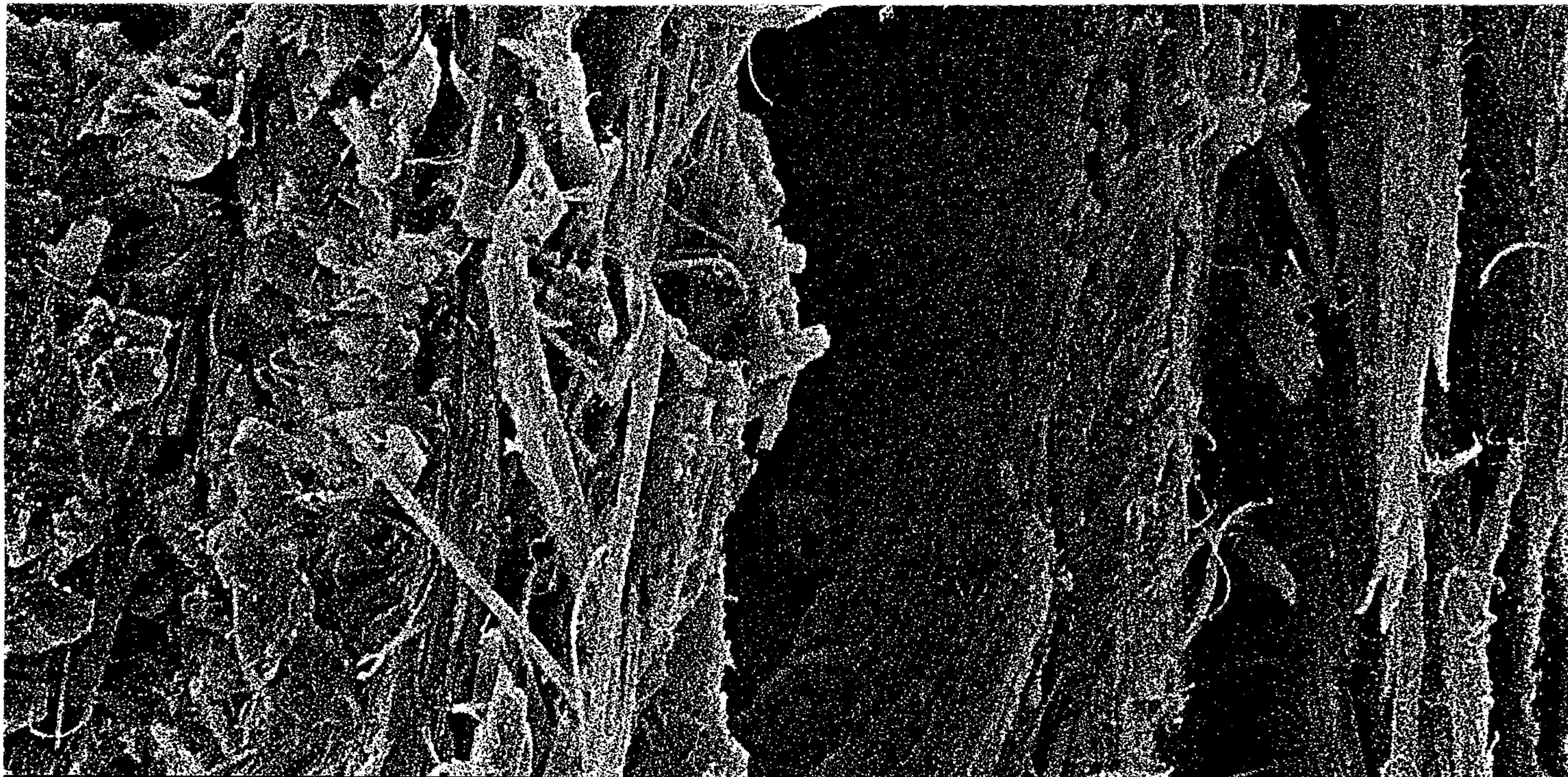

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THE USE OF OPTICAL TECHNIQUES FOR ANALYSING COMPOSITE MATERIALS

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SOMMARIO

Vengono presentate alcune applicazioni di tecniche olo-interferometriche all'analisi e alla caratterizzazione dei materiali compositi. Alcuni provini in fibra di vetro e resina epossidica sono stati provati utilizzando l'interferometria olografica con una sensibilita' fuori dal piano "variabile" per localizzare eventuali difetti o scollamenti. La tecnica moire'-olografica e' stata, invece, impiegata per analizzare alcuni campioni in grafite-peek. Questa tecnica che e' stata ampiamente utilizzata nell'analisi di modelli trasparenti viene qui applicata allo studio di modelli opachi. Infine e' stato utilizzato un metodo tradizionale di moire' per interferenza meccanica fra due reticoli. Si sono evitati, cosi', le decorrelazioni fra reticolo deformato e indeformato registrando passo, passo i reticoli deformati e sovrapponendoli, successivamente, con quello deformato. Queste misure sono state eseguite osservando con un microscopio un reticolo di fase, replicato sul modello.

ABSTRACT

Some applications of holographic techniques, for investigating and characterising composite materials, are presented. Fibre-glass and epoxy-resin specimens have been tested, using simple holographic interferometry with variable out-of-plane sensitivity to locate eventual debondings and defects. On the other hand, the moire'-holographic technique has been employed for analysing graphite-epoxy specimens. This technique has been widely used in the analysis of transparent models and here the authors show how to use the same method for opaque models such as graphite-peek composites. A simple moire' has been also used to avoid vibrations and possible decorrelations always present in normal work conditions. These measurements have been performed using a phase grating replicated on models, observed by means of a microscope. The correlation between unloaded and loaded gratings has been later obtained overlapping the two images.

INTRODUCTION

In the choice of experimental analysis methods, composite material must be consider as behaving very differently to metals. A Fibre-reinforced plastic is simply a heterogeneous medium which may have multiple defects. Various types of failure can occur in these materials: interlaminar debonding, matrix degradation, fibre fracture and fibre-matrix interface separation.The experimental investigation aims at adequately describing the critical level of damage and, to achieve this, a wide range of topics must be explored, including the characterization of mechanical properties, the mechanical behaviour, damage and safety. It is important therefore to use experimental techniques that can both detect faults in and characterize such materials. This paper is concerned with the experimental analysis of composite specimens. Some interesting results obtained using holographic interferometry and holographic moire are shown. The first technique is well known [1] and has been used in a variety of engineering applications. Here it is employed to detect debonding defects in glass-reinforced epoxy composites. The optical components have been rearranged in order to improve the method's detectability [2].

The transparent moire'-holographic technique has long been used in the structural analysis of engineering components [3], its main advantage being that measuring sensitivity can be widely varied from 0.01 mm (less than mechanical interferometry) to 0.002 mm (more than holo-interferometry) [4]. A suitable grid is essential for obtaining useful measurements and this fundamental problem is shared by all moire' techniques,be it moire' interferometry [5] or holographic-moire'.

Recently the authors have employed holographic moire' in the structural analysis of reinforced circular discs [6] and the usefulness of this technique has been demonstrated in applications to transparent models of different thickness. As far as the authors are aware, no examples of application of holographic moire' in reflection measurements are reported in the literature. Reflection measurements [7] permit non-transparent models to be studied and can even reveal the behaviour of the mechanical components.

HOLOGRAPHIC INTERFEROMETRY

Specimens were tested using holographic interferometry both in double exposure and real time. Rectangular plate (240x30x1.5mm) specimens of fibre-glass and epoxy resin (Fig. 1) were loaded at uniform pressure, according to the scheme of Fig. 2, where sensitivity is maximum for out-of-plane displacements. These tests aimed at detecting eventual interlaminar debonding.

The two models made from continuous fibres depicted in Fig.3 have different fringes patterns due to interlaminar debonding in the second specimen(b).

This technique failed however to detect faults deep down in the structure or those with interlaminar development. Some changes were therefore introduced to improve the analysis. The rectangular plates were thermally stressed and the mirror MM shown in Fig. 2 was mounted on a movable platform. Carrier fringes were then introduced by means of microdisplacements and rotations both to eliminate global and to focus local displacement. By way of example, Fig. 4 shows how a blind hole, drilled on the opposite face, is strongly evidenced with this technique.

REFLECTION HOLOGRAPHIC MOIRE'

Two conditions have permitted the implementation of reflection holographic moire': the development of a simple method of phase-grating manufacture and the arrangement of the optical bench in such a way that the distortion of reflected images is limited(see Fig. 5).

Fig. 5 shows the coaxial arrangement of both lighting and reflection beans. Two symmetrical orders (± 1) are filtered and focussed onto the holographic plate M. In the case at hand, two lenses have been used to focus, only one of which L1 represents the Fourier transform system. Actually, this lens both collimates the light beam and produces the diffraction spectrum from the beam reflected by the phase grating, replicated on the model M. The grating has been manufactured along the lines described in an earlier paper [8] . Here an aluminium coating has been used to enhance reflection efficiency.

Referring to Fig. 6, the light beam ,produced by a coherent source, converges at right angles with the phase grating on the model and is reflected and diffracted. The zero order follows the same trajectory as the lightwave, while two symmetrical orders, such as n, diverge along symmetrical paths. For an unloaded model we can write:

$$\underline{A}_o(x, z) = A_o e^{\left[\left(\frac{2\pi i}{\lambda}\right) z\right]}$$

$$\underline{A}_n(x, z) = A_n e^{\left[\left(\frac{2\pi i}{\lambda}\right)(z \cos\theta_n - x \sin\theta_n)\right]} \qquad (1) \qquad \sin\theta_n = \frac{n\pi}{p}$$

$$\underline{A}_{-n}(x, z) = A_n e^{\left[\left(\frac{2\pi i}{\lambda}\right)(z \cos\theta_n + x \sin\theta_n)\right]}$$

where x and z are the carthesian coordinates, λ is the length of the lightwave, p is the grating pitch and A_o and A_n are constants. If we filter only two symmetrical orders, say $\pm n$, the resulting light intensity is:

$$I_1(x) = \underline{A}_n^{\,2} + \underline{A}_{-n}^{\,2} + \underline{A}_n \underline{A}^*_{-n} + \underline{A}^*_n \underline{A}_{-n} = 2A_n^2 + A_n^2 \left[e^{2\pi i(2nx/p)} + e^{-2\pi i(2nx/p)}\right] \quad (2)$$

Now, once the model has been deformed by loading along the plane (tension, compression, bending) in the direction of grating sensitivity, the pitch changes and it follows that:

$$\sin\theta_n = \frac{n\lambda}{p'(x)} \qquad (3)$$

The mathematical expressions similar to (1) and (2) can be written, taking into account (3).

Superimposing either by real time or by double exposure the light intensity before and after loading we get, in the reconstruction process, two symmetrical diffraction orders ± 1. If we consider only one of two orders, say +1, The resulting light intensity represents a system of fringes with frequency twice (2n) the starting frequency and displacements can be obtained along the direction of the grating's sensitivity. In this case the intensity in the x direction is :

$$I(x) = 4A_n{}^2 [1 + \cos[2\pi x (2n/p - 2n/p'(x))]] \quad (4)$$

Some preliminary tests were conducted within the framework of of a broad research programme aimed at studying the fatigue of structural components made of composite material with thermoplastic matrix. The technique described herein was then implemented to characterize some peek and graphite peek specimens in the static field. The results are reported below.

The specimens were subjected to a pure bending stress. A phase grating was replicated on the models' surface using a bonding agent suitable for thermoplastic resins (Redux 410, Ciba Geigy). The grating was replicated from a master grating, obtained with two laser beams (He-Ne λ=633 mm) on a holotest 10E75 Agfa holographic plate which was subsequently bleached and aluminized under vacuum(p = 10E-5 Torr). A grating of about 140 lines/mm was obtained and the ± 1 diffraction orders were filtered, resulting in a apparent pitch of 3.57 mm.

Figure 7 shows the fringe pattern of a graphite-peek specimen, subjected to a bending load. As can be seen, there are slight dissymmetries caused by loading. Strain gages were mounted on these specimens and the comparison of maximum strains revealed more than satisfactory results, with errors of less than 10%.

MOIRE' and MICROSCOPY

One of the main problems using moire' with high sensitivity is the correlation between the two gratings: loaded and unloaded. During real working conditions either vibrations or small movements are always present and it becames very difficult to superimpose the two gratings. The aim of the present research is then the direct measurement of deformations on specimens loaded on normal testing machines, out of holographic bench.

A grating with medium frequency was replicated on specimens along the lines above mentioned and a microscope was used to observe strain deformations on specimens.

Fig. 8 shows two gratings obtained by means of this method: a) represents the undeformed specimen while b) the same specimen with a tension strain of about 0.01%. The specimen was handmade with graphite-peek in our laboratories with a simple and economical procedure. The fringe patterns, shown in the pictures, were enhanced by means of a digital image processing code.

The specimen was stressed by means of a MTS testing machine and a Nikon microscope with a magnification of 65 allowed the surface control.

Gratings replicated on samples had a frequency of 100 lines/mm.

At the present, displacements and strains are calculated by optical superimposition of the two gratings. A complete automation of the process will be performed on the next future and the same methodologies adopted on previous works by one of the Authors [9], will be used.

CONCLUSION

The result obtained appears to validate the usefulness of the holo-interferometric technique for detecting defects very near to the examined surface. The displacement and rotation of the object beam allows a detailed examination of the specimen. The loading method requires special attention and in the case at hand, thermal loading proved to be the most convenient.

Reflection moire holography appears to offer some advantages over moire' interferometry [5]; the possibility of varying sensitivity without changing the grating on the model; at low sensitivities the method can be applied out of the holographic bench; the optical set-up by means of fibre optics can be optimized.

The technique, above defined for simplicity moire' and microscopy, is a good application of the normal moire' technique (mechanical interferometry). Several limiting conditions can be taken into account using this method:

1. Frequency density of the grating
2. Microscope magnification
3. Mechanical properties of material
4. Load intensity.

It is clear that the microscope magnification limits the grating frequency while the mechanical properties determines the grating frequency. Both type and intensity of load determine the frequency sensitivity of the grating.

There is a complete interaction between these parameters and a compromise generally must be found.

ACKNOWLEDGEMENTS

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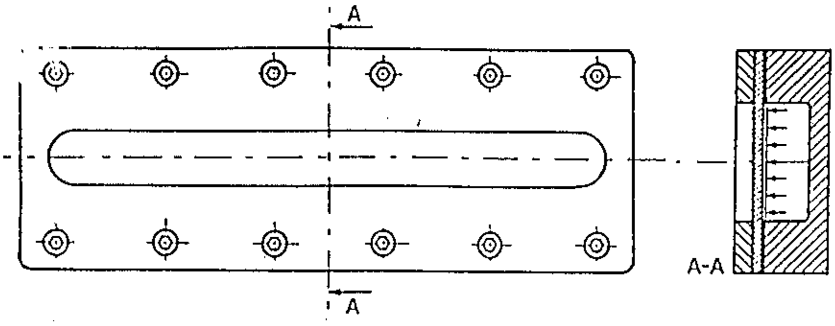


Fig.1 Piastra rettangolare e sistema di carico.

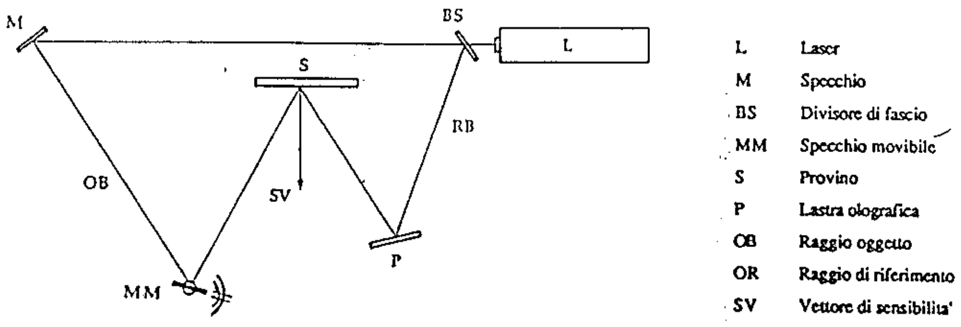
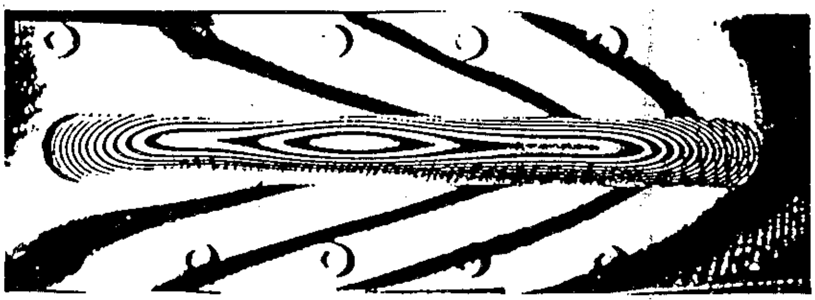


Fig. 2 Disposizione del banco olografico.



a) modello integro

b) modello con difetto

Fig.3 Sistema di frange per provini in fibra di vetro-resina epossidica.

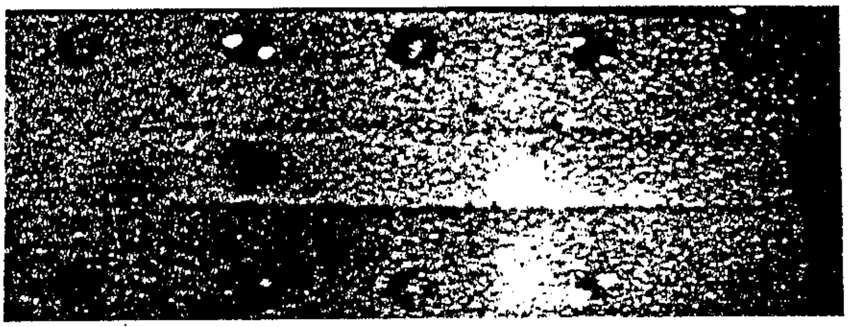
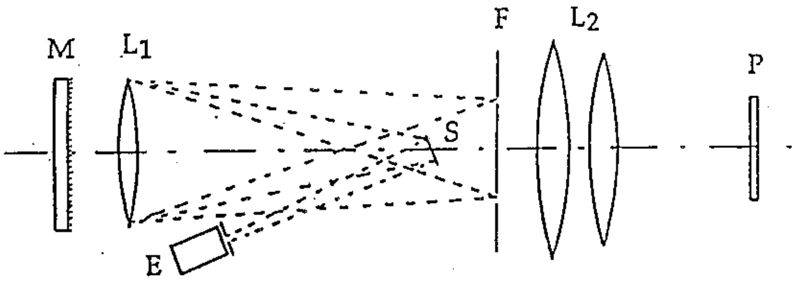


Fig. 4 Difetto circolare evidenziato con un carico termico.



M Modello
L1 Lente
L2 Obiettivo
P Lastra olografica
F Filtro
E Espansore di raggio
S Specchio

Fig. 5 Disposizione del banco moire'-olografico.

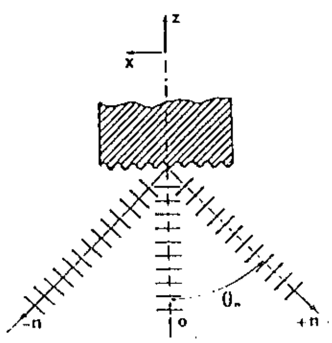
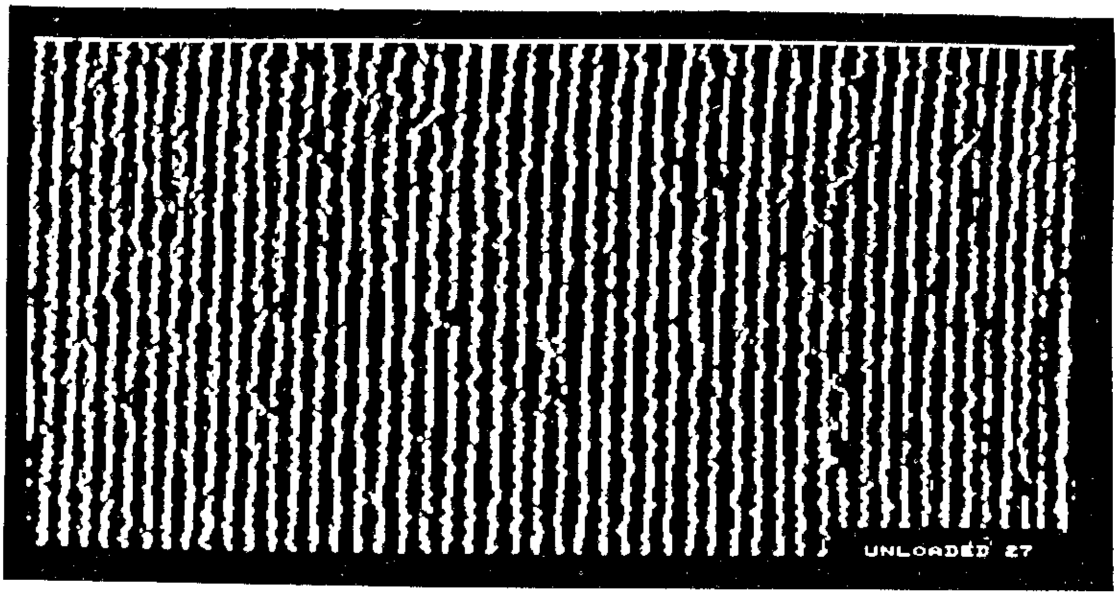


Fig. 6
Diffrazione dei fronti d'onda incidenti.

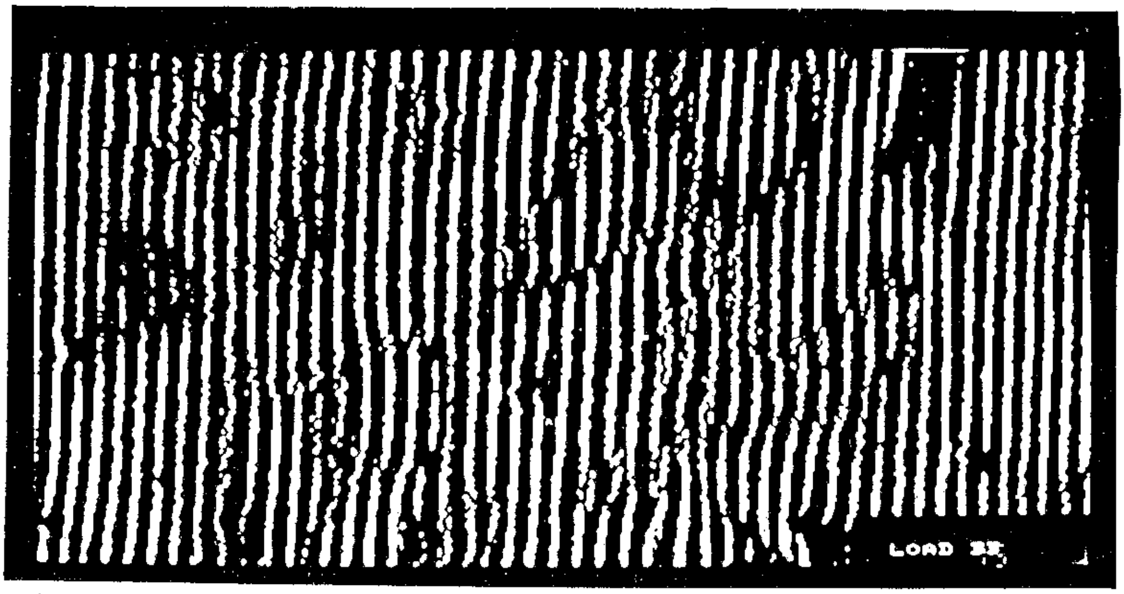
a) Sensibilita' longitudinale

b) Sensibilita' trasversale

Fig. 7 Sistema di frange per un provino in grafite-peek



a) Unloaded



b) Loaded

Fig. 8 Moire' and Microscopy Method.