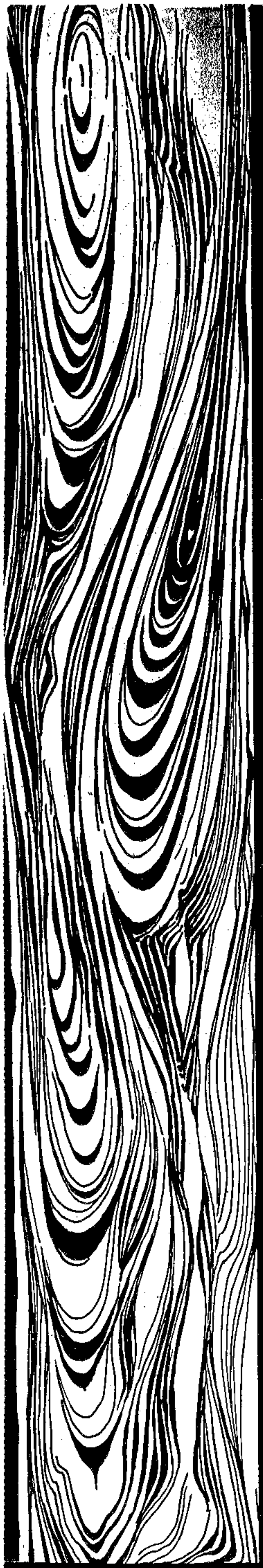

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VISUALIZATION OF STRAIN FIELDS IN ANGLE-PLY GRAPHITE-PEEK SPECIMENS DURING LOADING

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INTRODUCTION

Angle-ply laminates show highly nonlinear stress-strain tensile behaviour mainly due to the presence of transverse matrix cracking and delaminations. After unloading, which essentially follows a linear law, the composites show large permanent strain. The strain field observable on the lateral surface of the specimen during loading cycle is generally nonuniform because of the presence of cracks and for the different layer behaviour.
A new experimental technique has recently been proposed for observing the strain field on the lateral surface of a specimen subjected to mainly static but also fatigue loading [1]. The technique is based on observations with an optical microscope and subsequently monitoring a phase grating printed on the lateral surface of the composite specimen. The in-plane displacements and strains can be calculated from the pitch variation measurements. Here the technique is extensively applied to several angle-ply laminates subjected to static loading. An automated procedure for depicting and computing displacements and strains based on image processing is presented. A series of results related to strains in the nonlinear stress-strain field is analyzed. The presence of transversal matrix cracks and its influence on the strain field is also discussed.

EXPERIMENTAL PROCEDURE

As mentioned above a phase grating of about 200 lines/mm was replicated on the lateral surface of graphite-peek laminates to evidence the behaviour of the different layers under fatigue load cycle. A gold coating allowed a good reflection efficiency of the grating replica and its observation, performed by means of a binocular microscope, proved satisfactory. The different loading steps were recorded and digitized by a CCD camera and converted into a numerical array of 480 rows and 512 columns using a IBM personal computer. The images were sent to an HP-DN400 work station where a software code (DIP) converted the initial data into 3D representation of the displacements and deformations of the tested specimens. In particular the initial numerical array was first enhanced using algorithms commonly used in image processing analysis: first the look-up table was changed, then a Prewitt filter was used twice taking into account the grating frequency. At this point an interactive algorithm was used, able to recognize the grating lines: it looks for the brightest pixels (both centre and maximum of the single lines) and follows the different paths so as to set, line by line, the whole picture. The algorithm requires the assistance of the operator and requests it at the beginning when the search of of the different lines starts and when a noisy area is present. At the end of this process a certain number of points describes the lines and a triangular frame is then provided automatically. This frame behaves like a finite element model: the shape of the elements are optimized and the values of the displacements can be easily calculated in all the model by simple interpolations. The displacement data can now be reconstructed by a three dimensional model of the frame or, using shading algorithms, such as the Gouraud and the Phong ones, a clearer 3D reconstruction can be achieved. The representation of displacements was in our case very poor because these are global parameters and are unable to evidence the great differences between the layers of composite laminates of this type. But it was easy to obtain strains from displacements simply calculating a numerical derivative of the 3D frame just described above. A 3D reconstruction of the derivative of

both the frame and the shading can again be made. More details of the complete procedure can be found in [2].
The grating technique is particularly useful during loading on the test machine because it is little affected by vibrations and noise, but on the other hand it is not very sensitive to the displacements themselves. Besides the grating-microscope, an optical interferometric technique, suitable only on holographic bench, has been used to observe in greater detail the strain field. This technique is known as moire'-interferometry [3] and consists in superimposing two phase gratings, the first replicated on the lateral surface of the test model and the second given by the interference of two laser beams. This method is easy to apply on an holographic bench and the superimposition of the two gratings gives a fringe pattern system representing the pitch changes and thus the displacements of the specimen loaded. The fringe pattern was studied in real time and here it was recorded with a CCD camera, digitized and converted using the usual procedure in a 3D reconstruction model. A grating of 1000 lines/mm was used and such a great sensitivity restricted the use of the method to the holographic bench. The test consisted in the following stages: a fringe pattern of the unloaded specimen was first recorded; after a loading fatigue cycle on a test machine the specimen was checked again on the holographic bench and a new fringe pattern system was recorded.
Figure 1 shows a 3D representation of the strain field obtained for a graphite-peek angle-ply $[45/-45]_{4s}$ laminate. From the image the nonuniform behaviour along the thickness clearly emerges. The average value of 0.008 m/m was in good agreement with strain gage data.

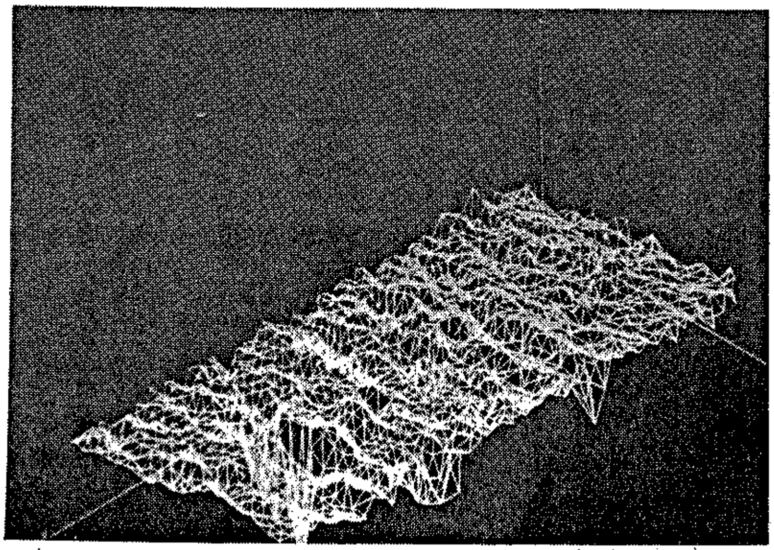

Fig. 1 - 3D representation in wire-frame of a strain field

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