SOME OBSERVATIONS OF FRACTURE SURFACES OF Fe-Si ALLOY SINGLE CRYSTALS

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In studying the fracture of single crystals it is very important to observe the fracture surfaces of the broken specimens. That can provide an additional insight into the fracture process itself, as well as the reasons why it occurred at all. This is the subject of this paper which will present some considerations about three features observed on fracture surfaces of single crystals specimens made of Fe-Si alloy (2.7 and 3.0 % of Si). Those are: the difference in the crack growth directions on the microscopic and macroscopic levels, the secondary cracking, and the points (or reasons) where (and why) the fracture started.

INTRODUCTION

As it is well known single crystals, as well as all crystalline materials in general, can deform only on *slip systems*, i. e., on certain crystallographic planes - the *slip planes* and in them only along certain directions - the *slip directions*. This is the cause of the "difference" in crack growth directions on microscopical and macroscopical level. Sometimes the crack is forced, by the direction of loading, to deform in certain direction, which is different from the crystallographically allowed direction along the slip direction.

Another interesting feature observed on some broken specimens was the phenomenon of secondary cracking. It can be observed how the crack is kinking for 90 degrees several times leaving the behind at each "shoulder" secondary crack of the same direction.

On certain fracture surfaces, by careful observations, one can clerly notice

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the point where the fracture of the whole "rest" of the cross section of the specimen started. The reason for that is either some previously existing small initial crack, or some damage due to cutting in the notch on the specimen, or some other cause, like impurity, inclusion, etc.

EXPERIMENTAL DETAILS

Specimens were single crystals of Fe-Si alloy which contained 2.7 and 3 % silicon. They were obtained from the Max Planck Institute, Duesseldorf, Germany. Experiments were conducted at Research Laboratory of Instron Corporation at Canton, Massachusetts, USA. Two specimens broke during the fatiguing precracking, since they were prenotched and prepared for the four point bending test, and two brore during the four point test itself. The crack orientations and other experimental details are presented in Table 1, Nikolić(1).

TABLE 1 - Experimental details of the five considered specimens

SPECIMEN #	% Si	CRACK PLANE	CRACK TIP ALONG	CRACK GROWTH DIRECTION	SPECIMEN BROKE DURING
1	2.7	$(\bar{1}10)$	[111]	[112]	DID NOT FRACTURE*
2	3.0	(010)	$[\bar{1}01]$	[101]	FATIGUE PRECRACKING
3	2.7	(001)	[100]	[010]	FATIGUE PRECRACKING
4	2.7	(001)	[100]	[010]	FOUR-POINT BENDING
5	3.0	(010)	$[\bar{1}01]$	[101]	FOUR-POINT BENDING

RESULTS AND DISCUSSION

Figure 1 presents the side surface of the specimen # 1 showing the fatigue crack. The crack is growing in the zig - zag way along the slip plane traces forming the macroscopical - "required" growth direction. This specimen did not brake (*), and this picture is presented only to show the difference in growth directions on macroscopical and microscopical levels. Figures 2 (specimen # 2) and 3 (specimen # 3) show that the blocks of material on the fracture surfaces are either parallel to or make an angle with the macroscopical crack growth direction, depending whether the macroscopical and crystallographically possible directions coincide or not, respectively. An attempt was done (Nikolić (2)) to explain this phenomenon as a function of the slip plane traces directions positions with respect to lines of discontinuities between the constant stresses sectors in the full solution for the stress field around the crack tip given by Rice (3). If the slip plane traces are parallel to the stress sectors boundaries the deformation is the regular shear, the dislocations are easily emitted from the crack tip, and the material "blocks" are parallel to the macroscopical crack growth direction (Figure 2). If the slip plane traces are perpendicular to the stress sectors boundaries the deformation is of the kink-type shear, an additional source of dislocations is needed, and the material "blocks" make an angle with the macroscopical crack growth direction (Figure 3).

Another interesting feature was observed broken specimen # 3. This was the phenomenon of secondary cracking, Figures 4 and 5. It can be observed how the crack was kinking for 90 degrees several times leaving behind at each "shoulder" secondary cracks of the same direction. From details in Figures 5a and 5b can clearly be observed how the small secondary crack is displaced for the whole crack opening displacement whenever the crack is crossed by an active slip plane. This is better observed in details shown in Figures 5c and 5d. This supports the theory that the crack should arrest at the slip line. Slip lines here disturb small secondary cracks that are in that way losing the energy to propagate.

Figures 6 and 7 show the complete fracture surfaces of two specimens of the same orientation, specimen # 3 and 4, respectively. Here one can observe where the fracture starts on the fracture surface itself. Figure 6 shows the fracture surface of one half of the specimen that was broken during the fatigue precracking. It can clearly be observed that there was a small fatigue crack of about 500 microns and that then the fracture continued in the brittle manner across the rest of the ligament. Another important feature is that the front of the fatigue crack is wavy and the angle is neither 180° nor 45 ° (angles of the slip plane traces). It is obvious that the crack front tended to position itself in the microscopically preferred [110] but the speed of growth was too large for it to achieve taht. Thus the fatigue crack remained wavy with the angle of approximately 15 to 20 degrees with respect to the notch front.direction. Figure 7 shows the fracture surface of one half of the specimen that was broken during the four point bending test. There are two reasons for this. The first is that the specimenwas loaded at room temperature, and this orientation of the crack is considered brittle. The second reason is that there was a crack-like flaw in the material probably introduced by spark cutting of the notch. It can be seen that the whole fracture had started from point where the notch was "indented". The fracture spread from that point across the whole ligament in the brittle manner, (Detail A in Figure 8).

Figures 9 to 11 show the whole fracture surface and two details of it, respectively of specimen # 5, which was of the brittle orientation though it broke in a more or less ductile manner. The specimen was cyclically loaded and unloaded in four point bending, without reversing the bending moment and it broke after 14 cycles. Figure 9 shows the SEM micrograph of the whole fracture surface. The strong necking due to ductile deformation can readily be observed. An interesting feature is shown in next two figures. The material was torn from the surface in such a manner that we can easily make a distinction of the ductile and brittle part of breaking. In the analysis done with the stereo-pair it was concluded that the planes before and after the ductile part of breaking (the white ridge) are on the different levels. The crack thus changes the planes of fracture. They are the planes of the same orientation but at different heights with respect to the original notch surface.

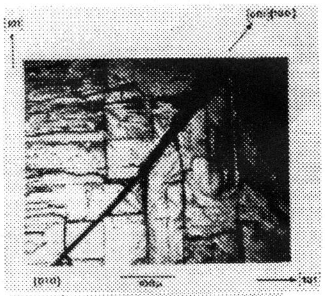
CONCLUSION

In this paper are presented some of interesting features observed on the fracture surfaces of several single crystals specimens made of Fe-Si alloy. Those are: the difference in crack growth directions on microscopical and macroscopical levels, the phenomen of secondary cracking, and points of the fracture initiation on the fracture surface itself. This paper presents an attempt to describe those features and to give plausible explanations for them. This is specially important for the first feature.

REFERENCES

(1) Nikoli}, R. R., "Experimental Study of Crack Tip Processes and Plastic Flow in Ductile Crystals", Doctoral Dissertation, Harvard University, Cambridge, Massachusetts, USA, 1989.

(2) Nikoli}, R. R., Proc. of the Scientific Meeting "Mechanics, Materials and Constructions", Serbian Academy of Sciences, Belgrade, 1995. pp. 55-56.



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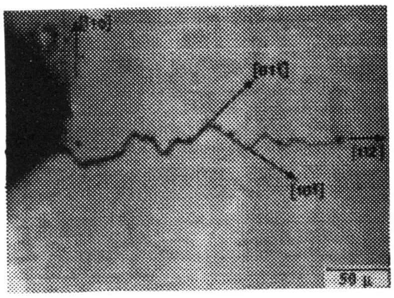

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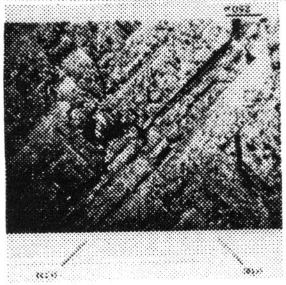

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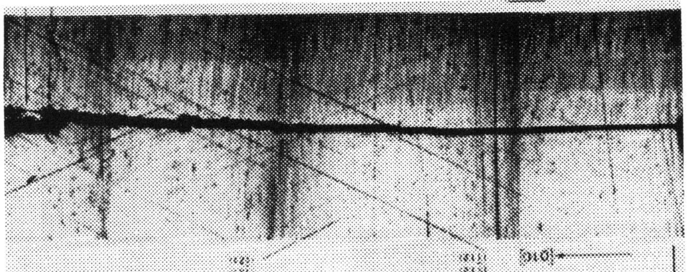
Figure 1 Side surface of specimen # 1

Figure 2 Fracture surface of specimen # 2

Figure 3 Fracture surface of specimen # 3



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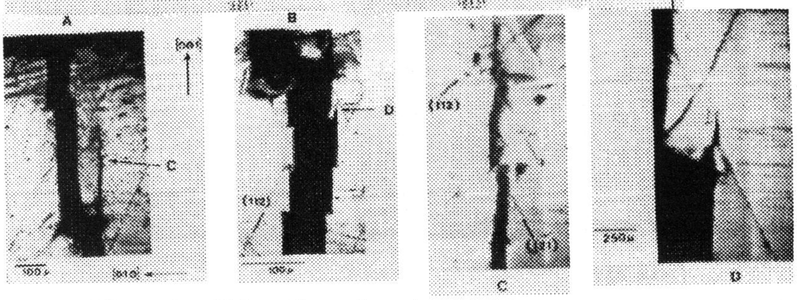

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Figure 4 Side surface of specimen # 3

Figure 5 Enlarged details of side surface of specimen # 3

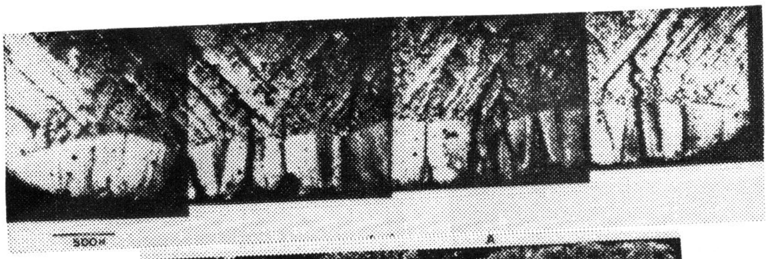

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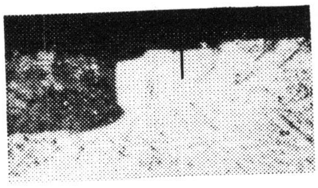
Figure 6 Complete fracture surface of specimen # 3
Figure 7 Complete fracture surface of specimen # 4



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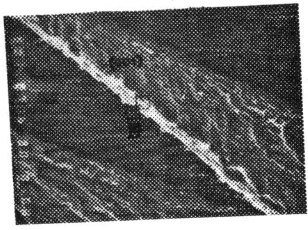

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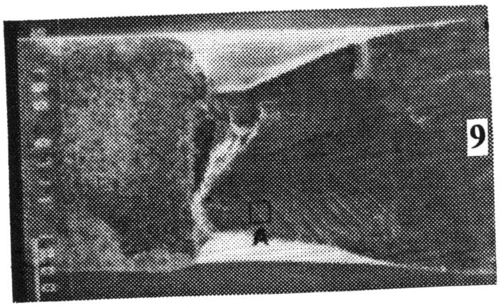

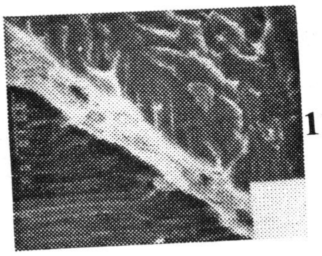

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Figure 8 Detail A of fracture surface of specimen # 4
Figure 9 Complete fracture surface of specimen # 5

Figure 10 Detail A
Figure 11 Detail B