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Speckle photography method of analysis of displacements at the crack tips developing in brass specimens subject to tension

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BRASS SPECIMENS containing a central circular hole were tested in tension by means of a double-exposure laser speckle photography method. Displacements fields were measured in the neighbourhood of the crack propagating from the hole playing the role of a stress concentrator. Large magnification (8, 10, 20 ×) enable high resolution of the measurements (ca. 0.2 mm). The measurements were repeated at various stages of crack development and yielded the values of displacement increments. Plastic strains were found to concentrate along several fanshaped narrow zones extending from the crack tip to the specimen boundary. The triangular regions contained between the plastic zones are rigidly displaced (disregarding the elastic deformation).

Badano rozciągane próbki mosiężne z centralnym otworem kołowym przy użyciu dwuekspozycyjnej laserowej fotografii plamkowej. Mierzono wartości pola przemieszczeń w otoczeniu szczeliny rozwijającej się od otworu pełniącego rolę koncentratora. Zastosowanie dużych powiększeń (8, 10, 20 razy) zapewniło dużą rozdzielczość pomiaru (ok. 0,2 mm). Pomiarów dokonano dla kolejnych etapów rozwoju szczeliny, uzyskując wartości przyrostów przemieszczeń. Stwierdzono, że odkształcenia plastyczne koncentrują się w kilku wąskich strefach rozłożonych wachlarzowo od końca szczeliny do brzegu próbki. Trójkątne obszary pomiędzy strefami poruszają się ruchem sztywnym (z dokładnością do odkształceń sprężystych).

Методом лазерной спекл-фотографи с двойной экспозицей исследовались растягиваемые латунные образцы с центральным отверстием (в плоском напряженном состоянии). Измерялись значения поля перемещений в окрестности распространяющейся от отверстия трещины. Использование больших увеличений (8, 10, 20 раз) обеспечивало хорошее разрешение измерений. С помощью измерений на очередных этапах распространения трещины были получены соотвествующие им приращения перемещений. Было установлено, что пластическая деформация концентрируется в нескольких узких веерообразных зонах расположенных от вершины трещины до края образца. Треугольные области между пластическими зонами перемещались практически жестко.

1. Introduction

THE STRENGTH parameters of engineering structures are frequently determined by the conditions of plastic propagation of defects and microcracks existing in the material of the structures; due to this fact, several specialists have decided to study the nature of cracks and their development conditions and, consequently, to determine the corresponding fracture criteria. The leading role in the fracture mechanism is played by the phenomenon of plastic yielding which takes place in the crack tip zones, hence much attention has been paid to this particular problem. Numerous interesting results have been obtained here by the etching technique [1, 2, 3, 4]; some examples of images obtained by this method are shown in Figs. 1 and 2 which present the discontinuous, laminated structure of the plastic zone.

These results inspired the present author to initiate attempts to apply other methods of analysis to the same problem. The investigations are aimed at veryfying results concerning the plastic zones appearing at the crack tips, obtained by such methods like photoelastic models [5, 6], photoelastic coatings [7], caustics [8], moiré [9, 10] and holographic methods [11, 12, 13], and also the metallographic methods mentioned above.

A considerable drawback of the etching technique consists in the fact that it is not capable of providing us with quantitative results concerning the actual displacements observed in the region tested. Relative values of the displacements measured at the surface

FIG. 1. Plastic zone around the crack tip visualized by etching a steel Fe-3Si specimen [3].

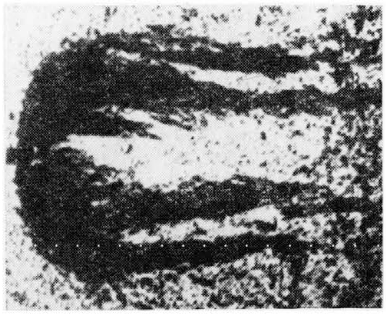

FIG. 2. Plastic zone around the crack tip propagating in mild carbon steel [1].

are obtained by repeated die forging (replication) performed during the crack development process, the corresponding points of the surface being identified by means of the microcrack systems produced by grinding [1]. The conceptual similarity of measuring the mutual displacements of the surface points due to the die forging (replication) and the speckle photography techniques [16, 17, 18] suggested that the latter method should be used to verify the former investigations; the corresponding results are given below. Other examples of successful applications of the speckle method in the analysis of cracks, presented in papers [14, 15], confirm the suitability of this method to our purposes.

The speckle photography method of measuring the magnitudes and directions of the displacement vectors at all points of the surface analysed was described and discussed in detail in several papers (cf. [16, 17, 18]) and hence these problems will not be dealt with in this paper.

2. Investigation technique

The specimens tested were cut out of brass M63 strips subject (after rolling) to recrystallization annealing and softening. The specimens were formed as thin strips with a central circular hole of diameter 0.5–1 mm serving as a stress concentrator fixing the starting point of the crack (Fig. 3). The specimens (with or without the concentrator) were tested in tension; the curves obtained are shown in Fig. 4. The optical systems (Fig. 5) enabled $8\times$, $10\times$ or $20\times$ magnification of the image. In the field recording and analysis process the argon laser was used, while a He-Ne laser was applied to the point analysis. The diameter of the speckle, at the magnification of $8\times$, was 2.7 μm. The specimens were tested in a specially constructed tensile testing machine (Fig. 6) securing a simultaneous and uniform translation of the grips, contrary to the classical mechines in which one grip

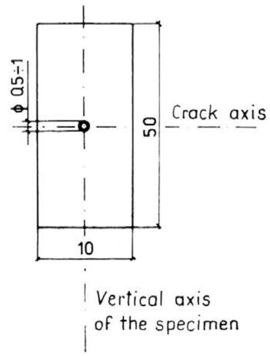

FIG. 3. Specimen.

is fixed and the other one moves. This improvement was aimed at the maximum possible elimination of the external, perturbing displacement field imposed over the field analysed. The starting point of the crack was assumed to be located at the immobile middle point of the tension system. During the tension process (crack development) repeated, double-exposure recordings of the consecutive stages were made. The specklegrams obtained were analysed by the point and field methods. Some of the specklegrams were analysed point-wise by scanning of the entire surface, the results being then compared with the

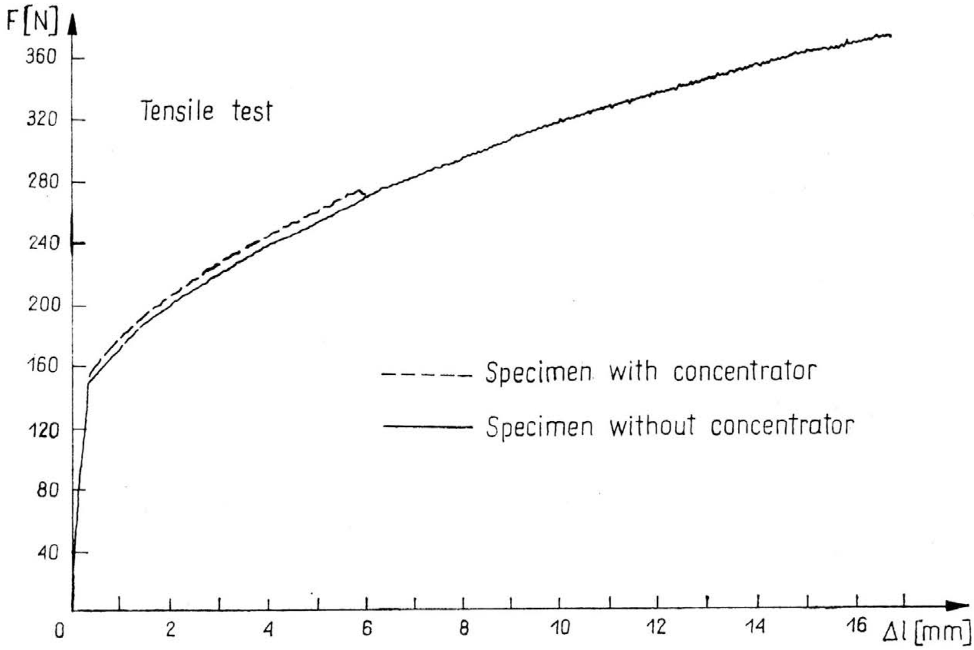

FIG. 4. Curves obtained from the brass M63 tension test.

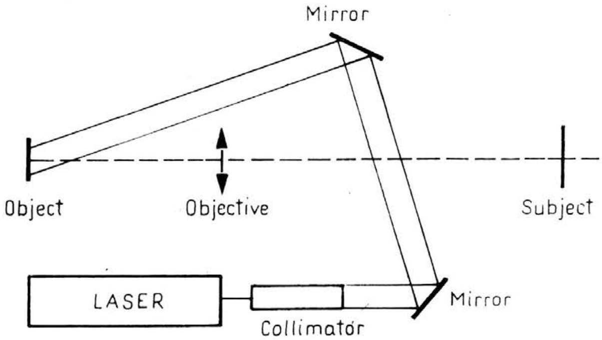

FIG. 5. Scheme of optical system used for specklegram recording.

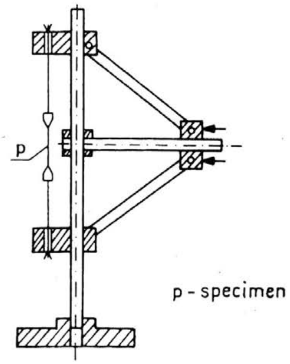

FIG. 6. Tensile testing machine.

results obtained by the field methods. Consequently, the remaining specklegrams were analysed by the field method, the point method being applied o certain selected regions only.

3. Analysis of results and conclusions

During each test of a specimen, the optical system shown in Fig. 5 was used to perform double-exposure recordings of the individual states of the object. The first recording was made to register the elastic strain state of a specimen in which the crack was at rest. Several specklegrams were made and analysed for each specimen. In order to explain the method of analysis. let us discuss it in detail in the case of a single, selected specklegram; in all remaining cases the procedure was indentical.

The point-wise analysis of a specklegram proceeds as follows: displacements (d) and angles (α) are determined, the latter denoting the angles between the displacement directions and the vertical axis of the specimen; measurements are repeated for the consecutive points lying on curve a (Fig 7), then along curve b, etc. Putting the results together, two curves (d and α) are obtained for each scanning line. Examples

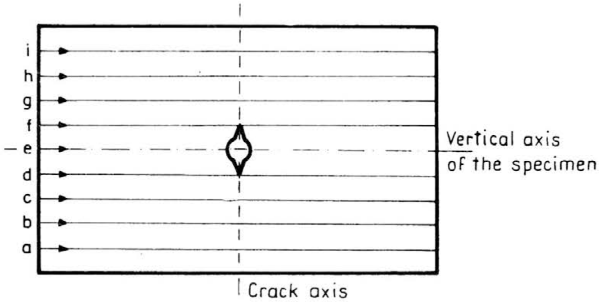

FIG. 7. Directions of scanning of the specklegram surface.

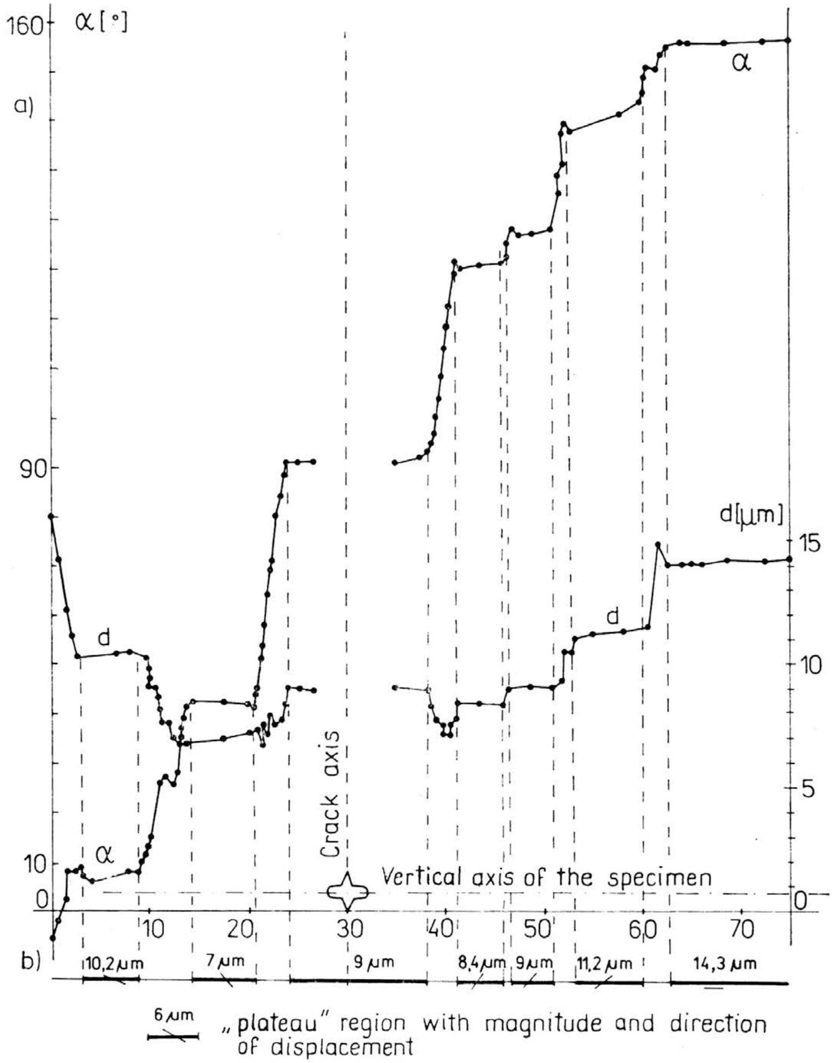

FIG. 8. a) Graphs of variation of d and α of scanning line f. b) Plateau regions referred to the scanning line.

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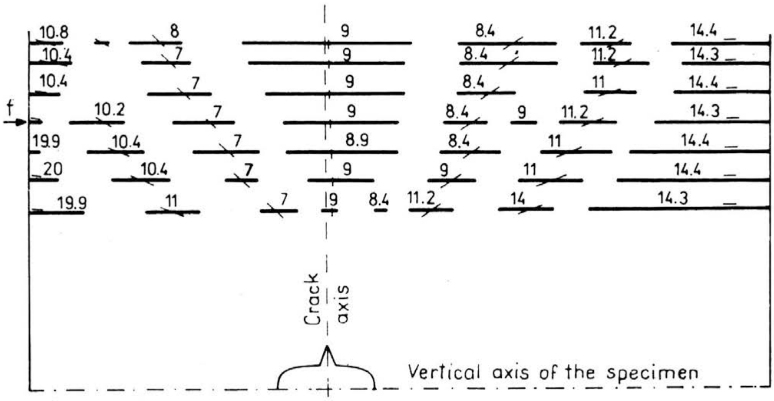

FIG. 9. Plateau regions at one half of the specklegram surface. The regions are presented together with the magnitudes (measured in μm) and directions of recorded displacements.

of such curves for the line f (marked by an arrow in Fig. 9) are shown in Fig. 8. Two regions of stabilization of d and α (plateaus) are seen; they are marked at the line f. A similar procedure is applied to each scanning line and then the global presentation of these regions for the entire tested specimen surface is made. The results are seen in Fig. 9.

The results are then compared with those obtained by means of the field analysis. Figure 10a presents a schematic picture of the interference lines obtained from the field analysis of the specklegram discussed above; Figs. 10b and 10c represent the results obtained from the field analysis of the same specimen tested at an earlier stage of crack propagation. Arrows denote the direction of displacement of the diaphragm from the optical axis during the process of recording of the field image, and the magnitude of that displacement.

The point-wise analysis yields the total value of the displacement, while the field analysis — the value of its component parallel to a certain direction, so that the results cannot be compared directly; to make this possible, components of the displacement (d) (obtained from the point analysis) parallel and normal to the specimen axis are evaluated. In the field analysis the results are recorded for at least two components, normal and parallel to that axis. This was taken into account in all the comparisons made. The results obtained by the two methods are shown to coincide with each other, what makes it possible to simplify the analysis and base it on a much less time-consuming field method, the other method being used only in certain selected regions. Such an approach was applied to all the specklegrams obtained, and the corresponding results will be presented in a separate paper.

Summing up the results obtained so far, it may be concluded that in the materials tested there exist certain narrow bands in which large variations of the magnitudes d and α occur; they are the slip bands. The regions contained between these bands are characterized by constant values of d and α and represent the rigidly displaced blocks.

Analysis of all the specklegrams was followed by the comparison of the results concerning the consecutive stages of crack development in the individual specimens, in order

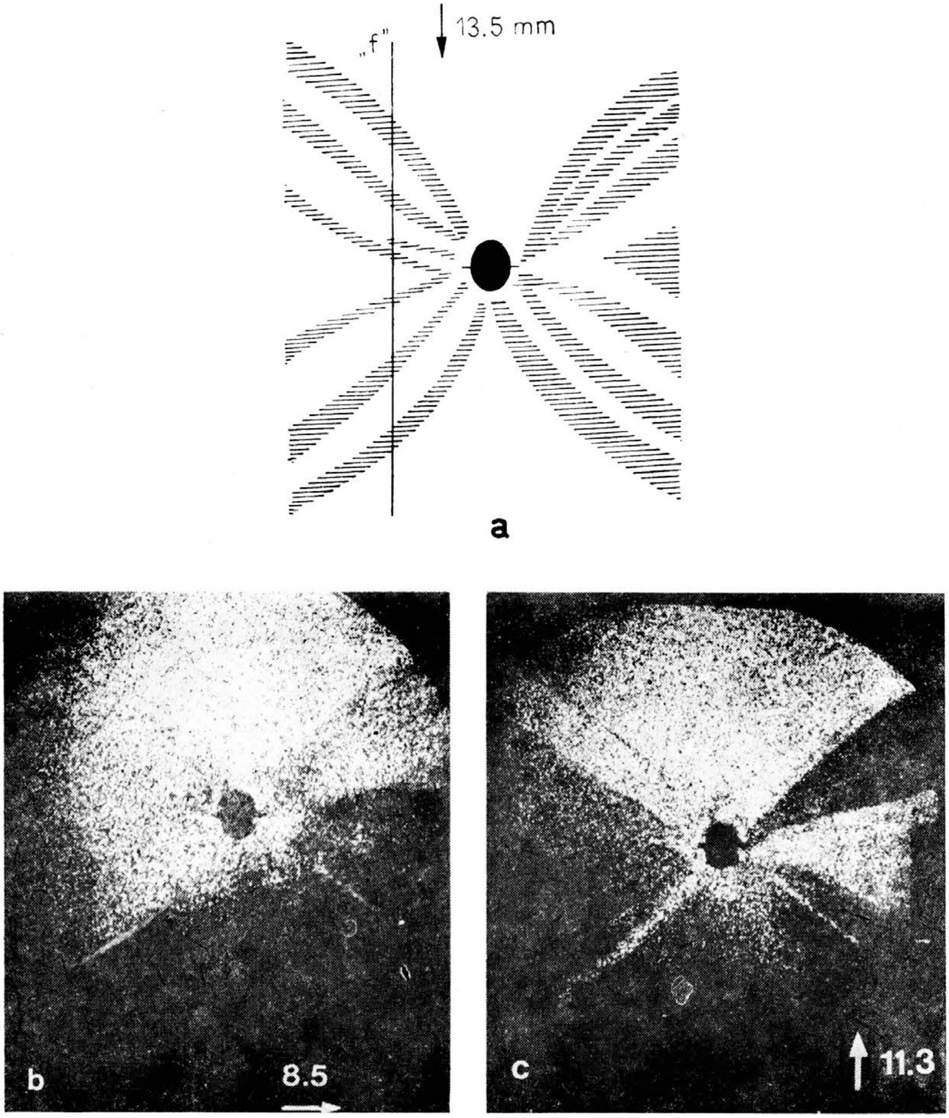

FIG. 10. a) Field analysis image for the case discussed; curve f is shown and the magnitude and direction of displacement of the diaphragm from the optical axis of the system. b, c) Field analysis images of another stage of propagation obtained for two directions of displacement of the diaphragm.

to follow the fracture process. It may be concluded that during the crack propagation process the slip bands are formed; they start from the original crack tip and reach up to the boundary of the specimen. Rigid blocks always move along the formerly formed slip bands, but not always along the neighbouring ones. The slip band formed at a certain stage may later be swept by the block. New slip bands are created only at the initial stage of crack formation. Later on the blocks are displaced within the bounds determined by the most far-reaching bands.

4. Conclusion

For a given material and specimen geometry, the plastic zone at the crack tip is of a discrete character: it consists of elastically-deformed regions separated by narrow plastic slip bands. The specimens considered in this paper were narrow, what allowed for almost rigid displacements of the blocks since the slip bands reached the specimen boundaries. It may be conjectured that if such conditions did not exist, the blocks would deform as elastic bodies within the bounds imposed by the constraints which result from the existence of the slip bands. This conclusion is confirmed by metallographic investigations [2, 3, 4].

The results derived above seem also to lead to another conclusion: the mathematical models used in fracture analysis assume the existence of compact, uniform plastic zones; hence such models may (at least in such cases like those discussed here) lead to results which have nothing in common with the actual, discrete character of the real fracture processes.

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