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USE OF THE FOURIER TRANSFORM FOR COMPOSITE MATERIALS QUALITY CONTROLS BY IMAGE PROCESSING

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ABSTRACT

A piece in composite material consists of a glass fibre reinforcement imbedded in a matrix. Most of the characteristics of the piece depend on two main factors : the impregnation quality of these glass fibres by a resin and the distribution of their directions in the final piece.
The first part of this paper presents two methods that give a quantitative evaluation of the impregnation evolution of glass fibres by a resin during the fabrication of the piece. A treatment based on the mean grey level value of each image gives a first method of impregnation evaluation. A second possible treatment uses a test pattern underneath the composite material during the fabrication of the piece. The evaluation of the impregnation rate is based on the calculus of auto correlation or cross correlation functions.
The second part of this paper is dedicated to the calculus of a rose of directions on an image in grey levels. This rose is based on the analysis of the image in the spectral domain i.e. on the Fourier transform of the image. This is a very useful tool, and not only for quality controls on composite materials.

Keywords: Fourier transform, image processing, quality control, rose of directions, composite materials.

INTRODUCTION

A piece in composite materials is composed of a frame, or reinforcement, in fibres imbedded in a resin. Mechanical properties of the piece, its final aspect or the time required for its fabrication depend on the quality and the rapidity with which the resin penetrates the fibres of the frame. There exist two main types of reinforcement : reinforcements that become transparent or translucent at the end of manufacturing phase, like glass fibres, and the ones that remain opaque, like carbon fibres. This paper and quality control it describes concern the first type of reinforcement. Depending on the way the fibres are arranged, there are two different names for the frame in glass fibres: if they are woven, and then are all in only two directions, horizontal and vertical, we call the reinforcement 'woven'. If they are all put together with no arrangement at all, so the fibres show all the possible directions, we call it 'mat'.
A large part of composite products is made by lamination of glass fibres mats or woven. In order to study the performance of these mats or woven, it is important to evaluate all the fabrication parameters. There is a lot of different parameters, and different ways to evaluate

them. Many non-destructive tests are based on ultra-sound or X-rays inspection (Robert and Blake, 1990). Our tests are made under usual visible white light (natural or artificial produced by standard lamps) as they are daily made in industrial environment by operators. The aim of this paper is show how to make them automatically.
The main quality parameter for laminates is the impregnation i. e. the way resin penetrates into the reinforcement (mat or woven). This parameter has a great influence on mechanical properties. If impregnation is bad, fibres and resin are not well bonded and the fibres contribution to the resistance is partly lost. It is well known that bad impregnated fibres are less transparent or translucent than the other on the final piece.
Other important quality parameters concern homogeneity and orientation of the reinforcement because this one drives the mechanical properties.
For the moment, really efficient methods to obtain quantitative and objective measurements of these parameters do not exist. The acquisition of numerical images with cameras and the treatment of these images on computers can solve the problem. Then we can obtain image quantification based on a great number of pixels. This article presents different methods to evaluate these quality parameters.

EVALUATION OF THE IMPREGNATION EVOLUTION

To manufacture a piece in composite material, an operator uses a mould. He puts some resin on it, and then the reinforcement. The ones that interest us for this quality control are made of glass fibres. They are white without resin become slowly translucent. during the impregnation phase. The more the resin penetrates between the glass fibres, the more the reinforcement becomes translucent. This transformation is well visible and so, the operator knows the level of impregnation by the observation of the translucent level. The quality and speed evolution of the mat impregnation can be correlate with the evolution of translucence. So, we are going to observe the translucence evolution with time. To use this phenomenon for impregnation evaluation, we carry out the experiment on different test patterns which will allow us to quantify the translucence evolution. Images are taken during impregnation phase with a camera. Grey levels of the images we obtain are sensitive to variation of light conditions during the experiment or between two experiments. We could use special lighting conditions (Batchelor et al. 1985). We choose to keep as close as possible to industrial conditions and then to correct grey levels according to the illumination variations.

EVALUATION OF TRANSLUCENCE

The first pattern test we use is a very simple one. It is just a black background. In these conditions we can see an evolution of the colour of the tested material from white to black, because of the penetration of the resin between the glass fibres. The blacker the colour, the more the translucence - and the impregnation - is important. We consider that the mean translucence at a given instant is correlated with the mean colour of the image at this moment. The final colour can give us a relatively precise idea of the maximal capacity for the material to be impregnated. This method gives results that are very close to the findings of an operator, because it also use a direct visual impression. To minimise the illumination dependence, we add to the pattern test - and so, on each image - a black test and a white test. These two colours are considered as references to correct the illumination level.
This method gives the results presented below. The figures 1 and 2 show the results of this experience with different glass fibres. On each figure, there are two or three curves corresponding to different experiments in the same conditions. These curves show the good

reproducibility from one test to another, because the differences between two curves of impregnation of the same material are less than 5%. So, we can see the differences of impregnation speeds between two different materials : a mat with soluble sizing (fig. 3) shows a faster impregnation than a mat having a sizing non-soluble in the chosen resin (fig. 2).

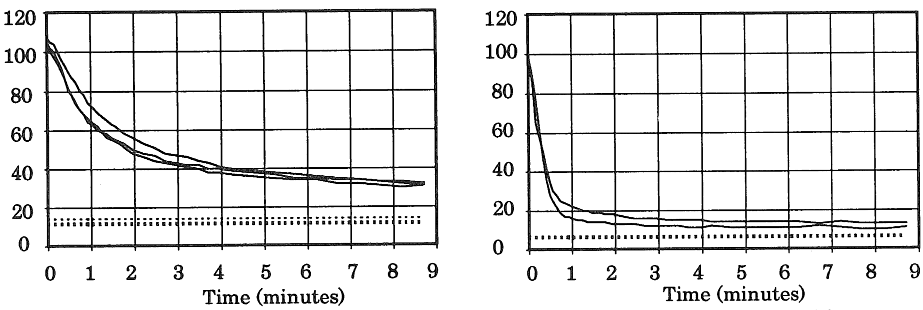

Fig. 1 and 2. Impregnation evolutions of two different materials in the same conditions.

EVALUATION OF TRANSPARENCY

The previous method was dedicated to the evaluation of material translucence during the impregnation phase, that means the light *quantity* transmitted through the impregnated reinforcement. We used, for that first evaluation, a very simple pattern test because we just wanted to detect a variation of the mean value grey value of the composite material piece. What we are going to do now is something different. We are going to appreciate the transparency evolution of the impregnated material, that means the restitution *quality* of a shape viewed through the tested material. For doing that, we are going to replace the black background used until now by a more complex and significant pattern test. This pattern looks like a checker-board with an alternation of black and white squares.
This pattern test is hidden at the beginning of the experiment. It becomes slowly visible on the images. But this time, because we want to appreciate something that we can call the *readability* of the pattern test, we use for the quantification of each image, a treatment that can shows its level of presence in the image. For this purpose, we use on the images mathematical treatments based on the Fourier transform : the auto correlation and cross correlation functions.

Auto correlation Function.

The auto correlation function (Besançon, 1988) (Kunt, 1981) of an image I, where I(x,y) is the grey level of the pixel (x,y), is defined by the formula (1) :

$$F_{Auto}(a,b) = \sum_{x,y} I(x,y).I(x+a,y+b) \qquad (1)$$

This function is able to detect the presence of periodicities in the image I. On the auto correlation images, the progressive apparition of the pattern is well visible. The more the test pattern is visible on the images of the experiment, the more the characteristic auto correlation pattern of the test pattern is visible on the auto correlation images.
To quantify this phenomenon, we add the white squares grey levels and we subtract to the result the sum of the black squares levels. We divide this result by the number of measure points used. On the images of the beginning, the pattern test is not visible yet and accordingly,

the grey levels distribution in the auto correlation image is relatively uniform. There is not a big difference between the sum of the levels of the future white squares and the sum of the levels of the future black squares. The final result of the preceding calculus will give a value close to zero. The more the pattern test becomes visible, the more the levels of the black areas decrease, whereas the levels of the white areas increase. The result will also increases. This is the way we will appreciate the quality of the pattern test presence. The figure 5 shows an example of curves obtained for two experiments in the same conditions.

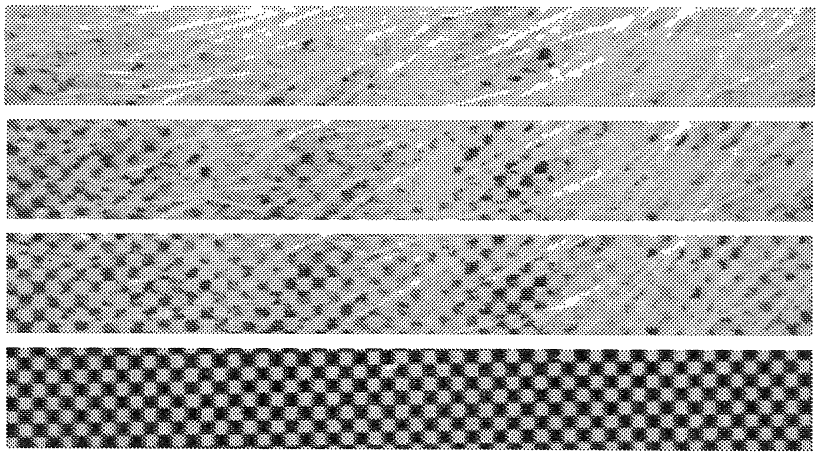

Fig. 3. Images of impregnation evolution.

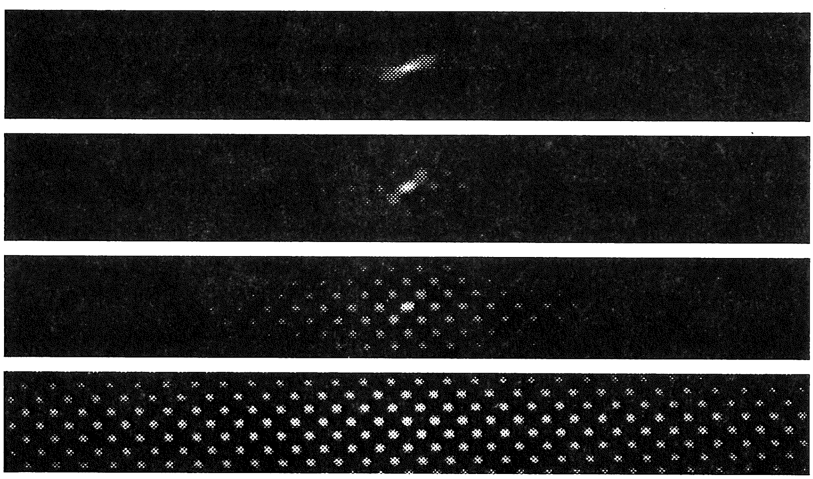

Fig. 4. Images of the corresponding auto correlation functions.

Moreover, the sensibility to the impregnation evolution is better, especially during the final phase where the preceding method using the mean reaches its discrimination limit. Actually, we are close to the level of the black test.

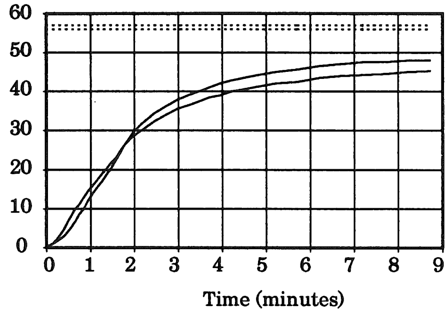

Fig. 5. Impregnation evolutions measured by auto correlation .

Cross correlation function

The cross correlation function (Besançon, 1988) (Kunt, 1981) of an image I, where I(x,y) is the grey level of the pixel (x,y), with an image P, where P(x,y) is the grey level of the pixel (x,y), is defined by the formula (2) :

$$F_{Cross}(a,b) = \sum_{x,y} I(x,y).P(x+a,y+b) \tag{2}$$

This function, which is very similar to the preceding one, is able to detect the similitude of the image I and the test pattern image P. The auto correlation method and this method are very close, and accordingly, the experimental results we obtained are very close either.

These measures are very interesting for manufacturers who can use them not only to check the quality of fibre-reinforced pieces, but also contribute to the knowledge and the characterisation of its glass-fibres and its resin. Because these results are reproducible and objective, they can be archive for ulterior comparisons.

DIRECTIONS DETECTION

As we said before, composite materials are made of two different elements : a resin and a reinforcement which is made itself of a great number of glass fibres. Each of them contribute to the mechanical properties in their direction. Accordingly, it is important to be able to detect distribution of directions on an image of reinforcement, i.e. to have a representation of the reinforcement anisotropy on a rose of directions (Coster and Chermant, 1989). This is a diagram in polar coordinates which shows the level of "presence" of each direction. The directions detection is usually performed by the detection of a certain number of pixels (3 or 5) in a row on binary images. A problem of this method is that it is not possible to detect all the directions but only some of them which correspond to a special alignment of those 3 or 5 or more pixels. Moreover, it will be more interesting to have a directions detection method that can be used on grey levels images.

A better approach of this problem is to use the auto correlation function of the reinforcement image. As a matter of fact, this image contains all the information we need to build a rose of directions. In each direction, we represent the sum of the grey levels in that direction on the auto correlation function. With this method, the number of directions that are inspected depends on the resolution of the auto correlation function image. For example, for an image of 256 by 256 pixels, it is significant to calculate the sum of grey levels each degree. This is of a great interest because it allows to discriminate thin variation of direction in an image. Fig. 6 presents a binary test image, its auto correlation function and the rose of directions we can deduce from it. On fig. 6a, there are lines in two main directions, with small variations. Fig. 6b shows the corresponding auto correlation function. The contribution of these two main directions are well visible. In this simple case it is also possible to quantify the mean step between different lines, in both directions. In real cases, this is not really possible because there are to many directions and no real step, as we will see on fig. 7. Fig. 6c presents the rose of directions computed as earlier explained. The two main directions are highlighted and quantified.

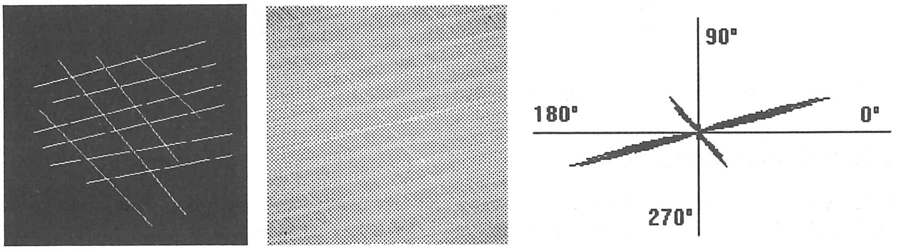

Fig. 6a, 6b, 6c. Binary test image, its auto correlation function and its rose of directions.

Fig. 7 presents exactly the same treatments but this time on a real case. The rose of directions shows clearly that there is no glass fibres in the vertical direction and that the main part of them are oriented at 160° approximately.

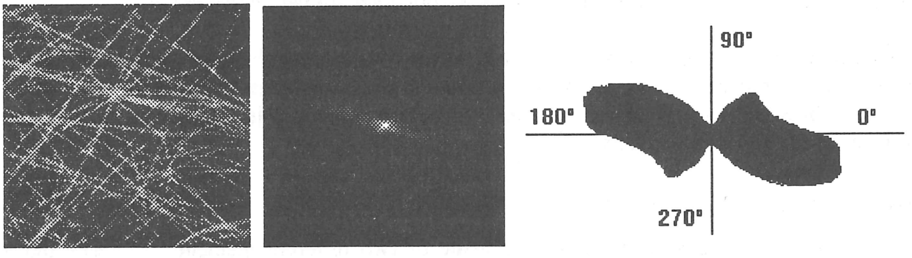

Fig. 7a, 7b, 7c. Application of the method of directions detection in a real case. The image used here is a grey level image of a glass fibres reinforcement.

This method of rose of directions calculation has two main advantages : it gives a quite continuous representation in polar coordinates of directions presence and it works on grey levels images. Moreover, if it is interesting for composite materials quality control, it can be also applied for cartography, texture images (wood ...), and many other cases.

REFERENCES

Batchelor BG, Hill DC, Hodgson DC. Automated Visual Inspection. UK: IFS Publication Limited, 1985: 39-181.

Besançon JE. Vision par ordinateur en deux et trois dimensions. Eyrolles, 1988: 23-48.

Coster M, Chermant JL, Précis d'analyse d'images. Presse du CNRS, 1989: 259-289.

Kunt M., Traitement numérique des signaux. Dunod, 1981: 329-336.

Robert A, Blake J. Non-destructive testing of fibre-reinforced plastics composites. Edited by John Sommerscales, 1990: 150-190.