A CONTRIBUTION ON THE PHOTOGRAMMETRIC DETERMINATION OF THE CRITICAL CRACK-TIP-OPENING DISPLACEMENT

M. GRUBER and O. KOLEDNIK
Technische Universität Graz, Abteilung für Fernerkundung, Bildverarbeitung und Kartographie, Graz, Austria
Erich Schmid-Institut für Festkörperphysik der Österreichischen Akademie der Wissenschaften, Leoben, Austria

Abstract: The critical crack tip opening displacement (CODi) which characterizes the fracture toughness of engineering materials is determined by using stereo images from the scanning electron microscope (SEM). The surface pair of the stretched zone region is analyzed and documented in three dimensions. Further the parameters of the photogrammetric task and the accuracy of the measurement are presented.

Zusammenfassung: Die quantitative Untersuchung der Bruchoberflächen und die Bestimmung geometrischer Größen in diesem Bereich, insbesondere der Rißöffnungsverschiebung, ist für die Erforschung von Bruchvorgängen sehr wichtig. Im folgenden werden zwei Bruchmechanikproben anhand der vorliegenden rasterelektronenmikroskopischen Aufnahmen untersucht und die Oberfläche der jeweiligen Bruchhälften photogrammetrisch ausgewertet. Die mikroskopische Aufnahme erfolgte durch Kippen der Proben stereoskopisch und erlaubt daher eine räumliche Vermessung. Durch die Identifikation identer Punkte auf den zugehörigen Probenhälften wird die geometrische Beziehung zwischen beiden Oberflächen hergestellt. Der Vergleich von Querprofilen an der Rißfront führt zur quantitativen Bestimmung der Rißöffnungsverschiebung, die als Kenngröße für die Bruchzähigkeit der Probe dienen kann.

Introduction

The fracture toughness of a metallic body depends primarily on the amount of the plastic deformation energy which must be put into the body to produce an increment of crack extension. For a fracture under small-scale yielding conditions the plastic deformation is confined to a region close to the new fracture surfaces. The plastic deformation can be detected by putting together the broken pieces of the body and measuring the misfit between the upper and the lower fracture surfaces. This can be done by making stereo image pairs of the two fracture surfaces in the scanning electron microscope (SEM) and analyzing corresponding regions on the photograms [2]. In [3] this method was applied to measure the critical crack tip opening displacement CODi, for a ductile fracture. CODi (which is the maximum displacement which appears at the tip of a fatigue pre-crack before the crack begins to grow) is a measure of the fracture thoughness of the material. It is the purpose of the current investigation to detect the misfit between the two fracture surfaces of a transcrystalline brittle (cleavage) fracture and to determine CODi.

Material

The material investigated is an annealed structural steel with 0,17% C. The microstructure consists of ferrite grains (with a mean intercept length of 17 μm) with small carbide particles and great number of elongated MnS-inclusions inbedded.

At room temperature the yield strength and the ultimate tensile strength were about σ_{YS} = 298 MPa and σ_{UTS} = 426 MPa. At -196° C the tensile test gave a fracture strength of σ_{UTS} = 990 MPa without any macroscopic plastic yielding.

Testing Procedure

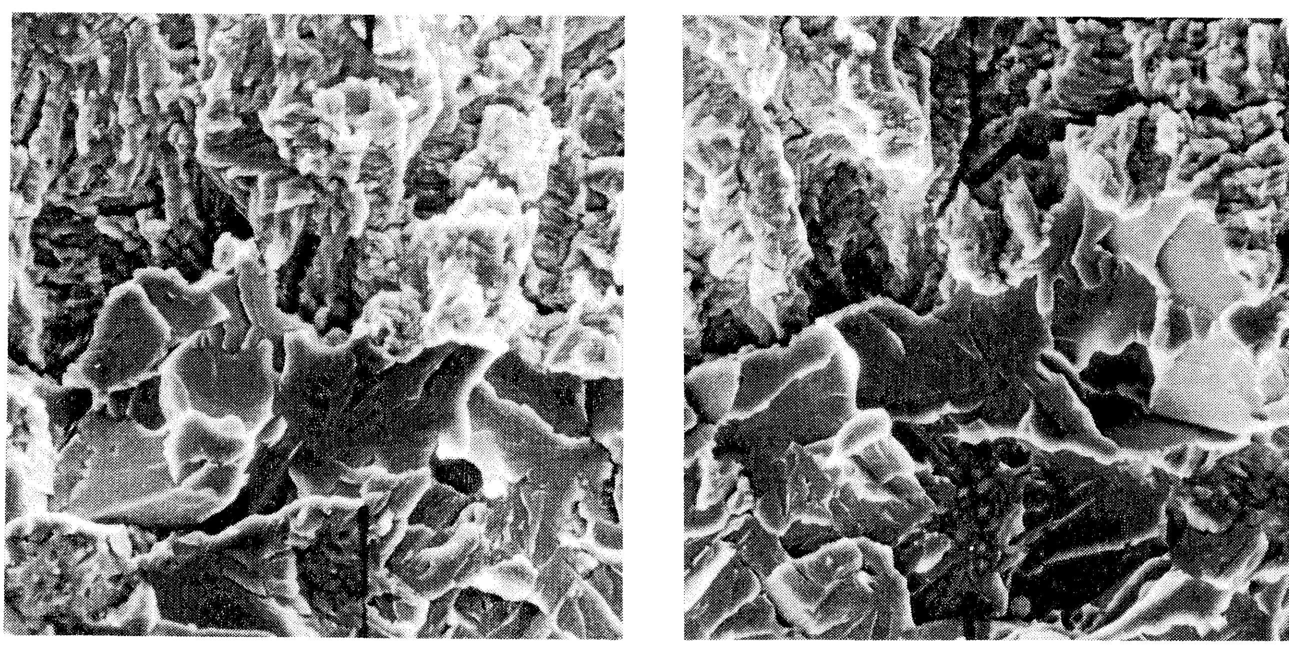
From this material two fracture mechanics specimens (CT1-specimens) were machined with a ST-crack plane orientation, i.e. the MnS-inclusions are directed parallel to the crack front. Specimen I was both precracked by fatique and broken up in liquid nitrogen (-196° C), Specimen II was precracked at room temperature and broken up in liquid nitrogen. During the final stages of the precracking the maximum stress intensity range was $\Delta K_f \sim$ 13,7 MPa m (for Spec. I) and $\Delta K_f \sim$ 15,8 MPa $\sqrt{m}$ (for Spec. II), respectively. The fracture toughness of the two specimens were a little bit different: in terms of the critical stress intensity K_{IC} = 25.2 MPa $\sqrt{m}$ for Spec. I and K_{IC} = 29.6 MPa $\sqrt{m}$ for Spec. II.

From the corresponding regions near the midsection of each specimen half stereo image pairs were produced by the tilting method with a scanning electron microscope (SEM).

The magnification scale of the SEM-micrographs was about 1000 x and the tilting angle was 10°. This leads to stereo models, which give an acceptable accuracy and intersection qualitiy for stereoscopic measurement on an analytical plotter.

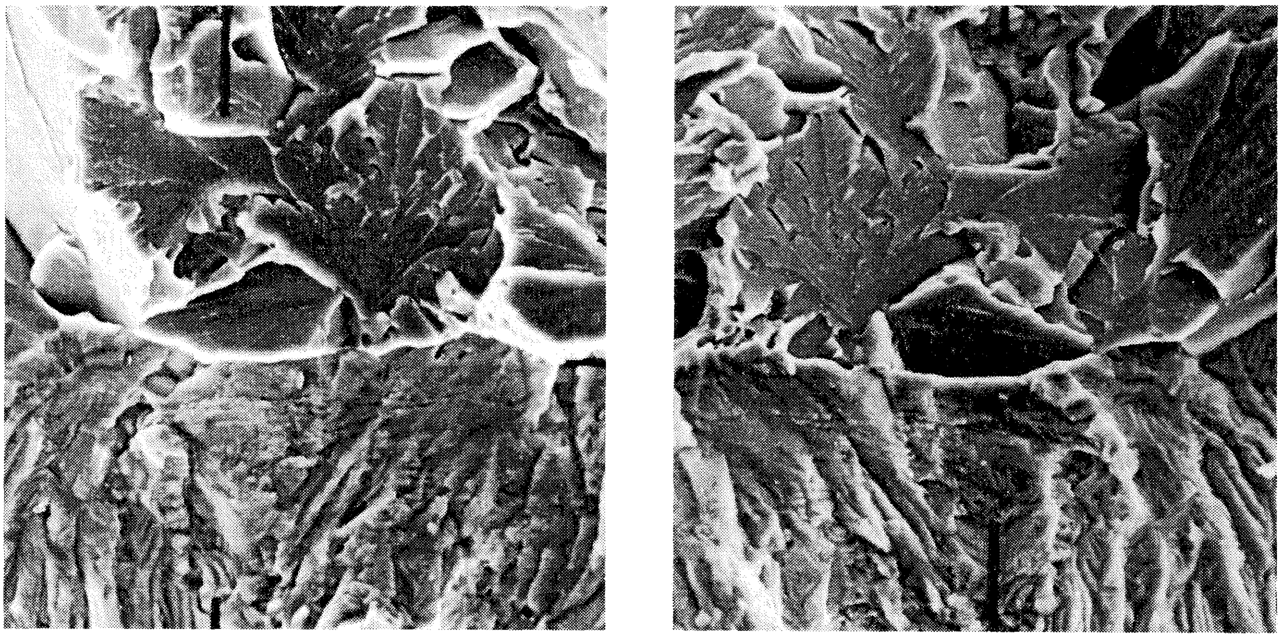
Photogrammetric Orientation

The photogrammetric orientation of the stereo models was done on a KERN-DSR analytical plotter and yielded a 3-dimensional local coordinate system. The main task of the current investigation was to find the orientation of the two halves of the specimen relatively one to another. The accuracy of this depends on the possibility of finding conjugate points on both surfaces of the two counterparts. The selection of these points was done under the influence of a plastic deformation of the specimen during the cracktest. That means, that only small undeformed structures can be used. The region inside of some cleavage facets was appropriate for that purpose and a number of 15 - 20 corresponding points could be defined on both parts. It is necessary to remark, that the destortion of the microscope (which was determined with a calibration grid) was found to be smaller than the pointing accuracy. The tilting angle between the stereo images was taken as an instrument-parameter directly from the microscope.



a b

Fig. 1 SEM - Micrograph of Specimen I at a magnification of about 1000 x, broken in liquid nitrogen: (a) side 1, (b) side 2.



a b

Fig. 2 SEM - Micrograph of Specimen II at a magnification of about 1000 x, precracked at room temperature and broken up in liquid nitrogen: (a) side 1, (b) side 2.

The accuracy of the orientation of the specimen halves can be documented by the amount of the remaining differences between the coordinates of the control points. The similarity of the two surfaces is better presented by the comparison of the plots of the photogrammetric measurements. The figures below show the situation of specimen I and II. For specimen I two groups of conjugate points have been selected, one on the left half and one on the right half of the specimen. For each group the differences between the coordinates of the measured points are smaller than 0.5 µm. Because of the plastic deformation it was not useful to compare the whole surfaces of the pieces. The remaining differences in that case would be some 3 to 5 µm, too large for the current task.

Measurement of Profiles

Based on the orientation results the measurement of conjugate profiles was performed. These profiles were analyzed on both specimen halves perpendicular to the fatique-crack front to evaluate CODi.

First the profiles were measured on one surface, then the corresponding profile points could be remeasured using the known X and Y coordinates and this yielded to the corresponding height values. The accuracy of correspondence in X and Y coordinates was better than 0,5 µm and allows an accurate determination of the hight differences.

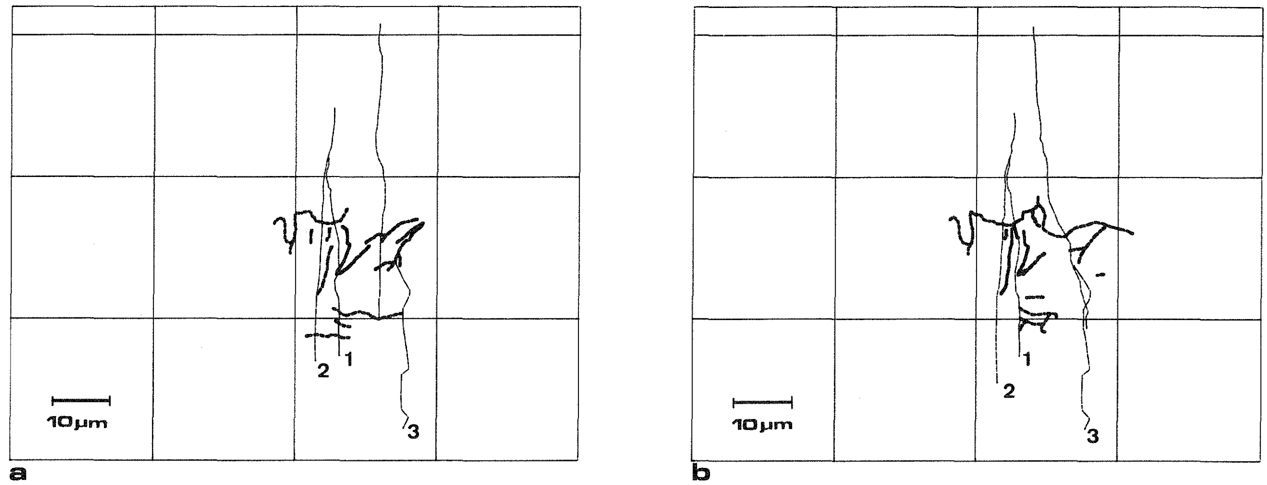


Fig. 3 Plot of the photogrammetric measurement of the specimen surface of Specimen I (a) side 1, (b) side 2.

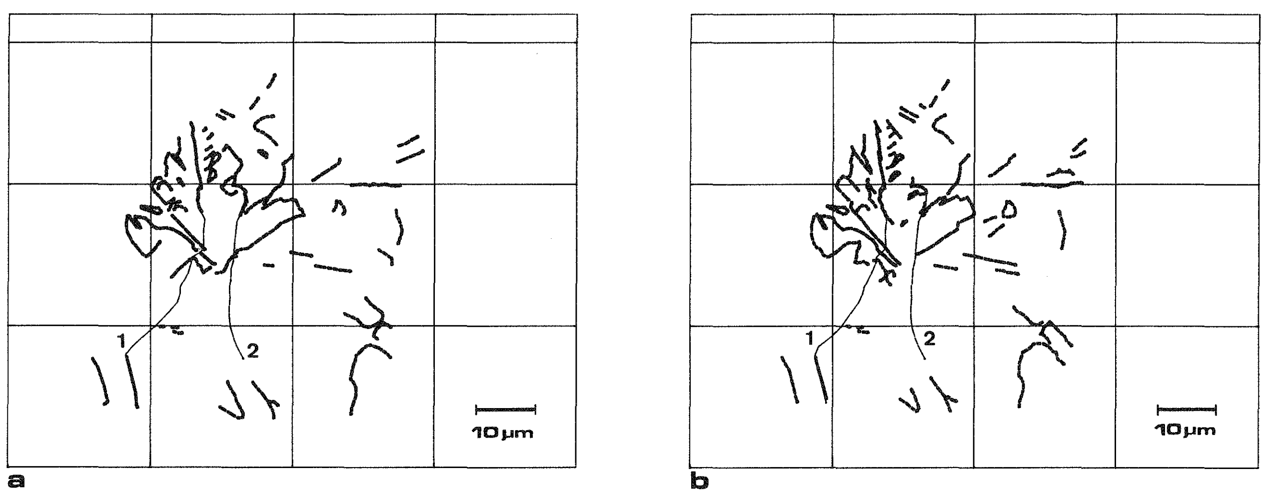


Fig. 4 Plot of the photogrammetric measurement of the specimen surface - left region of Specimen II. (a) side 1, (b) side 2.

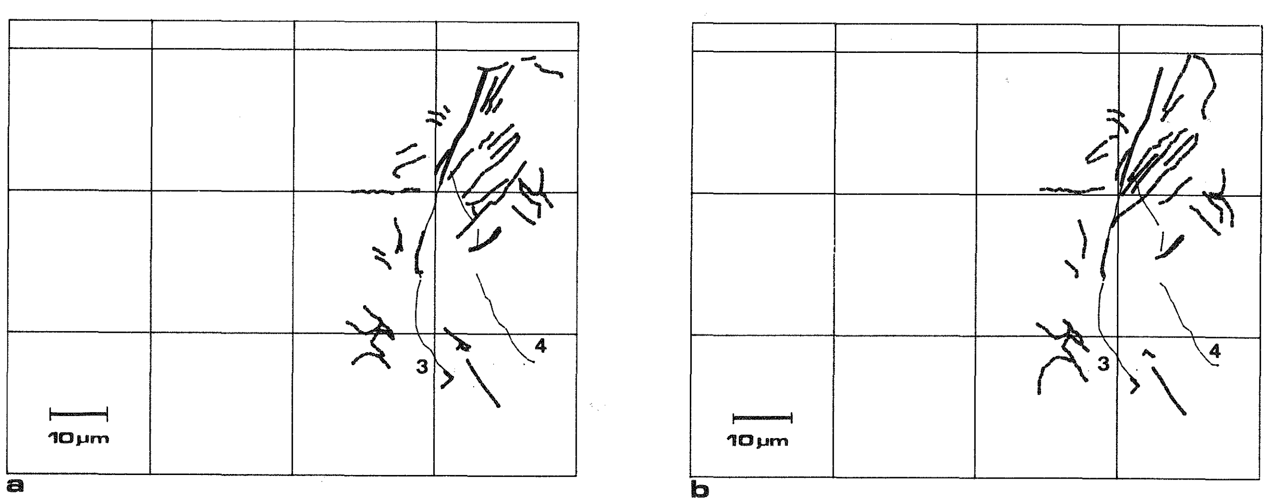


Fig. 5 Plot of the right region of Specimen II. (a) side 1, (b) side 2.

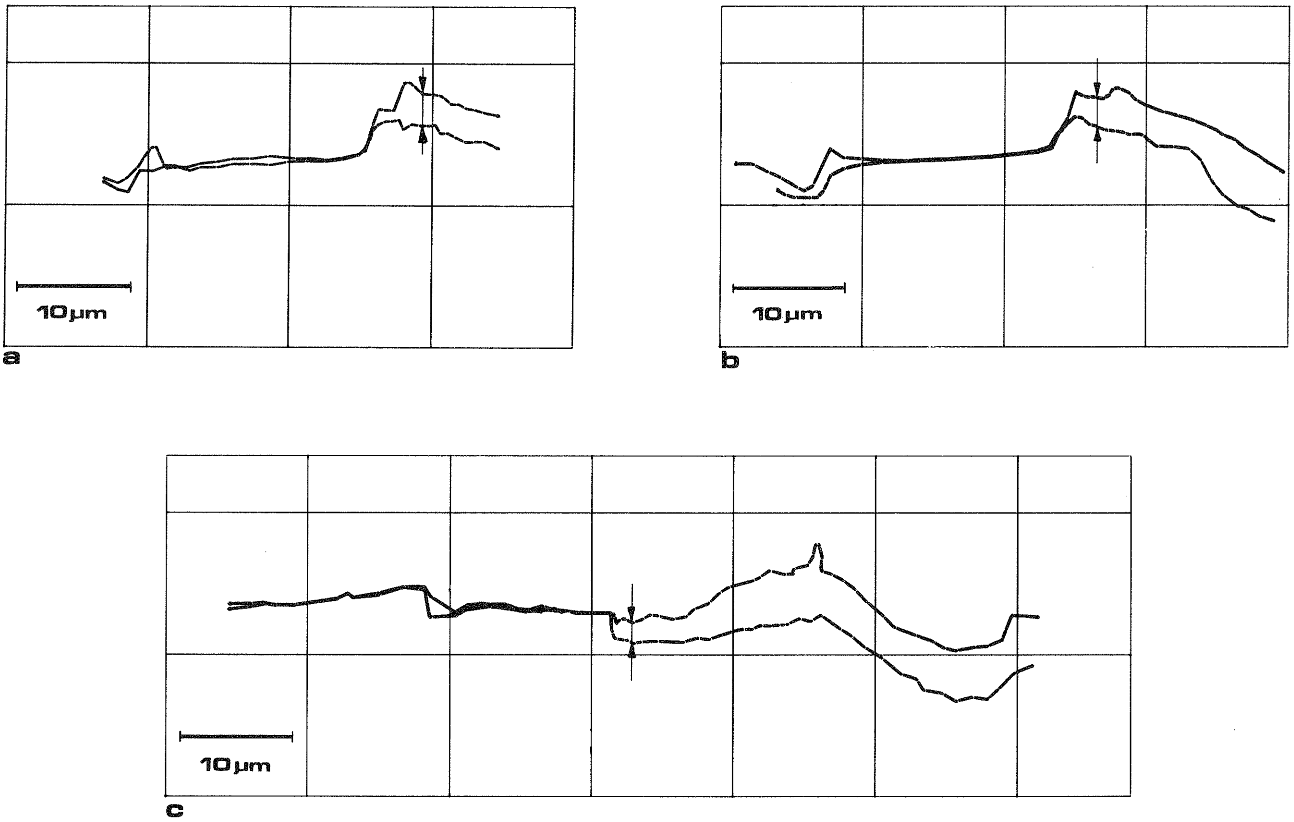


Fig. 6 The corresponding profiles of Specimen I and the CODi, determined near the fatique crack front (arrows). (a) profile 1, (b) profile 2, (c) profile 3.

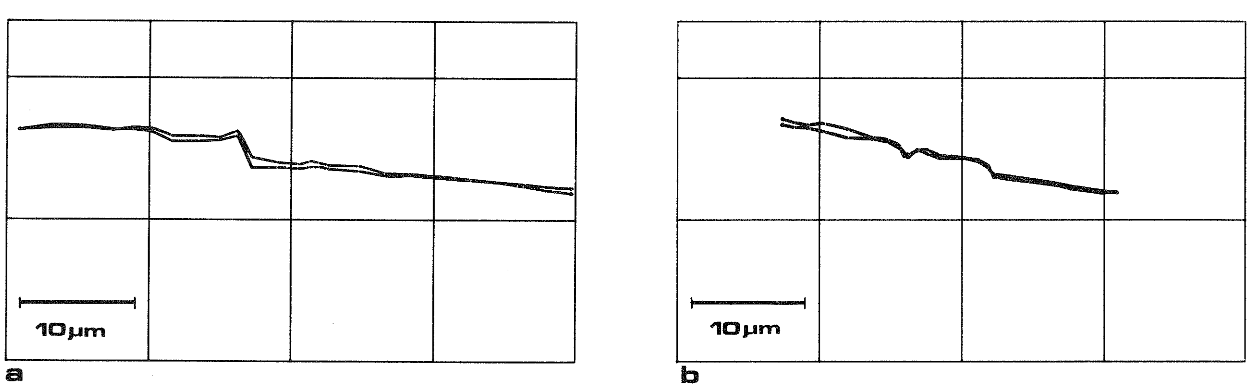


Fig. 7 The corresponding profiles of Specimen II, left side. The specimen was precracked and broken up at -196° C. The CODi value is smaller than the accuracy of the measurement. (a) profile 1, (b) profile 2.

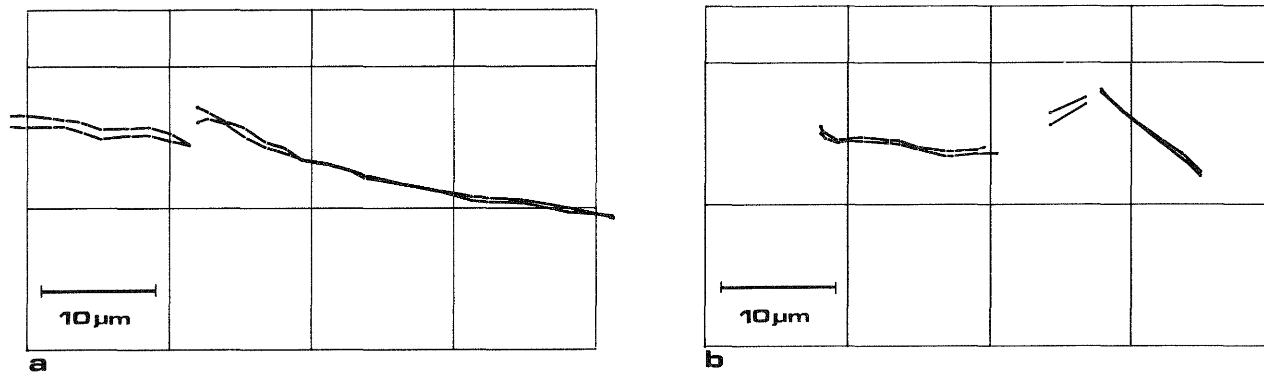


Fig. 8 The corresponding profiles of Specimen II, right side. The specimen was precracked and broken up at -196° C. The CODi value is smaller than the accuracy of the measurement. (a) profile 3, (b) profile 4.

The profiles are presented in the following figures and give a rather good impression, of how the CODi values differ between the two specimens investigated. The CODi of specimen I is very small, only of the order of the accuracy of the analyzing method. The CODi of specimen II is larger by a factor 4.

Discussion

From the view of fracture mechanics the most interesting result of this investigation is that the mode of precracking has only a little effect on the critical stress intensity (as it should) but a large effect on the critical crack tip opening displacement. So it seems that the measured COD of Specimen II was formed already during the precracking. If the breaking in liquid nitrogen produced this COD, the CODi of Specimen I would be not so different from the CODi of Specimen II. But the physical reason of this effect is not fully understood up to now and should be subject of future investigations.

The measurement method using stereo images from the scanning electron microscope is accurate and effective to compare the fracture surfaces of the specimen halves. This depends mainly on the possibility of identifying corresponding points, profiles and structures on the conjugate surfaces. The material presented in this paper was very suitable for that task and promises good results with specimen of similar structured surfaces.

References

[1] S.K. Gosh, Photogrammetric calibration of a scanning electron microscope. Photogrammetria 31 (1975) 91-114.

[2] O. Kolednik, A contribution to tereophotogrammetry with scanning electron microscope. Practical Metallography 18 (1981) 561-573.

[3] O. Kolednik and H.P. Stüwe, The stereoscopic determination of the critical crack tip opening displacement. Engineering Fractrue Mechanics 21 (1985) 145-155.