificial vision works in visible spectrum. In other words, they can see things than the human eye would be able to see. This is explained because the CCD is able to receive signals-stimulus with wavelengths in the visible spectrum.

Acquire images out of visible spectrum range; there exist other kind of cameras, which allows things seeing that the human eye cannot see them. Cameras able to work for all spectral ranges are known as multispectral cameras. For example, IR spectral range usually allows measuring the objects temperature. Normally, these cameras are known as thermal cameras and operate over wavelengths of 14000nm.

Literature reported that thermal cameras [35,36], is mean Infrared vision has employed for *NDT* (*Non Destructive Test*) in end parts in order to mechanical properties testing. However, literature not presents that it kind of technology has been used for sensing the flow front evolution during the filling mold stage.

2.2 Calibration

In [37] explain the *2D* projective transformation, in other words an *homographic* that is done in order to calibrate *2D* planes with *CCD* camera for ensuring that both dimension mould and *CCD matrix* has a rate of correspondence and proportionality geometry.

In order to use an AVP system or multiple AVPs in the same mould [33], the must be calibrated previously even for each AVP. For this purpose, some points are marked in the mould, which must be detected, by all of this sensor devices, camera vision, projector and thermal camera. The technique used to calibrate the system in case of 2½D moulds is called “eight points algorithm” [37]. For the case in-plane is better and most suitable the *2D* homography algorithm.

As the mould that is used in the tests is plane then suitable algorithm is 2D homography for our work. This algorithm is a projective transformation which is defined by the equation (2):

$$\begin{bmatrix} x'_1 \\ y'_1 \\ k \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ k \end{bmatrix} \tag{1}$$

In (2) interests to find the nine elements h_n which are the parameters to estimate for calibrating both real world coordinates and pixel of image. Matrix **H** is homogeneous, k**H** also would be a problem solution. Therefore, it is possible divides each element of **H** among h_{33} to obtain an eight elements matrix. Then, with h33=1 equation (1) can be written as following:

$$\begin{bmatrix} x & y & 1 & 0 & 0 & 0 & -x'x & -x\acute{y} \\ 0 & 0 & 0 & x & y & 1 & -y'x & -y'y \end{bmatrix} \begin{bmatrix} h_{11} \\ h_{12} \\ h_{13} \\ h_{21} \\ h_{22} \\ h_{23} \\ h_{31} \\ h_{32} \end{bmatrix} = \begin{bmatrix} x' \\ y' \end{bmatrix} \tag{2}$$

Where, x' and y' (in centimeters) are the values in the *x- axis* and *y-axis* for the real world lengths; x and y are the pixel values for each image. H is the calibration matrix which h_n elements are computed. It allows that using the *2D* homography algorithm such as (2), it is able to perform metrology to plane moulds by means of AV.

3 EXPERIMENTATION

3.1 Experimental setup for artificial vision in the LCM processes

The visible spectrum camera transfers the acquired images to *PC* (via fire-wire – 400Mbps/s.) which are calibrated images with the mold.

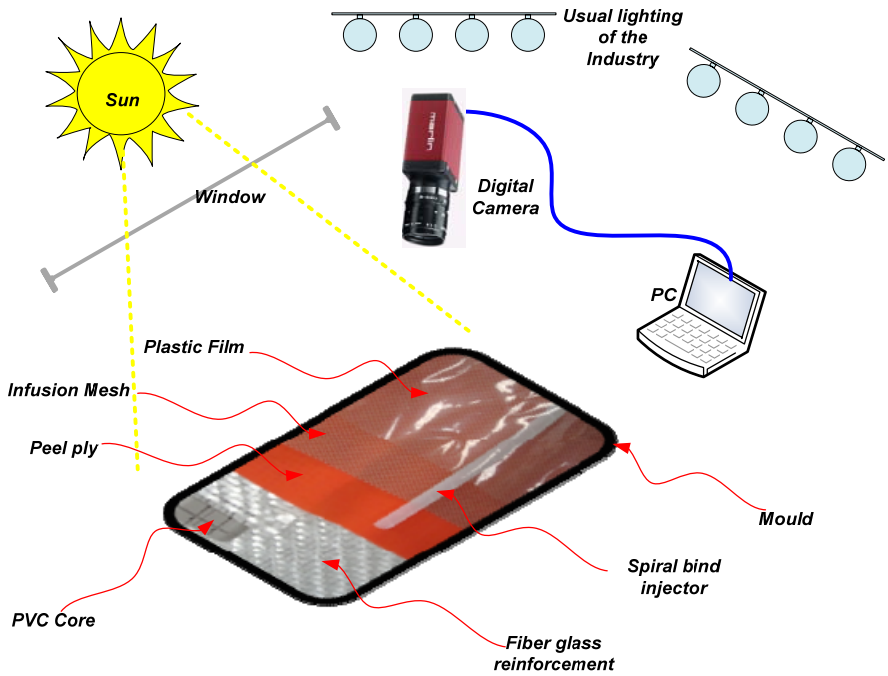


Figure 1 The experimental setup consisted of a transparent glass mold, whose dimensions are (120x120). cm. The glass fiber fabric was placed on it.

Camera is located above the mold; lens set can be handled in order to change the field of view. The Figure 1 shows the suitable experimental setup to perform the tests proposed here. The complete workstation consists of mold, resin pot, vacuum pot, vacuum pump, projector, visible and thermal (IR) spectrum cameras (W/B) with firewire-built-in port, personal computer (PC), and *RI* raw materials for either lab test or industrial manufacturing.

3.1.1. Materials for test and industrial conditions

Figure 1 shows the raw materials used for both to infuse a mold and manufacture conditions. A successful AV system is conditioned to light quantity that captures it. Normally, industries have not controlled the light quantity during their manufacturing processes. For these above reasons, the tests were developed with uncontrolled light quantity. Therefore, the developed algorithms could be taken out from lab and they could be useful, for instance in the industries for the abovementioned applications.

The main concern when we started this work was the light quantity captured by camera. This situation allow us to know more about the raw materials which are used in manufacturing processing and we are able to solve the high light quantity that the fiber glass fabric captures and so, it reflects towards the optic lens and *CCD* camera. Infusion mesh has been the solution. It is rather used always in the last ply as a resin distributor.

For the AV systems is essential a great homogeneity of the light diffusion on the experimental setup as well as setting-up of the saturation and brightness suitable levels in the camera parameters in order to obtain the best images which detect the resin flow front evolution in the scene.

Therefore, several radial injection tests have been performed to obtain the abovementioned goals. Tests were done using of one ply of reinforcement fiber glass fabric with orientation *+90/-90* and epoxy resin. Images have been captured by means of Camera Marlin 145B2 with the picture size of *1392 x 1040 pixels*.

Figure 1 illustrates the raw materials which were used in the tests. The typical radial injection test was conducted several times. Resin flows from the injector gate of the mold towards vent gate which wets the fiber glass fabric and other materials.

3.2 Monitorization of the elliptic flow front during injection process

At the beginning research, we saw the possibilities with AV to monitor the progress of the elliptical flow front in order to make a study of the impregnation and the flow progress. Figure 15 shows the flow elliptical shape during a real RI injection process. Figure 16 is the 3D representation of the image in the Figure 15. It was obtained by analysis and processing images software. Therefore, at first sight we can means that the gray level plays a fundamental role if we want to study the flow movement and the associated saturation issues. This idea is taken into account and taken advantage for develop the following experimentation.

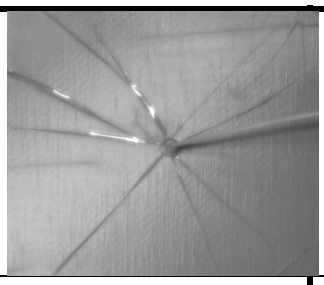
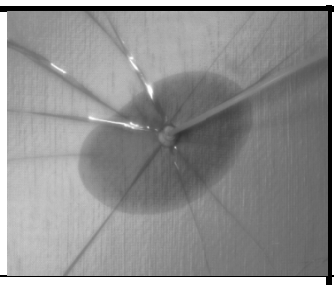
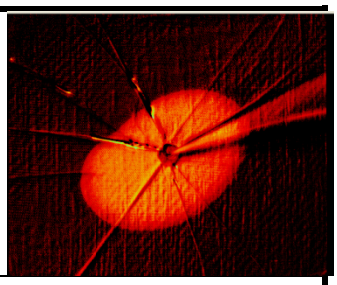
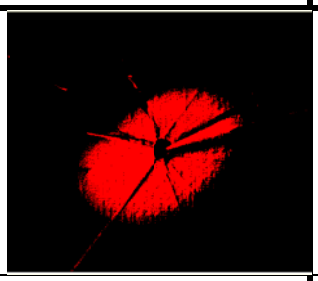
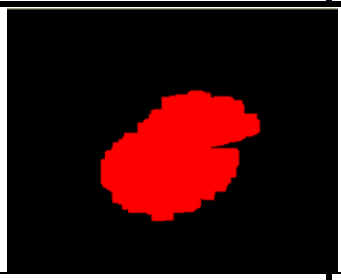
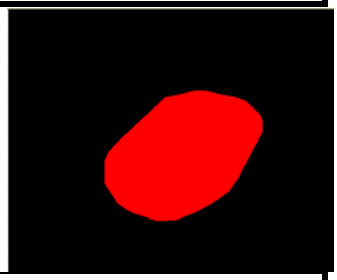
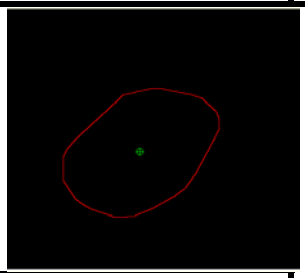
3.2.1. Novel approach for experimental pattern recognition of the flow elliptical shape

The Table 1 shows the processing image for an application of AV systems for the flow pattern recognition, which is absolutely novel in this area. The tests were conducted for an anisotropic reinforcement as shows Figure 1. The gray levels for each image are the reference that monitories the mold at every time. This novel approach opens an unexplored way in order to obtain reliable reinforcement characterizations with a given resin matrix among other applications of usefulness.

This part of work presents a algorithm for experimentally detecting the flow elliptical shape which is described in Figure 13 and Table 1.The Table 1 summaries the experimental pattern recognition of the flow front evolution and its corresponding to computed elliptical contour.

In the Figure 13 is shown the algorithm steps for recognizing the elliptical flow front or shaped contour sensed by means of a visible spectrum camera. In this sense, the Figure 2 illustrates an empty mold then is an important input for the algorithm because

is the reference of computes. The steps are numbered in each table in order to explain the sequences of the algorithms.

1 	**2** 	**3** 
Figure 2 Reference image of mold denoted as p_a	Figure 3 Temporary image of mold denoted as p_b	Figure 4 Subtraction between temporary and reference images. $p_n = \lvert p_a - p_b \rvert$
4 	**5** 	**6** 
Figure 5 Threshold at level which look for Bright objets45	Figure 6 Filtered by advanced morphology for remove small objects – 6 iterations – square –	Figure 7 Filtered Basic Morphology with proper close – size 7x7 -
7 	**8** 	**9** 
Figure 8 Filtered basic morphology – Erode objects - size 3x3 - 3 iterations-	Figure 9 Filtered "Dilate Objects" – size 7x7 -. 3 iterations – Square	Figure 10 Filtered Advanced Morphology with "convex hull" – connectivity 4/8
10 	Table 1 Elliptical shape obtained by filtered of low computational cost than above	
Figure 11 Filtered Basic Morphology with gradient out – size 5x5 - square		

The filling time stage last seven (7) minutes approximately. After the processing image such as the Figure 11, it is obtained the coordinates belongs to the resin flow front. Therefore, about the flow front, if we have the image coordinates we are able to know the real world coordinates for every time. Moreover, all metric measurements

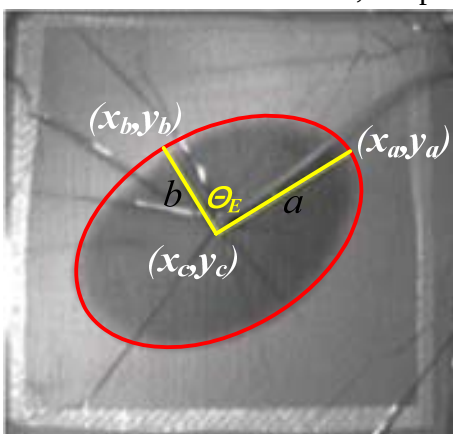
about length, area and so on, it can be done on the mold using the AV system calibrated correctly.

Success for optimum and efficient recognizing of the flow front evolution at every time depends on the processing image chosen. The described algorithm is very efficient since is very quickly and low cost computational.

3.3 Measurement of the main parameters of the elliptical flow front

According to the Figure 11, it ensured the monitoring and recognition of the contour flow front by the developed algorithm, seeing Table 1.

Then, it can be measured the length of the main axis and its orientation angle for the elliptical flow, as shows the Figure 12. With yellow color are drown or overlaid both major (*a*) and minor (*b*) axis in the corresponding temporary image. The computes of the coordinates that represents average fitted ellipse are drown with red color just around the flow front. For it, the performed process is described as following:



Where,

$\boldsymbol{\Theta_E}$, *ellipse orientation angle*

$(\boldsymbol{x_a}, \boldsymbol{y_a})$, *ordered pair that defines major axis.*

$(\boldsymbol{x_c}, \boldsymbol{y_c})$, *ordered pair that defines center*

$(\boldsymbol{x_b}, \boldsymbol{y_b})$, *ordered pair that defines minor axis*

Figure 12 Relationship between ellipse main parameters defined by analytical equations and elliptical flow front evolution

The equations (3) to (7) shows the mathematical formulation that has been used for computing the ellipse main parameters; where each variable is defined in the Figure 12:

$$\emptyset_E = atan\left[\frac{y_a - y_c}{x_a - x_c}\right], \textit{For computing ellipse orientation} \tag{3}$$

$$a = \sqrt{(y_a + y_c)^2 + (y_a + x_c)^2} \;\; ; \;\; \textit{Computes the major axis length} \tag{4}$$

$$b = \sqrt{(y_b + y_c)^2 + (x_b + x_c)^2} \;\; ; \textit{Computes the minor axis length} \tag{5}$$

Equations (6) and (7) allow computing the ordered pairs or coordinates x and y rotated $_E$ grades respect the *x-horizontal axis*.

$$x^* = x\cos\emptyset_E + y\sin\emptyset_E + x_c; \tag{6}$$

$$y^* = -x\sin\emptyset_E + y\cos\emptyset_E + y_c \tag{7}$$

If is done the measurement of the main axis and angle of the ellipse then it is able to obtain the ellipse characterization theoretically, which means to identify the main

parameters of elliptical flow front: major axis, minor axis and angle from the monitoring by the visible camera. Experimental results are shown in the Figure 13 and in Figure 14.

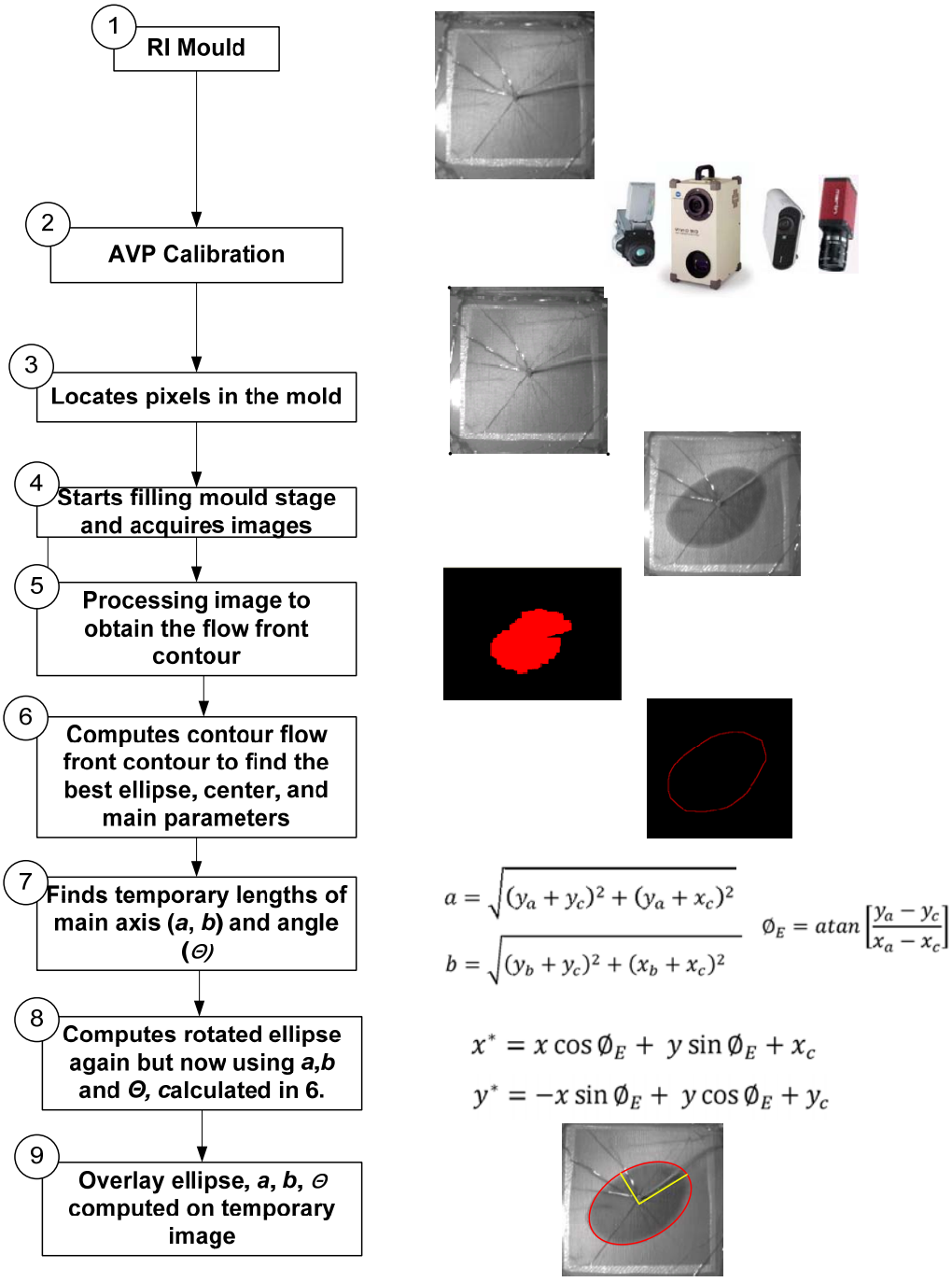


Figure 13 Steps for measuring the ellipse main parameters by AVP

Theoretically, elliptical flow front should be oriented 13,1º since it is the manufacture information. However, experimentally it has obtained 30º which is rather stable for all filling mould stage. This result confirms the current issue related to the reliability about the characterization parameters measured by means of other methods. Therefore, it highlights the importance to use an optimum and effective sensor (camera) and the efficient algorithms which defines a robust AV system.

During filling time, *a,* and *b*, they increase the length in proportion to time which confirms that the expansive evolution of the elliptical flow. Moreover, the rate *a/b* keep the proportionally for all filling mould which means the relationship between *a,* and *b* with the flow behavior against time. This approach contributes to open a way for reliable characterizations of fabrics.

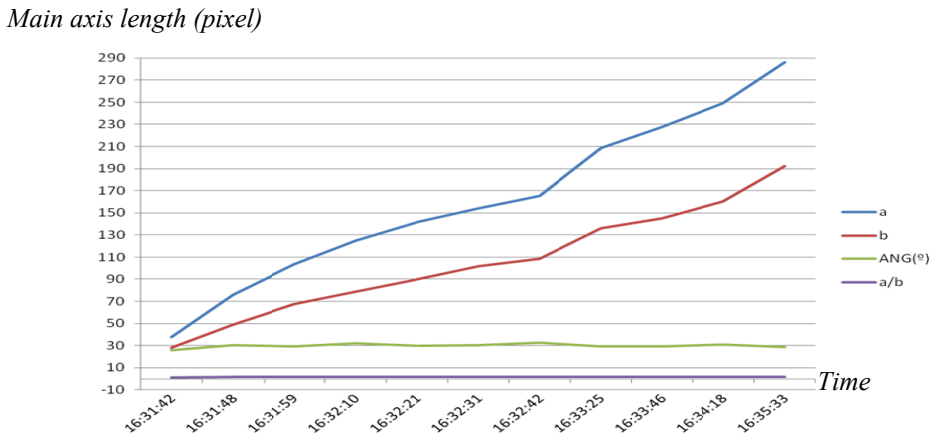


Figure 14 Ellipse main axis evolution, inclination angle and rate, *a/b*

3.4 Measurements of the unsaturated flow zone

This test has been performed in a place with uncontrolled light; it would be the industry conditions. The infusion mesh helps to diffuse the light so it is the light filter and allows identifying between resin and dry fabric, absolutely. The pressure injection was to *0,5bar.*When gradient of pressures increase then flow front velocity increases and viceversa. To higher velocities decreases the unsaturated zone, this means that the L_{us} is lower. The Figure 15 shows the portion of the elliptical shape that must be recognized and measured using a sampling green line. The Figure 16 shows the elliptical flow front represented in 3D view using the gray level in the z-axis. This representation can give excellent information about the impregnation during the filling time.

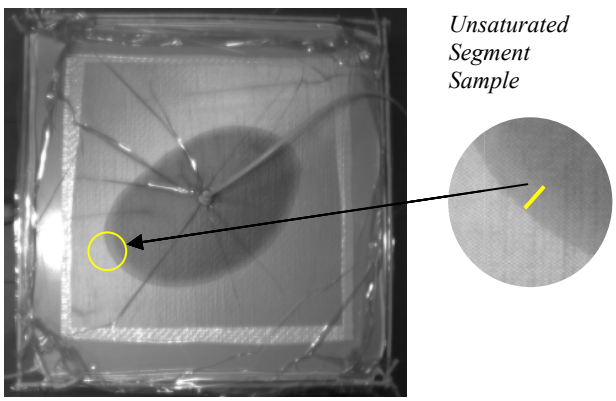


Figure 15 Unsaturated zone which is studied around the flow front.

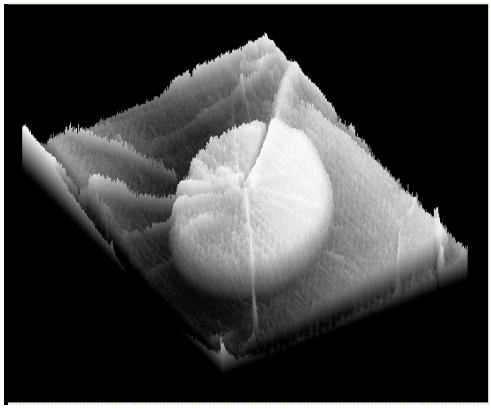


Figure 16 Three-dimensional 3D ellipse view

Measuring the unsaturated zone length for several different angles and times from a radial injection allows contributing for the analysis and understanding of the physic phenomena of the impregnation in the resin flow front. For RTM manufacturing

process, scientist have demonstrated that the flow front velocity affects the quality of the finished part. Flow front velocity changes with the injection flow rate or pressure.

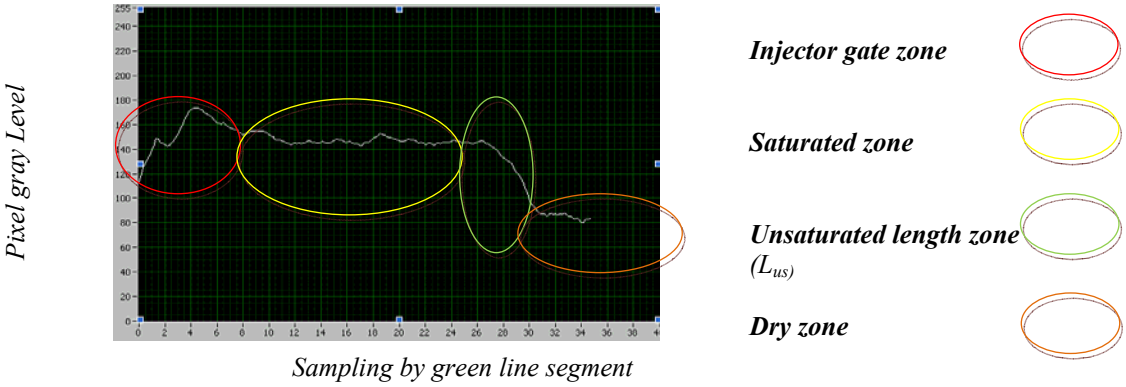


Figure 17 Flow front cut for explaining the saturation zones in order to measure L_{us}

Therefore, unsaturated zone length depends on the injection flow rate or pressure strategy. The Figure 17 shows the graphic ***Pixel gray level =f (Green radio-vector length)***, where also illustrates the different impregnation zones such as it defined for this test and in contrast with the literature. L_{us} is measured ten (10) times on the same elliptical temporary flow front taking account the drop down on the shortcut profile performed with the green line for each computed angle (a green line or radio-vector turns from 0º until 360º to go round every angular profile into the ellipse).

Results are shown in Table 2, and Figure 27. The graphics $\boldsymbol{L_{us} = f(\theta)}$ for each instant of time shows the L_{us} dispersion relate to the physic phenomenology (gradients of pressure, nature of fabric, crease noise, among others) around the flow front.

The analysis of the Table 2 for the instant of time 1300, it is also performed for two more different instants of time in the same filling mould process. Instants of time 348 and 725 have been analyzed and the unsaturated flow length measured by the steps shown in Figure 27 and Table 2.

In the second column in the Table 2, it has performed a reverse function which inverts the pixel values in the image of the Figure 18 which produces a photometric negative of the original image. This handle allows improving the contrast for plotting the gray levels against length (cm); seeing it in Figure 19, Figure 21,Figure 23 and Figure 25.

The mean value of L_{us} during the instant of time 348 is *3,88cm*. For the instant of time 725 is *4,48cm,* and for the instant of time 1300 is *4,53cm.* The mean value L_{us} during filling mould increases as a function of the distance from injector to the flow front unsaturated. Moreover, the L_{us} presents light variations as a function of place on the flow front where is measured it; however, L_{us} keeps in a narrow range, among 3 and 7,5cm approximately.

The analysis of above results, allows confirm that using cameras helps to monitor, understanding and measuring the flow front evolution as well as studying the impregnation phenomena.

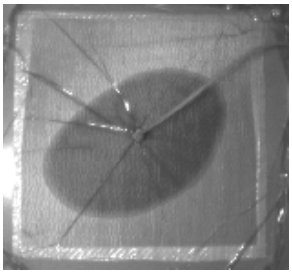
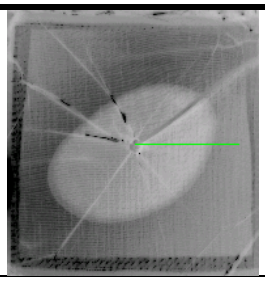
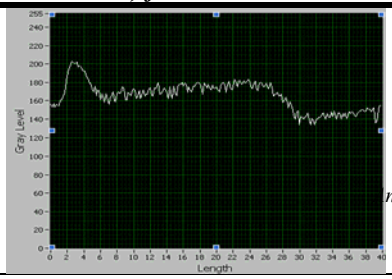
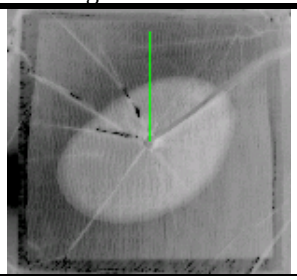
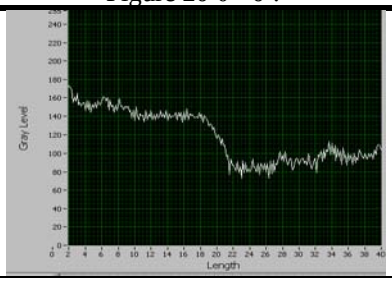
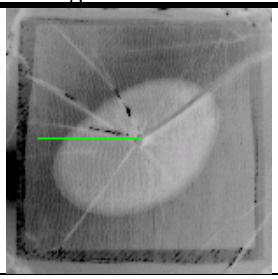
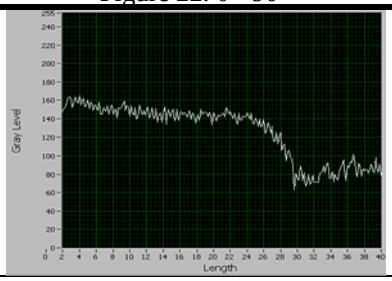
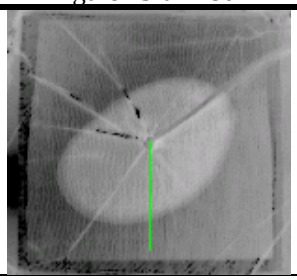
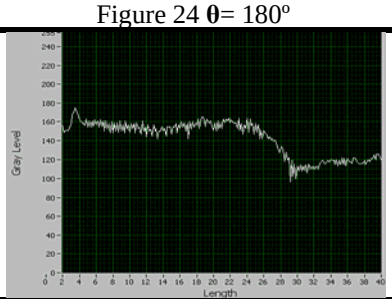
Instant at the Flow front	***Shorcut green line to θ***	***Gray level (0-255) profile against length (40 cm) for line to θ°***
 Figure 18 Instant 1300	 Figure 19 **θ**= 0º	 Figure 20 **θ** =0º.
	 Figure 21 **θ**= 90º	 Figure 22. **θ**= 90º
	 Figure 23 **θ**= 180º	 Figure 24 **θ**= 180º
	 Figure 25 **θ**= 270º	 Figure 26 **θ**= 270º

Table 2 Profile of the unsaturated flow zone length taking shortcut across the flow front for instant 1300 by the green line. It is a off-line analysis

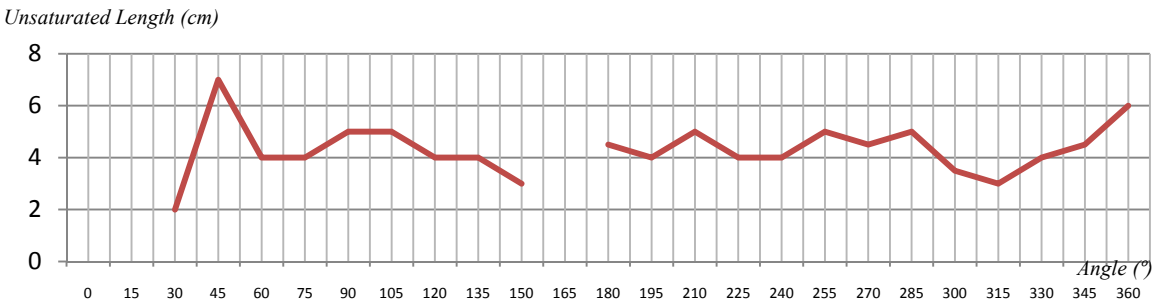


Figure 27 Graphic of $L_{us} = f(\theta)$ *for instant 1300*

4 ACKNOWLEDGEMENT

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5 CONCLUSIONS

In this paper, the first section proposed a deep revision of the state of the art about the flow sensor technologies and the resin impregnation and void formation mechanisms in LCM manufacturing process. As result of the literature review it can be highlighted that currently, both the digital cameras and AV technologies have been very little unexplored and almost unknown in the LCM field.

In the second section, this paper reviewed some fundamentals and it proposed an interesting analysis and illustrations related to the usefulness of visible and thermal (IR) spectrum digital cameras and artificial vision to open minds in order to see the cameras and artificial vision as a great opportunity for scientist and development engineers in the manufacture industry whose object of work uses LCM process. Moreover, cameras decreases tooling integration costs and improve spatial resolution by means of the use of stereovision techniques which allows that millions of sensing elements with a single input/ output port monitories the mould and the manufacturing process. Cameras and Artificial Vision involves these advantages as well as the non-intrusiveness ensures reliable-end parts.

The third section proposed for the filling mould stage in RI (Resin Infusion) process a novel experimental approach based on AV Systems. The experimental goals in the present paper has been achieved by the development of an experimental setup for AV which was calibrated for the real mold dimensions and the CCD camera in order to monitor the elliptical flow front behavior with the suitable brightness and contrast for carrying out it in both labs and industrial conditions.

Latter, it was presented the novel experimental measurement approach of the main elliptical flow parameters when resin is injected in the anisotropic fabrics. In this sense, it was also presented the novel approach for experimental pattern recognition of the elliptical shape of the resin flow for each instant of time during a filling mould stage. In addition, the last task developed for this work was the measurement of the unsaturated zone length by the CCD camera gray levels.

These measurement approaches could be applied to the LCM process in order to go a bit deep in the study of the impregnation phenomenon, monitorizing the unsaturated length to control the injection parameters for instance the flow front velocity, pressure or estimates of void content during a manufacturing process.

Therefore, future works could be conducted taking accounts the following aspects:

- In order to involve thermal cameras for measuring interesting aspects relates to the temperature as well as in the filling time stage and cure time stage. Thermal cameras could be used for detecting; monitoring and measuring the flow front and cure temperature. Besides camera with a suitable setting up could detect the defects and preparations of mould carried out with error or omissions. For example, applications of suitable plies of demolding and protection products are very important in order to ensure an easy demolding of the end part which is going to avoid future damages in the mould.

- Developments of the discretization mesh which allows computing the arrival time of the flow front and its real location by the associated nodes in the mesh. It would be interesting to measure flow front location as a function of vent gate in order to monitoring towards a robust and RT- Real Time control systems in LCM process to yield high-quality parts. In this sense, it should be able to monitor a manufacture industrial part completely (i.e. boat, automotive application, etc).
- Artificial vision could be used to study the kinematic of void content and air bubbles. The unsaturated flow zone is the better indicator the void content of the part at moment. This knowledge is very important to detect the fails during the manufacture processing and it could contribute to increases the techniques for minimizing these issues. Achieving void content measurement in real time. When the air entry inside the mold being able to detect the void content and during estimates it for RI process in order to minimize this issue. Moreover, monitorizing the unsaturated length at the flow front is very useful in order to estimate and controlling the velocity.
- If the every manufacture conditions are sufficiently known then for predicting the filling time of a mould.

For the above explorations and results about artificial vision and flow sensing technologies based on digital cameras applied in composites, it proves could be a fertile research field.

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