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THIN REPLICA TECHNIQUE USED IN FATIGUE CRACK STUDY

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Abstract: *Optical methods enable a direct observation of the fatigue cracks. The complete study of fatigue crack propagation is possible by removing imprints from the surface of the mechanical structures. The paper focuses on the thin replica technique and its use in fatigue crack surveying.*
Keywords: *replica, fatigue, crack, optical microscope.*

1. INTRODUCTION

Surveying the fatigue crack propagation is possible only by the measurement of the precise crack length value. There is a great diversity of methods used today, and they could be classified according to [1], [2], [3] in two main groups:

1. Direct methods – with no calibration,
2. Indirect methods – which need device calibration.

Some work procedures and experimental results concerning the direct method applied via optical phenomena are presented in the paper. Sometimes, the complex shape of the specimens and of the structures doesn't allow the direct use of optical methods. Some specific techniques had emerged in order to solve this problem. The aim is to reproduce the surface of the structure with great accuracy using particular materials, which are adapted to freeze the pattern present on the surface, allowing later observations under microscopes.

The replica technique enables a very good crack surveying and makes the detailed study of the crack propagation, throughout the fatigue test.

2. THE REPLICA TECHNIQUE

A replica is an impression from the specimen surface, taken at paticular moments. It allows the local study of the surface at the moment and also, the analyse of the history of the crack evolution.

For a quick and good identification of the replica position on the specimen's surface, is prefferable to engrave the surface by mechanical tracing, by applying grids or by marking with micro-indenters.

For the fatigue study, the replica technique has to keep spatial informations on a support able to follow the shape at a microstructural level. The crack propagation and some plastic evolutions at the crack tip generate specific changes in the micro-relief, reflected on the replica. Finally, the replica is studied by optical methods.

Materials used to obtain replicas are generally celullose acetate or other materials obtained from polymers. Here are two types of techniques:

a) Techniques with solid materials softened by organic solvents.
b) Techniques working with viscous materials which solidify.

The cellulose acetate is presented like foils with variable thikness, from milimeters to microns, or like sollutions to use when the access to the surface is very difficil. With the respect to the material's thikness, replicas could be divided [2] into: thin replicas (up to 0,2 mm foils) and thick replicas (materials or sheets with thicknesses over 0,2 mm).

The use of the technique and the interpretation differs on the replica's thickness. Generally, the material used is softened with organic solvent and it is applied on the specimen surface. After the solvent evaporation the replica becames solid. Solidification time variates from some seconds to minutes. The replica has the shape of a foil or small sheet. It is important to handly with care, to protect the new replica surface and to avoid dust deposition. The replicas are stored on cover glass or in boxes until the examination.

Another type - the polimerizable materials, are obtained by mixing two components. Homogenization is very important and also, a rapid use is desired to avoid the growth of the viscosity.

The general technique consists in the following steps:

- The preparation of the specimen surface by polishing, cleaning and eventual marking of certain zones.
- The fatigue load stops for some moments and the replica is applied on the specimen. The replica remains fixed in this position until the solidification is achieved. Than, the replica is removed carefully from the surface with an adapted pincers, to avoid deformation or its contact with other surfaces.
- The replica passes a visual examination before it is fixed on the cover glass or in a box, and it is denominated.
- The replica is studied under the microscope.

In order to observe replica it is possible to use the reflection technique (thik materials) [2], or refraction technique (thin materials). If there are dust traces or the replica is not clear it is preferrable to use the reflected ligth [3]. The contrast of the image could be improved by vapour deposition on the replica surface.

With optical microscopy it is possible to study thick replica if its surface is quite plane. The usual grossisment used to survey the crack parameters is from 250X to 1000X. There is possible to appear some focalisation problems because the replica surface at the crack tip presents pronounced differencies concerning the level (the replica shape rarely is perfect plane). White or polarised ligth is used to emphasise small relief variations along the crack path.

Electronic microscopy allows a detailed study of the shape and of the dimensions and eliminate optical effects. For example, if in the optical microscopy the depth of the analyses field for 1000X is about 1 micron, in an usual scanning electron microscope one can obtain a depth of 30 microns or larger for the same enlargement.

Therefore, a special treatment of the replica is necessary, to assure the electric circuit and to prevent the replica destruction by heating – small tension level are used, up to 12 kV and with moderate dimensions of the electrons beam. The replica are covered by vapour deposition.

To increase the resolution, greater energy of the electron beam should be used. In order to avoid the replica destruction, a specific technique was suggested in [2], [3], consisting in the deposition of a greater nickel layer (up to 0,1 mm) on the replica. In fact, a new replica is generated, but the new one is more resistent.

It should be mentioned that the precision of the thick replica technique in the fatigue crack analyze is up to 10^{-6} m, referring to the length determination. In laboratory conditions, the precision could be augmented.

3. SOME EXPERIMENTAL RESULTS

During a testing program in fatigue of a metallic alloy, the crack characteristics were surveyed on the lateral surfaces of compact tension specimens. The surfaces were polished finely, and in some cases the surface was etched in order to examine the crack propagation in relation with the microstructure.

More series of thin replica were achieved and studied for the crack growth determination, for the crack path analysis and for the overload effects study.

The experimental sequence consist in

- stopping the fatigue loading,
- charging the specimen at the desired load,
- softening the thin foil with an organic solvent,
- putting the foil on the specimen surface, in the region of the crack (it should be mentioned the time from softening to applying on the specimen surface is very short, about few seconds),
- removing the replica,
- fixing the replica on a glass cover.

All details of the measure sequence are noted in the experimental report.

Precedent studies [5], [6] allowed to test different replica techniques we can use for survey the crack propagation. Other result were published in [5] and [7].

Optical microscopy was used to observe series of the replica. Some representative images are presented as follows.

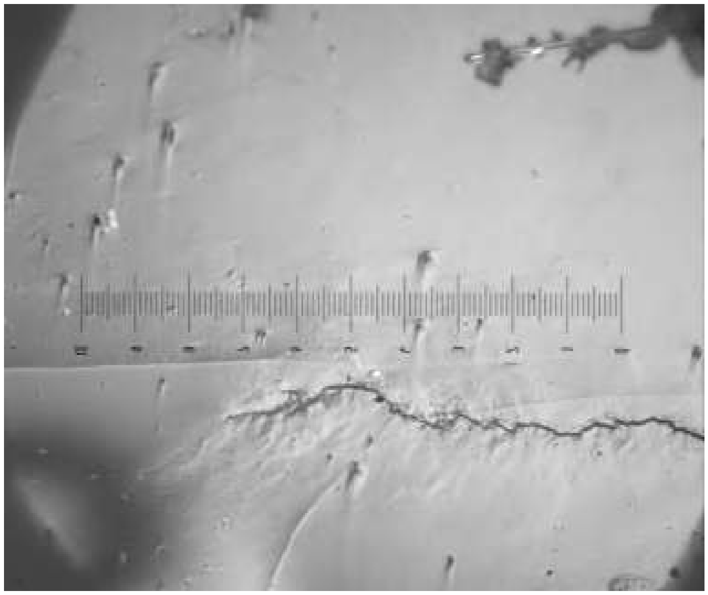


Figure 1: A general image of the crack on the rigth surface of the specimen, 200x. Observation in reflected ligth. The crack path is clear, the specimen surface was polished carefully. To measure the crack length at differents moments it is useful to observe and identify any particular detail of the surface, like inclusions, traces from polishing, or rolling traces

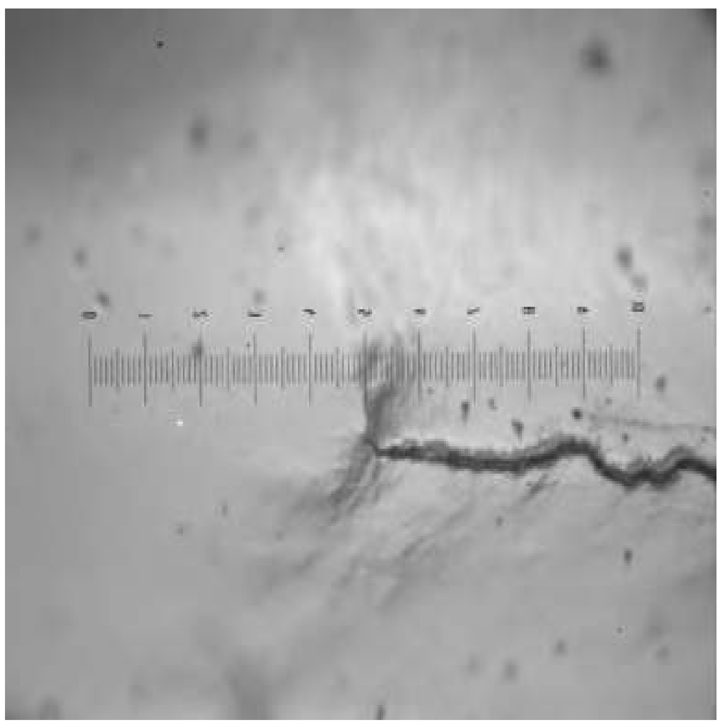


Figure 2: An image of the crack on the rigth surface of the specimen, 200x. Observation in reflected ligth. The image shows the shape of the surface immediately after an overload. The great problem of this observation is due to the deep difference that appears on the surface, so the optical observation becomes unclear. Even in this conditions is possible to observe an important plastic deformation at the crack tip because of the overload applied.

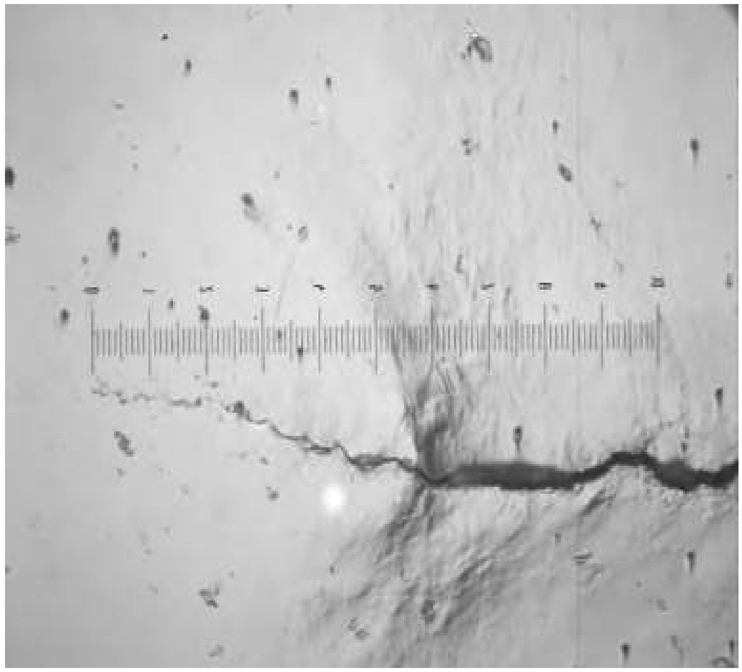


Figure 3: An image of the crack on the rigth surface of the specimen, 200x. Observation in reflected ligth. The image shows the propagation of the crack after the overload. A better solution to observe the replica's surface was to use the polarised ligth. The relief is visible and the deep sensation is more clear.

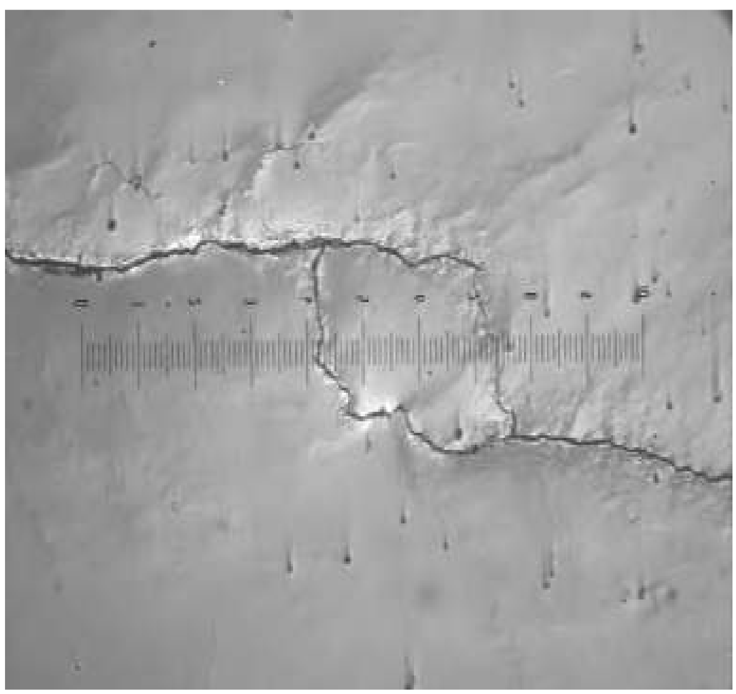


Figure 4: An image of the crack on the left surface of the specimen, 200x. Observation in reflected ligth. This remarcable image shows the crack oresents bifurcation, with an deviation of 30 microns. On the surface, the inclusions colonies are visible, their orientation is perpendicular on the crack plan in this case. One could remark the relief along the crack path and also a series of small cracks along the main crack path. This image is characteristic for the material tested and demostrates the effect of the microstructure on the crack propagation.

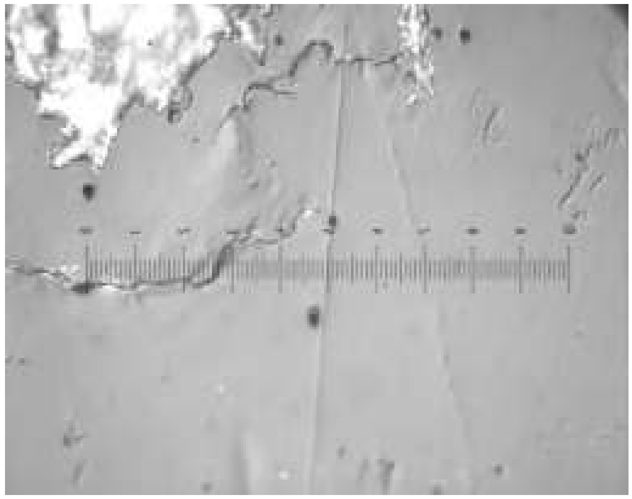
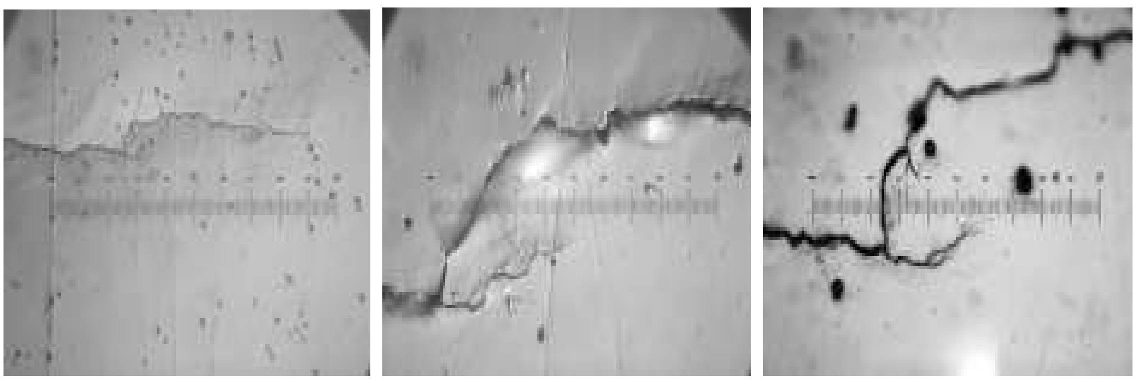
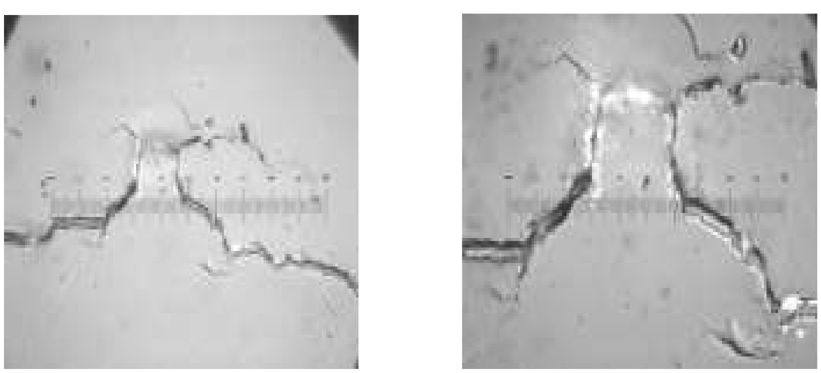


Figure 5: An image of the crack on the left surface of the specimen, 500x. Observation in reflected ligth. This also remarcable image shows the moment before the crack path bifurcation. In fact, in the middle of the specimen the crack advances faster than on the surface. In the left upper side of the image we can see the replica shape was affected when it was removed from the surface.



200x 500x 1000x

Figure 5: Images of the crack on the left surface of the specimen. Observation in reflected ligth. In the same position of the crack, at three different moments, this observations show informations depending on the scale we observe on the microscope. In fact, this series of observations was made to survey the behavior of the lost branch of the main crack. The second image present some unclear zones near the crack path due to the replica material which penetrates the crack



500x 1000x

Figure 5: Images of the crack on the left surface of the specimen. Observation in reflected ligth. Another spectacular change of the propagation path, with many secondary cracks following the main crack.

3. CONCLUSION

The thin replica method allows an accurate study of the fatigue crack characteristics. The use of this techinique is useful not only for the crack's length measurement but also allows a better understanding of the metarial behavior, concerning a series of phenomena that appears when the crack propagates. It is visible [7] the thick replica technique allows more clear images, as the surface of the replica material is more stable (concerning the plane surface of the replica) than the thin foil we use in the thin replica technique. But this technique is sometimes easier to use.

A great advantage is that the replica remains available long time after the test is performed.

To obtain a replica it is necessary to stop the fatigue test, but the specimen remains on its place.

The geometry and relief details removed from the specimen surfaces could be very fine in laboratory and also in other experimental fields.

One can use the optical microscope up to 1000X, but the manipulation is delicate and the surfaces examinated are small. In the scanning electron microscope, greater surfaces could be analized, with a better precision.

Finally, the replicas were preserved in special transparent boxes. Recent examination confirms that the study of this replica type is always possible even after ten years.

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