Stereo-photogrammetry as Applied to Fractography

J. D. BRYANT
Martin Marietta Laboratories, 1450 South Rolling Road, Baltimore, MD 21228, USA

ABSTRACT

Methods by which topographic information can be determined from stereo fractographs are described. A successful technique has been developed by equipping a standard Hilgar-Watts stereoscope with transducers, allowing for semi-automated determination of topographic coordinates of fracture surfaces. Means by which coordinate sets determined in this manner are used to construct surface maps are discussed. Details of the technique, and examples of its uses, are described.

KEY WORDS

Fractography; photogrammetry; stereology; profile determination; contour mapping.

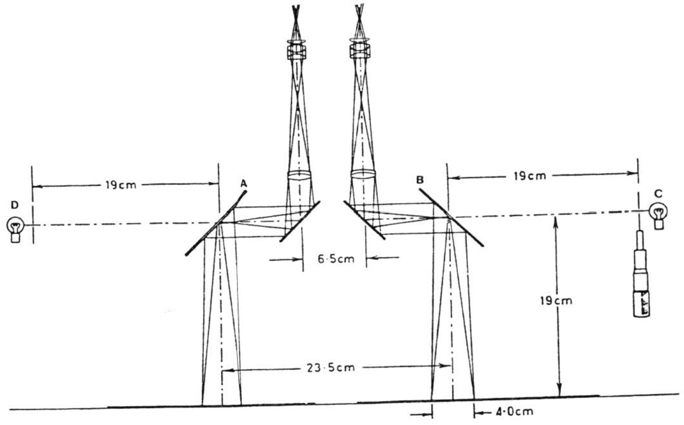
INTRODUCTION

Although the application of stereo-photogrammetry to fractography has proved to be a successful means of extracting quantitative information from fracture surfaces, its use has been severely limited until now. The complicated, tortuous nature of fracture surfaces generally requires a large matrix of topographic coordinates if that surface is to be described with any degree of accuracy. The acquisition of these data through conventional stereo-photogrammetry would prove an arduous task, and could present problems of reproducibility.

Several approaches have recently been used to obtain accurate topographic measurements from fracture surfaces and to make quantitative fractography more accessible (Banerji, 1988, Bauer and Exner, 1981). Of the non-destructive techniques used (Bauer and Haller, 1981), the approaches can be grouped into two classes: geometric and stereoscopic. In the geometric methods, as exemplified by the work of Simov et al. (1985), analytical geometry is applied to determine the metric characteristics of surface elements; several tilting angles are employed to calculate the topography of the surface under study. Standard aerial photogrammetry techniques, as have been used in fractography (Crone, 1968) fall into this category. This technique was recently used by Kobayashi and Shockey (1984) to identify micro-failures ahead of the main crack-tip in corrosion fatigue. The critical distinction between the geometric and stereoscopic methods is the visual stereo effect (Boyde, 1973). Stereoscopic methods, such as the one described in this paper, rely on the formation of a stereo image. Several teams of investigators (Howell, 1980; Bauer and Haller, 1981; Bauer et al., 1982), most notably Bauer and Exner (1981), have recently devised methods to automate stereo-photogrammetry. The technique used at the University of Virginia and described herein is one such method (Bryant, 1986).

METHODS AND INSTRUMENTATION

The basis of the present technique is the partial automation of a standard Hilgar-Watts-type stereometer. A conventional stereoscope is shown schematically in Fig. 1.



OPTICAL DIAGRAM

Fig. 1. Optical diagram of the Hilger-Watts stereoscope showing the position of the two light sources.

The stereoscope operates on the principle that the "mind's eye" will place separate images within the same focal plane when they appear to be equal distances from the eye. The large mirrors located at positions A and B in the diagram are half silvered, allowing the images of the two light sources (C and D) to be incorporated into the visual image of the photomicrographs, which are on the viewing stage. When the two light spots are superimposed (through translations), they appear at a certain elevation within the three-dimensional image of the micrographs. The parallax generated by the difference in angle of viewing between the individual micrographs of the stereo-pair can be used to determine the relative heights of features within the stereo image. The rise and fall of the light source in position C, as controlled by the micrometer, will be a measure of parallax between the two images. The motion of the light spot is consequently associated with an apparent change in height of the light spot image within the stereo image of

the micrographs. An analytical relation between the movement of the light spot and the apparent height change of its image in the stereoscope can be simply derived and is given by:

$$\Delta Z_c = \Delta P / 2M\sin(\alpha/2) \qquad (1)$$

where ΔZ_c is the apparent elevation difference, M the magnification, α the tilt angle between micrographs, and ΔP the parallax (translation of the light source) (Boyde, 1973).

The semi-automated method described here was developed to simplify the collection and handling of topographic coordinates for fracture surfaces, and to improve the accuracy and reproducibility of the data gathered. The system is a major improvement over the standard stereoscope in both the speed of data acquisition and the reproducibility of the data collected. In the standard stereoscope, the operator must take his eyes out of the viewer to record the micrometer readings as well as the X and Y translations of the viewing table. Doing so makes it difficult for the eyes to refocus in the same manner (so as to achieve reproducible height determinations). Also, the repeated reading, recording, and refocusing task causes much eye strain and fatigue, reducing the accuracy of the measurements taken.

Data Recording

In the semi-automated method, the motion of the light source is monitored using a transducer; it is the voltage signal from this transducer that is used to determine the changes in surface height within the stereo image. Through translations of the viewing stage, the virtual image of the superimposed light spots can be placed over any feature within the fracture surface. The light spot can then be lowered onto the fracture surface and the parallax recorded by depressing a hand-held trigger. The computer (ATT 6300) then records the voltage through an analog/digital converter. Two mapping methods, profile and topographic, have been devised to obtain the planar coordinates (X,Y), the choice of which determines the graphical form of the output.

In profile mapping, simple line profiles in any direction can by extracted from the fracture surfaces through the use of two additional transducers that monitor the translations of the viewing stage. Following rods mounted onto the frame of the stereoscope allow for direct measurement of positions within the micrographs. When used in this mode, the trigger event signals the simultaneous recording of the three signals used to determine the X, Y, and Z coordinates along a trace in any direction of the fracture surface.

In topographic mapping, a two-dimensional matrix of elevation coordinates corresponding to prescribed points on the micrographs is required for full surface description. A transparent grid placed over a single micrograph defines the point array; the virtual image of the light sources is then lowered onto these points. Rastering over the grid points sequentially files a one-dimensional array of elevation coordinates onto disc memory.

Data Management

The voltage signals recorded in the first stage of the mapping procedure, in either the profile or topographic mode, represent uncalibrated, unnormalized data points. A menu-driven program that uses the software written for this system allows the operator to convert these data files into the format required for graphic display. Signal calibration is considered first. In the case of topographic mapping, the voltage signal from the single transducer must be calibrated to displacements in microns; in the profile trace option, three voltage signals must be calibrated. To extract the magnification from the micrographs, the light spot is positioned over the upper and lower ends of the micron marker, triggering the computer at each location. By entering the length of the marker bar (along with the grid spacing, in the case of the topographic mapping), the data files are then calibrated to files of three-dimensional coordinates. The data files are subsequently normalized by subtracting the lowest value from each data set from all elements of that set. The set of coordinate pairs characterizing the profile trace is now prepared for plotting. For the topographic mapping files, the single, one-dimensional array must be folded to obtain a two-dimensional array in accordance with the size of the grid network used in the data recording stage. The calibrated, normalized data files can now be edited.

Graphical Display and Output

The sets of topographic coordinates can now be entered into the computer using graphics software. Profile traces can be previewed on the terminal prior to plotting, using either a dot matrix format or a high-resolution HP 7475 plotter. The display format is available to generate several topographic maps. The most useful are three-dimensional carpet plots (full or hidden line) and connected contour plots. Sample plots taken from the micrograph in Fig. 2 are provided in Figs. 3 and 4. Figure 3 shows the full line option of the carpet plot graphic display. The periodicity of the fractographic ridges along the left-hand side of the plot can be further highlighted by rotating the image i.e., by altering the viewing perspective. Figure 4 is a connected contour plot of the same region. The relative elevations of each contour are printed along each line. The surface was characterized in both plots by a 19 by 27 matrix of data points.

Fig 2. Fractograph taken from a tensile specimen of Ti-10V-2Fe-3Al.

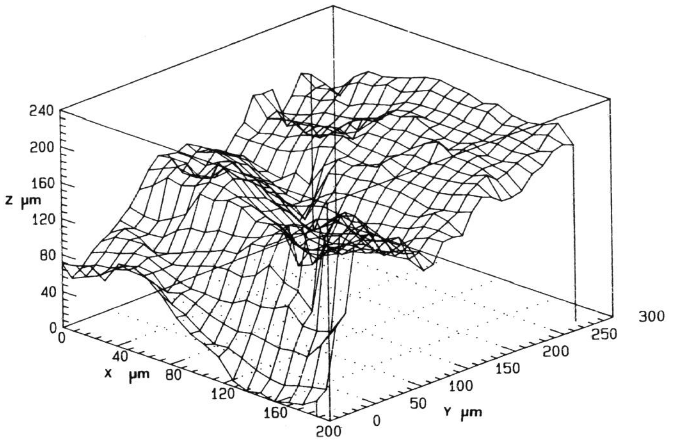


Fig. 3. Carpet plot constructed from the fractograph in Fig. 2. Options within the graphics software allow changes in perspective; this may be utilized to highlight features of interest.

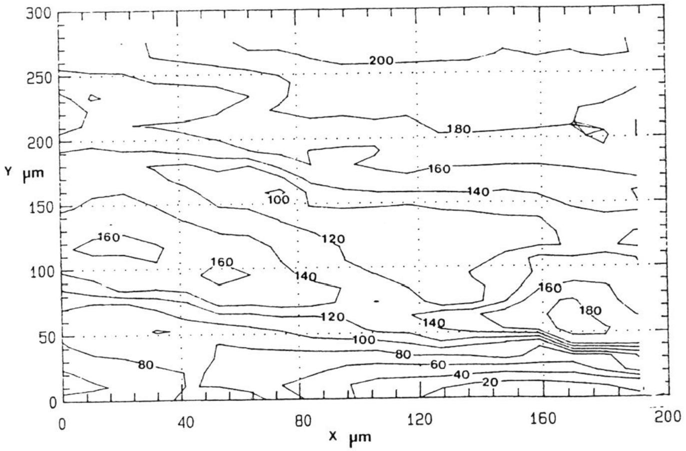


Fig. 4. An alternative graphics format for the fractographic coordinates taken from Fig. 2. The elevations associated with the contours in the plot are normalized to the lowest region within that plot.

EXAMPLE OF IMPLEMENTATION

In the study of high-strain-rate deformation in the commercial titanium alloy Ti-10V-2Fe-3Al, changes in fracture surface character were seen as a result of changes in imposed loading rate. The three carpet plots shown in Fig. 5. were extracted from the fracture surfaces of three fracture toughness specimens; the imposed loading rates (K_I) were varied over four orders of magnitude and are printed above each plot.

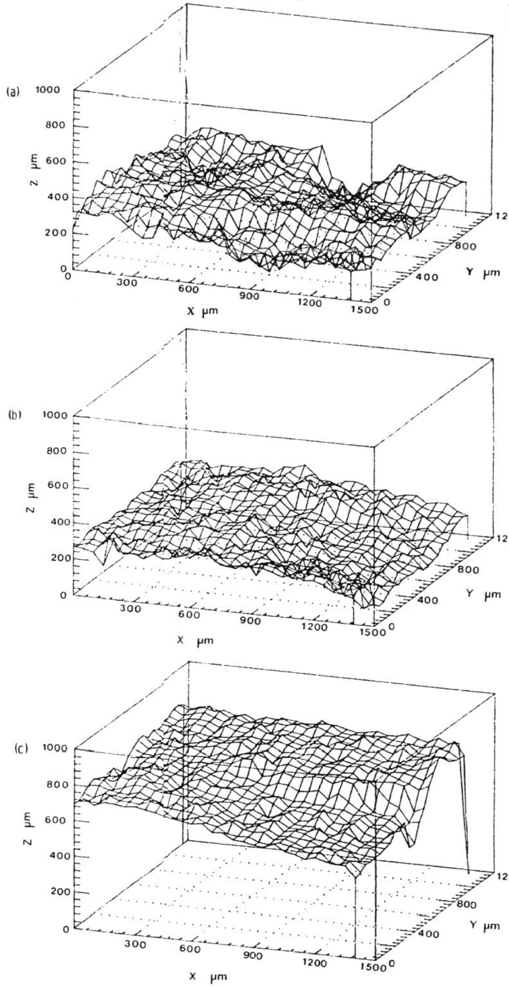


Fig. 5. Three carpet plots obtained from three fracture toughness specimens subjected to loading rates of a) 1.51, b) 2360, and c) 12800 MPa m/s.

Line profiles taken from each micrograph pair used to generate the maps are shown in the composite profile plot in Fig. 6. A trend of decreasing fracture surface roughness with increasing loading rate is clearly seen. Quantative measurements of surface roughness factors (R_S) or line roughness factors (R_L) can be easily extracted from the coordinate obtained through this method (Bryant, 1986).

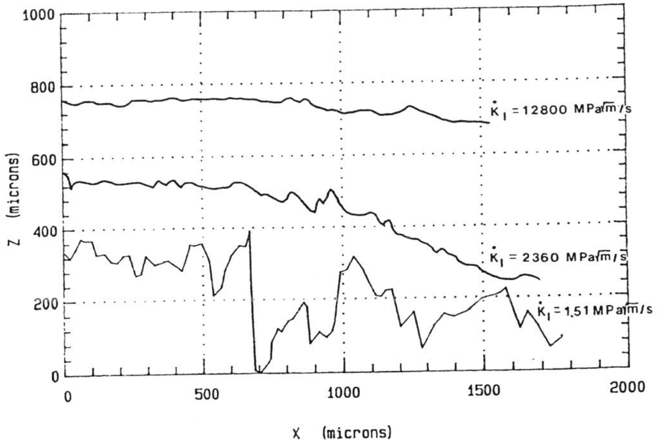


Fig. 6. Single profile traces (line traces) taken from the fractographic stereo pairs used to construct the plots of Fig. 5, showing the drop in fracture surface tortuousity with increasing loading rate.

SUMMARY

The method described has been successful in obtaining quantitative information regarding fracture surface topography by non-destructive means. It uses relatively inexpensive equipment and software. Calibrated topographic plots and line profiles can be determined from stereo micrographs with higher precision, reproducibility, and ease of collection than afforded through conventional methods.

Acknowledgments: The author wishes to thank Dr. H.G.F. Wilsdorf for his guidance in this work and the Office of Naval Research for their sponsorship of this project under contract N-00014-82K-0309.

REFERENCES

Banerji, K. (1988). Quantitative fractography: A modern perspective. Met. Trans. A, 19A, 961-971.

Bauer, B. and Exner, H.E. (1981). Quantification and reconstruction of spatial objects and surfaces by computer-aided stereometry. In: Proceedings of the 3rd European Symposium on Stereology, Ljubljana, Yugoslavia, pp. 255-262.

Bauer, B. and Haller, A. (1981). Determining the three dimensional geometry of fracture surfaces. Practical Metallography, 18, 327-341.

Bauer, B. Fripan, M., and Smolej, V. (1982). Three-dimensional fractography. In: Proceedings of the 4th European Conference on Fracture, pp. 591-598, Chameleon Press Ltd., London U.K.

Boyde, A. (1973). Analysis of SEM images. J. of Microscopy, 98 (3), 452-473.

Bryant, J.D. (1986). Semi-automated topographic mapping of fracture surfaces through stereo-photogrammetry. In: Micron and Microscopica Acta, 17, (3), 237-242.

Coster, M., and Chermant, J.L. (1983). Recent developments in quantitative fractography. Int. Metals Review, 28 (4) 228-250.

Crone, D.R. (1968). In: Elementary Photogrammetry, pp. 131-160, Frederick Ungar, New York.

Fior, G.O. and Morris, J.W. Jr. (1986). Characterization of cryogenic Fe-6Ni steel fracture modes: A three dimensional quantitative analysis. Met Trans. A, 17A, 815-821.

Howell, P.G. (1980). Stereometry as an aid to stereological analysis. J. of Microscopy, 118 (2), 217-220.

Kobayashi, T. and D.A. Shockey (1984). Environmentally accelerated cyclic crack growth mechanisms in reactor steel determined from fracture surface topography. In: Fracture: Interactions of Microstructure, Mechanisms and Mechanics, J.M. Wells and J.D. Landes, eds. pp. 447-462, AIME, Warrendale, PA.

Simov, S., Simova, E., and Davidkov, B. (1985). Electron microscope study of surface topography by geometrical determination of metric characteristics of surface elements. J. of Microscopy, 137 (1), 47-55.

Underwood, E.E., and Banerji, K. ( ). Quantitative fractography. In: ASM Metals Handbook, 9th ed., Vol. 12, pp. 193-210, ASM International, Metals Park, OH.