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Image Characterization of Carbon Fibre Reinforced Composites

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Abstract

A new methodology to detect fibres orientation in composite materials, using image processing tools is introduced. Several examples with manufacturing defects are studied using RIMAPS technique and the Variogram method. The characterization is made from digitized images of the samples. Combined use of RIMAPS and Variogram analyses identified the orientation of fibres and determined the values of the scale lengths that characterize the sample surfaces with every modification in the lamination process. All defects introduced were detected showing the outstanding features of these NDT techniques in determining any fibre orientation defect in plane composites manufacture.

1. Introduction

The use of composite materials in aerospace industry has been remarkably increased during the last decades. As a direct consequence, traditional materials like aluminium and steels are being replaced by new advanced composites due to their excellent relations between rigidity and resistance versus weight. The use of long fibres in prepregs with different polymeric matrices is of extended applications in the constructions of parts and components for satellite applications. It is well known that the mechanical design of composite products must take into account the fibres orientations of each ply used in manufacturing. Then, the determination of possible defects is the only way to ensure that the mechanical requirements will be fulfilled. In the present work we introduce a new and very simple methodology to detect fibres orientation in composite materials, using image processing tools. Different samples with defects introduced during the lamination stage of the manufacturing process, were used to be characterized using the Rotated Image with Maximum Average Power Spectrum (RIMAPS) technique and the Variogram method. Both NDT tools use digital images obtained from the samples surfaces. A compact digital camera, light microscopy (LM) and scanning electron microscopy (SEM) were used to obtain simple images as well as magnified details from different areas of the samples. In all cases, the RIMAPS and Variogram analyses gave a quantitative description of the orientation of fibres and determine the values of the typical scale lengths that were introduced with every modification. In the following sections the main characteristics of RIMAPS and Variograms are explained. The experimental procedure to obtain the sample plates is described and the results obtained from the study of three cases are presented. Finally conclusions are given to emphasize the importance of using RIMAPS and Variogram as quick tools to characterize the manufacturing processes of carbon fibre reinforced composites.

2. RIMAPS technique

The RIMAPS technique is based on the digital acquisition of information from a rotating image (RI) and the computation of the *x*-step of the two-dimensional Fourier transform (FT) for each *y*-line of the image obtained during the rotation. As a result, averaged power spectra (APS) and the maximum averaged power spectra (MAPS) are obtained for each angular position of the image, which are then used to characterize the surface topography.[1-11]

For each of the total number of measurements used to characterize the real surface from the original image, the rotation angle varies from 0º to 360º. For all angular positions, MAPS can be calculated for each RI and then plotted as a function of the angle of rotation. The number of total angular positions depends on the number of steps chosen to complete a full rotation of the original image. The resulting *XY* graph and the peaks of this graph are then used to characterize any surface topography, including the surface pattern orientation and a characteristic topographic form.[1-11]

Polar representation of RIMAPS results gives a more direct understanding of the main topographic directions present on a surface under study and allows proposing simple geometrical forms, or combination of them, to replicate the surface patterns in order to reconstruct the properties of the surface. In the following sections the polar representation has been adopted to characterize the sample plates made of carbon fibre reinforced composites (CFRC).

3. Variogram method

The Variogram method is based on a log–log representation of a characteristic roughness parameter versus the length scale. This algorithm is applicable to fractal and non-fractal surfaces characterization. It is well known that the geometric structure of rough surfaces is random, and that roughness features are found at a large number of length scales between the length of the sample and atomic scales. To understand the topography-dependent phenomena, the surface geometry must be described with parameters which take into account different length scales.

The Root Mean Square average (RMS), σ, is one of the parameters most often used to characterize the surface roughness from a profile measured along this surface. While such parameters are useful for many applications, they do not cover information on the range of length scales over which different topographic features exist. Indeed, conventional parameters depend only on a few particular length scales, such as the instrument resolution or the sample length, while rough surfaces contain roughness at a large number of length scales.

During the last decade, various methods based on fractal analysis have been proposed to characterize surface roughness at different length scales. Most of the methods are aimed at calculating fractal parameters, in order to characterize the roughness at several length scales. However, not all surfaces show fractal behaviour. In these cases, the surface topography may not be appropriately described using a fractal dimension. For this purpose, the log–log representation of the variance σ^2 versus the sample size is used to determine the fractal dimension from the slope of the resulting curve.(7-15)

Therefore, we use in the present work a new method for the quantification of length scale-dependent topography. From a given set of windows of different sizes of one digitized image, the RMS parameter is calculated for different window areas on a surface. The calculated roughness parameter is then represented on a log–log plot as function of the length scale (window area). Intersections of different slopes in the plot give crossover lengths that characterize the surface under study. This method is used to characterize the surfaces of the CFRC plates.

4. Experimental procedure

Sample plates of sizes 10cm $\times$ 10cm $\times$ 0.1cm, were prepared using glass fibres with NEMA-FR4 (IPC-4101-25) epoxy/polyphenylene oxide resin(16) and CE3-PAN M55J prepregs of unidirectional carbon fibres with a modified cyanate ester resin(17). Different fibre orientations were used in the lamination process. In order to check RIMAPS and Variogram detection capabilities, symmetric, non-symmetric and overlapped laminates were manufactured. The external laminates of both, glass fibres and carbon fibres reinforced composites, were in contact with peel plies(18) or release films(18) determining the topographic patterns of the plates surface. In all cases the samples were covered with bleeders(18) before the vacuum bagging for polymerisation in autoclave at 180º C during two hours.

All surfaces were observed using a compact digital camera, light microscopy (LM) and scanning electron microscopy (SEM). The digitized images of them were used to characterize their topographic patterns using the RIMAPS technique and the Variogram method. Using both NDT tools a quantitative description of the orientation of fibres and the existence of possible manufacturing defects were detected. Figures 1 – 3 show SEM micrographs of the release films, peel plies and bleeders used in manufacturing the plates. The Fig. 4 gives a SEM image of the resulting surface topography obtained after the polymerisation process.

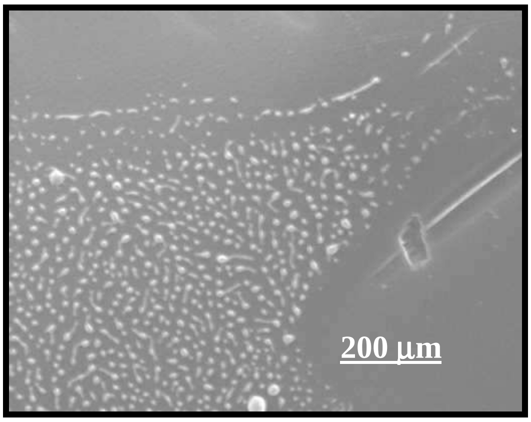


Figure 1. SEM micrograph of release film surface.

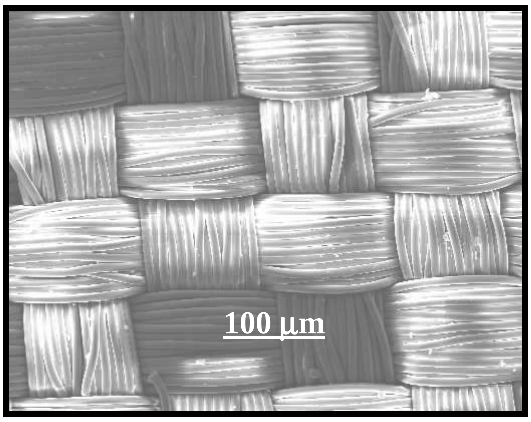


Figure 2. SEM micrograph of peel ply surface.

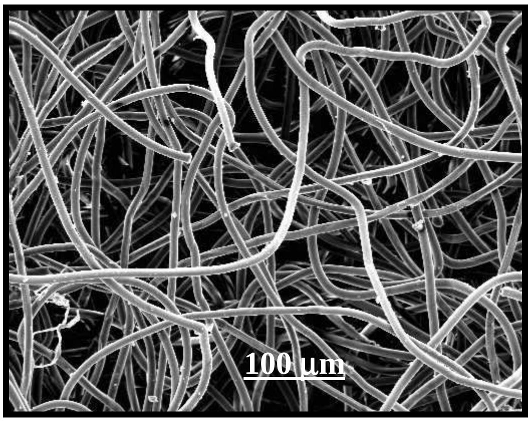


Figure 3. SEM image of the bleeder.

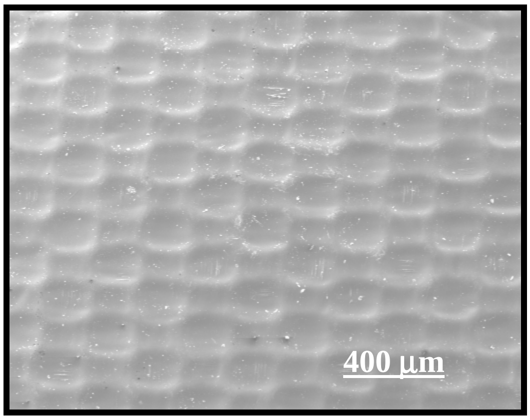


Figure 4. SEM image of CFRC surface.

5. Results

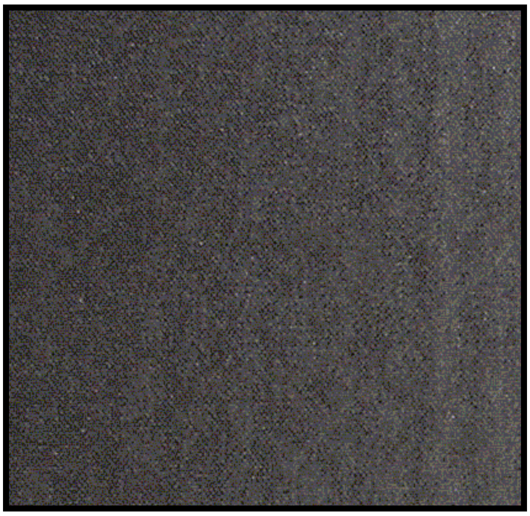
Three cases of CFRC plates are presented to explain the use of both RIMAPS and Variograms to characterize the manufacturing process of plane laminates. In all cases included in this work, the orientation of carbon fibres is the same but in one case the symmetry has been altered and in the other case the fibres were overlapped in one direction.

The appropriate manufacturing condition of a plane laminate with eight plies of unidirectional prepregs aligned following the angles 0º-45º- 90º- 135º-135º- 90º- 45º- 0º, is presented in Fig. 5. A digitized image of the plate obtained with a digital camera is given in Fig. 5a. Polar representation of RIMAPS analysis in Fig. 5b identifies all the directions corresponding to the fibres orientation. It can be observed that the intensity of peaks becomes lower for the inner direction of fibres. The Variogram results (Fig. 5c) give the typical length scales present on the surface topography of the sample under study. These characteristic lengths may be used as cut-off lengths for obtaining a 3D representation of the surface patterns (Fig. 5d).

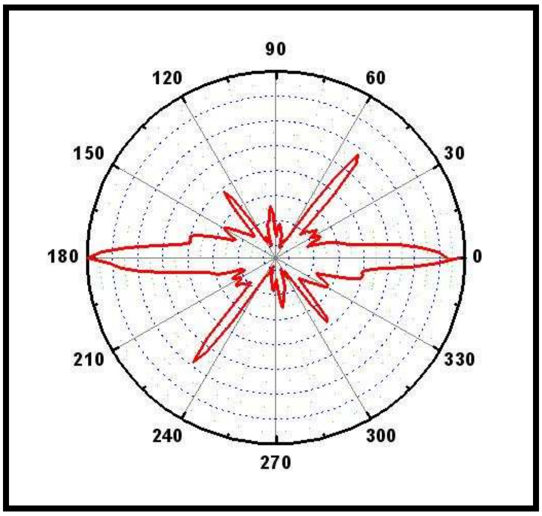
To represent a manufacturing process altering the symmetric condition of a plane laminate, the fibres plies were laminated in the following sequence: 0º-45º- 90º- 135º- 90º- 135º- 45º- 0º. This situation is illustrated in Fig. 6. The Fig. 6a gives the digitized image of the plate. RIMAPS spectrum of Fig. 6b identifies all the directions corresponding to the fibres orientation. As the symmetry has been altered, the intensity of the peaks representing the directions of 90º and 135º are greater than or comparable to the 0º peak intensity. The Fig. 6c includes the Variogram results with the characteristic length scales of the topography of the sample plate under study. In Fig. 6d a 3D representation of the surface patterns is included.

If the different plies are laminated conserving the symmetry but during the manufacturing process the fibres were overlapped following a given direction, the situation produces the effects illustrated if Fig. 7. The Fig. 7a gives the image of the sample plate with an overlapping of fibres in the 45º direction. Polar representation of RIMAPS spectrum in Fig. 7b detects all the directions corresponding to the fibres orientation. It can be observed that the intensity of peaks corresponding to 45º and 90º becomes comparable to the intensity of the 0º direction. The Variogram results (Fig. 7c) represent all the typical length scales present on the surface topography of this sample. Using one of these characteristic lengths as cut-off length a 3D representation of the surface patterns is presented (Fig. 7d).

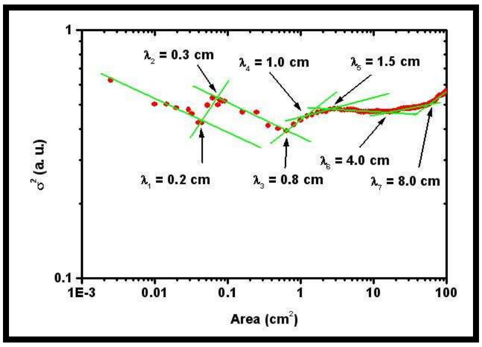
Finally, in the Fig. 8 a comparison is made of the results from the Variogram studies. The data distribution of all cases are clearly different, enabling the identification of lamination defects in plane laminates manufacturing.

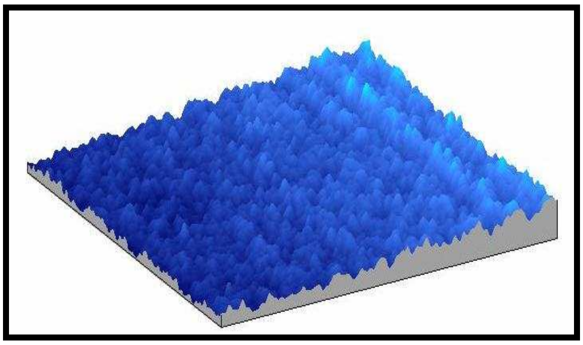


(a)



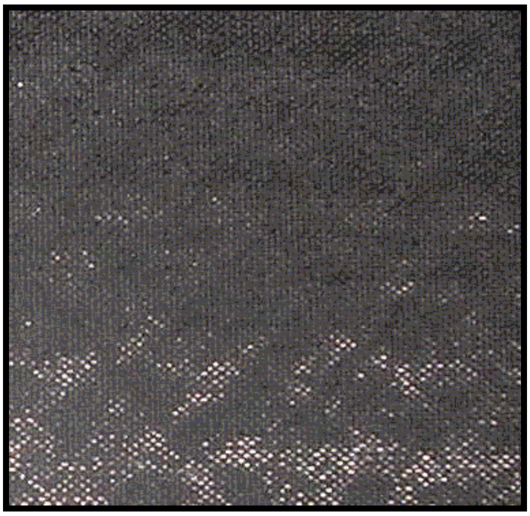
(b)

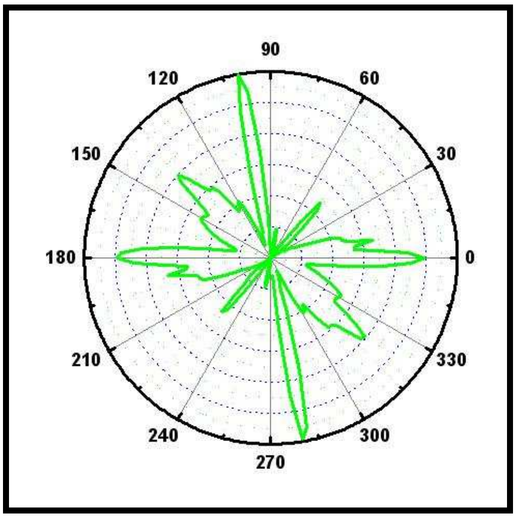




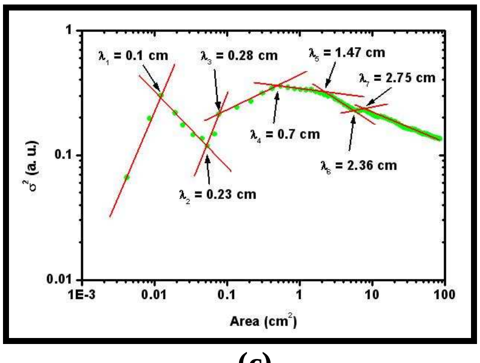
(c) (d)

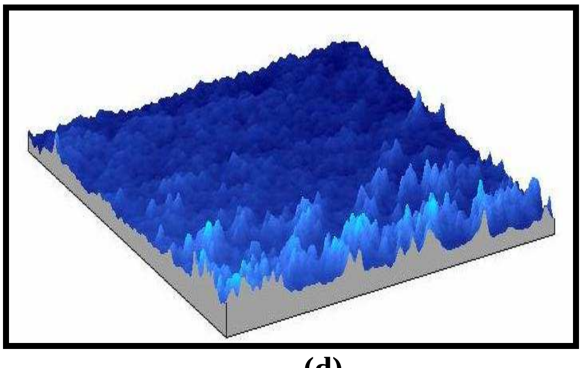
Figure 5. Symmetric sample plate study. (a) Digitized image of the plate. (b) RIMAPS analysis. (c) Variogram results. (d) 3D representation of the surface using a cut-off length of 3 mm.





(a) (b)





(c) (d)

Figure 6. Non-symmetric sample plate study. (a) Digitized image of the plate. (b) RIMAPS analysis. (c) Variogram results. (d) 3D representation of the surface using a cut-off length of 2.8 mm.

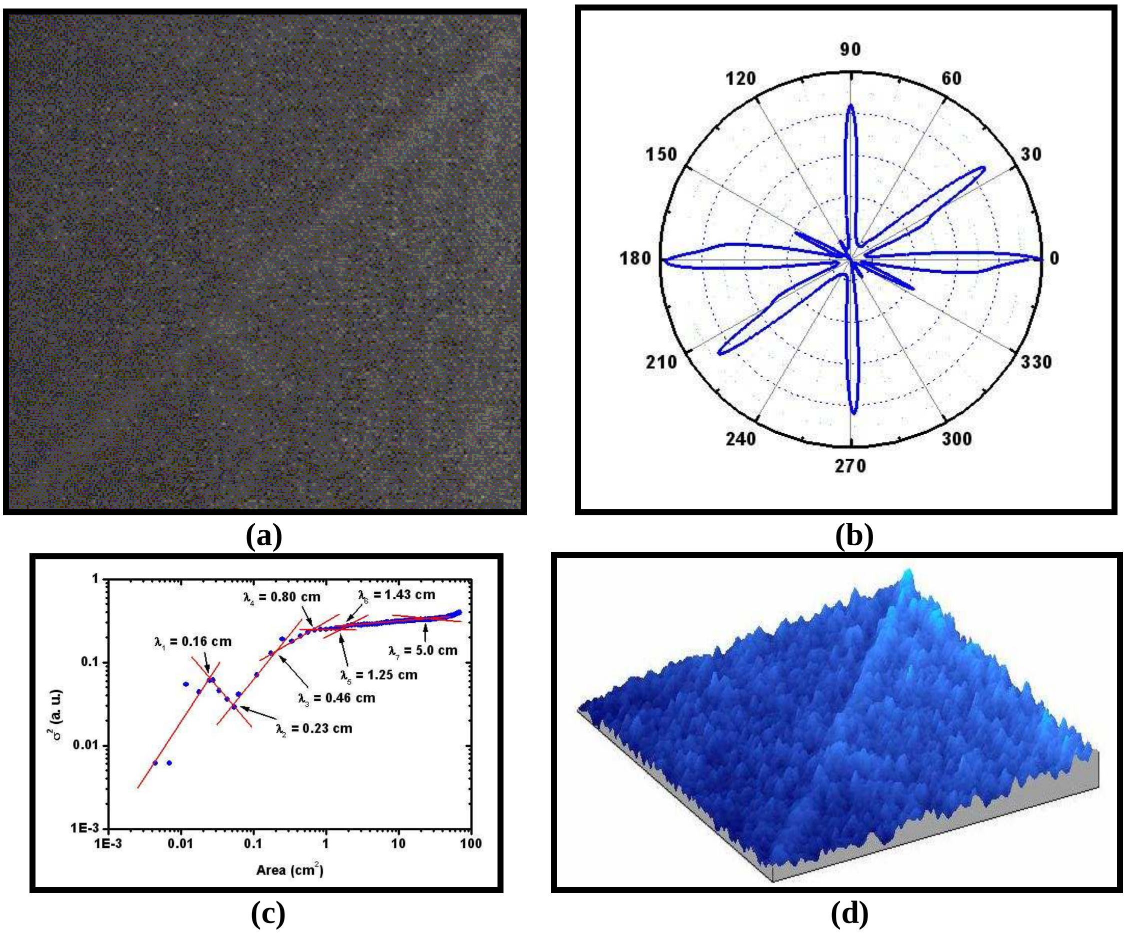


Figure 7. Symmetric and overlapped sample plate study. (a) Digitized image of the plate. (b) RIMAPS analysis. (c) Variogram results. (d) 3D representation of the surface using a cut-off length of 2.3 mm.

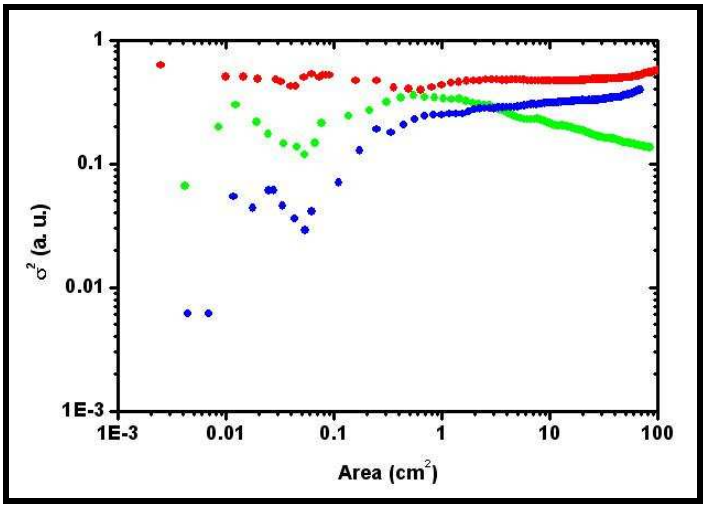


Figure 8. Comparison of Variogram results. The three cases represented are: ● symmetric laminate, ● non-symmetric laminate, ● symmetric laminate with overlapping of fibres. The distribution of data varies when a defect is introduced in the manufacturing process.

6. Conclusions

In all the cases presented in this work, the RIMAPS and Variogram analyses gave a quantitative description of the orientation of fibres and determine the values of the typical scale lengths that were introduced with every modification. All defects introduced were detected. The RIMAPS technique identifies those directions that represent the loss of symmetry in the lamination process as well as possible defects caused by fibre overlapping. The Variogram method brings the typical length scales that characterize each topographic pattern of the surfaces under study. But regardless of the quantitative results, the comparison of data distribution of the Variogram results from the different cases allows identifying immediately the existence of defects in the manufacturing processes. The combined use of these NDT techniques turned out to be a quick and user friendly way to determine any fibre orientation defect in plane composites manufacture.

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