MICRO-FRACTOGRAPHY OF CLEAVAGE FRACTURE BY EBSP TECHNOLOGY AND COMPUTER ASSISTED STEREOPHOTOGRAMMETRY

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A new method was developed to study the micro-fractography of cleavage fracture. The method is based on the information fusion of EBSP (Electron Back Scatter Diffraction Pattern) technology and computer assisted stereophotogrammetry. It enables to crystallographically index cleavage planes as well as directions on individual cleaved facets.

Introduction

A comprehensive model to explain the initiation and propagation of cleavage fracture has not yet been developed [1]. In order to investigate this type of fracture and the micromechanisms involved fractography is often applied to study cleaved facets. Common tasks in this respect are to trace river patterns to determine crack propagation directions and to search for cleavage fracture initiation sites. The distance of the latter regarding a stress concentrator such as a fatigue precrack is then measured in order to calculate a critical fracture stress. From fractography it is also known that under same test conditions the appearance of the fracture surface and the features on it depend on the cleavage plane as well as on the crystallographic crack propagation direction [2]. For a bcc metal several cleavage planes are theoretically possible [3]. Therefore a thorough fractographic analysis has to include a method by which cleavage planes as well as directions on such planes can be determined.

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In order to reach this goal the orientations of cleaved grains have to be determined as well as their location in space. For the former task we use the EBSP (Electron Back Scatter diffraction Pattern) technique in the Scanning Electron Microscope (SEM). Computer assisted stereophotogrammetry is used to get a 3-dimensional digital elevation model (DEM) of the fracture surface. With the „information fusion" of EBSP's and DEM's we are able to crystallographically index cleavage planes as well as directions on individual cleavage facets. We call this crystallographic and topometric fractography. In the following the methods will be described shortly and afterwards two typical examples will be presented.

2.) EBSP Technology and Computer Assisted Stereophotogrammetry

In the SEM we determine the orientations of single grains by the EBSP (Electron Back Scatter Diffraction Pattern) method [4]. The main advantage of this method is a fast determination of the orientation with a geometrical resolution in the submicron range and an angular resolution of less than 1° for relative orientation relations. This is superior to other methods previously used in the SEM such as the selected area channelling technique or the Kossel X-ray method.

The principle of the technique is that the electron beam is focused in spot mode on the surface of a tilted specimen which results in an interaction between the incoming electrons and the crystal lattice of the specimen. One product of this interaction is that incoming inelastically scattered electrons are elastically back scattered. The latter form diffraction cones which can be viewed on a phosphor screen and recorded by a sensitive camera. The appearing bands on the EBSP's are similar to Kikuchi Lines known from transmission electron microscopy. In [4] a detailed description how to determine the orientation was presented and in [5] the used experimental set-up was shown in more details.

To determine the 3-dimensional location in space of the cleaved facets we use computer assisted stereophotogrammetry. Images are recorded in the SEM under different angles with a resolution of 1024x768 pixels and the corresponding stereo images are implemented in an image processing package called XLTT (eXpandable Light Tablett Tool) which automatically matches corresponding points of stereo pairs and calculates the parallaxes. This is described in [6] in more details. The result is a 3-dimensional DEM of the fractured surface which contains typically 10 000 to 20 000 points. The time needed for a typical DEM is less than 10 minutes on the currently used UNIX workstation.

For the „information fusion" of both techniques a co-ordinate transformation has to be done, i.e. the EBSP and the DEM have to be related to a common reference co-ordinate system. About the exact procedure and the accuracy [5] gives more details. To index a plane data points from the DEM of this plane must be extracted. Through these points a least square fitted plane will be laid. From the EBSP measurements we get an orientation matrix which transforms space co-ordinates to crystal co-ordinates. The normal vector of the calculated plane times the orientation matrix gives then the crystallographic indexes of the plane. To index directions on cleavage facets a similar approach is followed. In this case the vector of the direction in the DEM is used.

3.) Experimental Results

3.1.) Testing Details

According to ASTM 399 we performed standard fracture mechanics tests on pre-fatigued CT specimens (a/W ratio 0.5) at 77°K. As a model material we used bcc Armco iron with a grain size between 700 - 800 μm. The chemical composition of the material is shown in the following table.

Element	C	Mn	Si	P	S	Cu	Cr	Ni
wt %	0,007	0,08	0,008	0,015	0,015	0,01	0,01	0,03

Tab.1: Chemical analysis of Armco iron, rest Fe.

As we were just interested in the process of the fracture initiation the tests were stopped after the first cleavage fracture propagation. To detect this we used the back face strain technique as described in [7]. The specimen was then fractured by fatigue.

3.2.) Examples of the crystallographic and topometric fractography

As a first example the crystallography of a tongue on a cleavage plane is investigated. The tongue is the protrusion on the cleavage plane in Fig.1. The points indicate sites of EBSP measurements. Two different orientations were determined. One for the points (1,5,7) lying on the cleavage plane and one for the points (2,3,4,6) on the tongue. The misorientation between the cleavage plane and the tongue lies close to

60° around a [111] vector which already indicates a twin relation. The necessary topometric information is gained from the DEM of that area. Combining the orientation with the calculated normal vector from a fitted plane gives the crystallographic indexes. We determined for the cleavage plane (0 0 $\bar{1}$) and for the plane of the tongue (1 1 $\bar{2}$). The common rotational axes between cleavage plane and tongue is [$\bar{1}$ 1 0]. The DEM including the determined indexes is shown in Fig.2.

Another cleaved grain is shown in Fig.3. The cleavage plane is again of {001} type. For this grain the indexes of the fracture markings shall be determined. The black line in the centre is an example of a base line which was used to calculate the vector of this line. The evaluated crystallographic indexes are superimposed along the markings which proves the definite crystallographic nature of them. The two main intersecting lines are parallel to the common axes between a {001} cleavage plane and a {112} twin plane, i.e. they are of a <110> type. This is for instance confirmed by the tongues on the lower right part of the image. Two secondary cracks on the lower right side of the image have a [0 0 $\bar{1}$] direction. This implies a secondary cleavage along a {001} plane. Finally other markings on that image were determined to be of <102> type which is also a possible common axes between a {001} cleavage plane and a {112} deformation twin. However, the twins on that grain do not have this crystallographic type as a common axes.

Conclusions

The information fusion of EBSP's and DEM's yields a smart method to investigate cleavage fracture facets. We call this a crystallographic and topometric fractography which enables to crystallographically index planes as well as directions on cleaved grains. In the present paper a tongue was determined to be a {112} deformation twin on a {001} cleavage plane. Furthermore several fracture markings on a {001} plane were found to have a precise relation with the crystallography between twins and cleavage planes.

Acknowledgements

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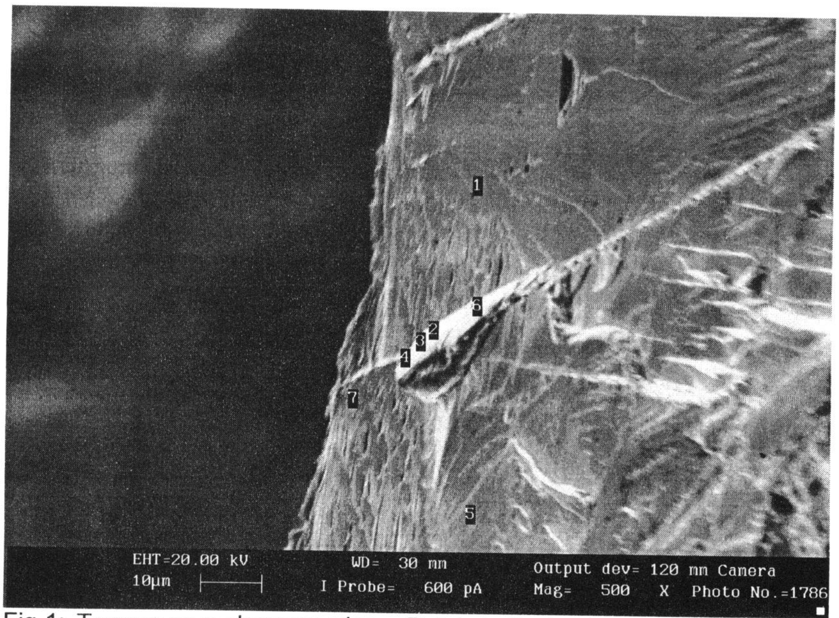

Fig.1: Tongue on a cleavage plane. Points indicate sites for EBSP measurements

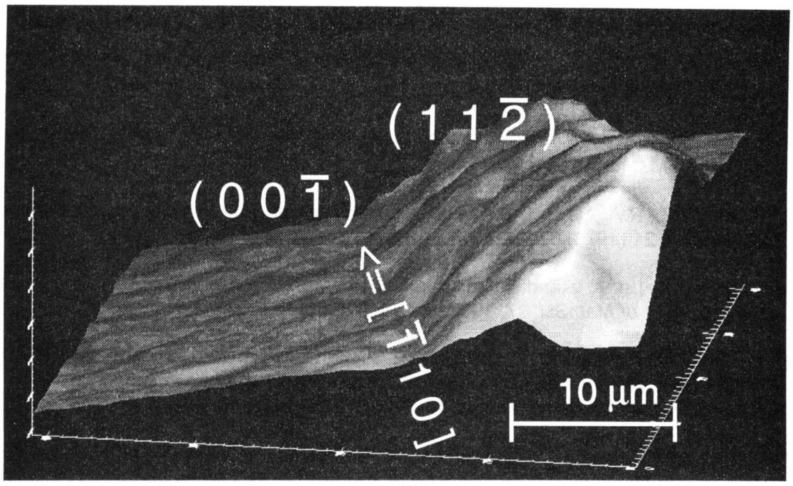

Fig.2: DEM of the tongue of fig.1 with superimposed crystallographic indexes.

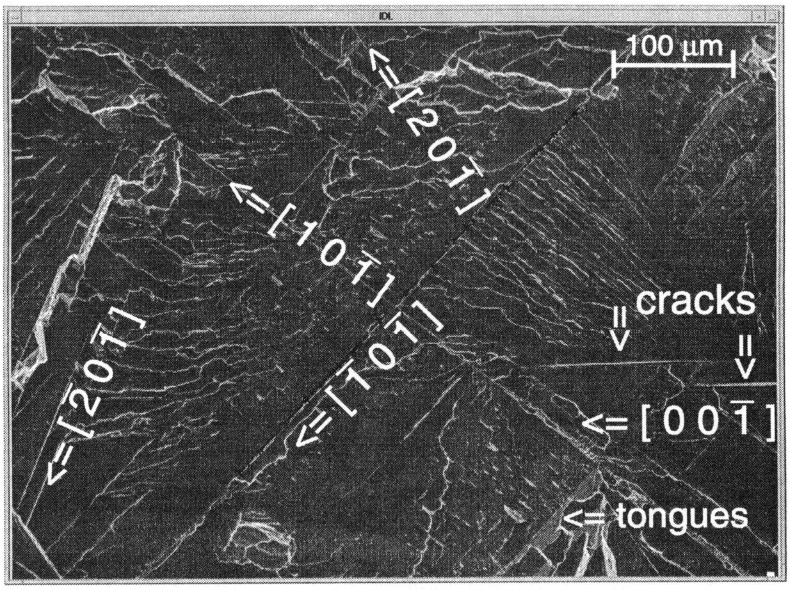

Fig.3: Crystallographic indexes of fracture markings on a {001} cleavage plane.