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EXAMINATION OF SAMPLES FROM DIPPER STICK OF A BUCYRUS-ERIE 280-D SHOVEL

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Examination of samples from a failed dipper stick from a Bucyrus-Erie 280-D shovel revealed a multiplicity of fatigue cracks all originating in surface areas damaged by galling due to lubrication failure. No cracks were associated with welds. The tensile properties and chemical composition of the unaltered metal showed that the material essentially conformed to the requirements of ASTM A203, Grade B.

It was recommended that lubrication practice be improved to eliminate galling. It was suggested that care be taken to avoid accidental arc strikes and that if one occurred it be repaired with all the welding precautions appropriate to the metal and circumstances. It was further suggested that the alloy not be changed, at least until the effectiveness of the recommended improvements can be established.

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INTRODUCTION

In a telephone conversation of 14 April, 1965, Dr. H. Marquis of the Iron Ore Company of Canada, requested an examination of fractures of a dipper stick from a Bucyrus-Erie 280-D shovel. The request was confirmed by a letter of 21 May, 1965, from Mr. K. R. Kilburn, Maintenance Engineer. On 15 July, 1965, two sets of samples were received from Labrador. One set was identified as a mantle head nut, the other as crusher concaves. A separate request covering such samples was on hand. A letter from Mr. Kilburn of 23 November, 1965, established that the samples identified as crusher concaves were actually those from the dipper stick referred to in the conversation of 14 April. The investigation then proceeded on this new basis.

The Iron Ore Company was interested in establishing:

"1. Confirmation of the type of material used in fabrication of the part.

2. How the current mechanical properties compare with those of the original material.

3. What metallurgical changes have been wrought by heat-treatment, service and welding.

4. What material and heat-treatment might give better service."

The location of the samples in the unit and especially their relationship to the failure were not given.

VISUAL EXAMINATION

The samples are shown in Figure 1. The identification letters were torch-burned into the surface to a depth of about 1/4 inch. Total thickness of the material was 1-7/8 inches. The size of the letters and the extent of heat affected zone rendered much of the material unsuitable for determining the original properties. Samples B and D showed no evidence of fracturing or cracking. Sample A showed a branched crack along the full width of the external surface parallel to the direction of curvature (circumferentially). A similar crack showed on the interior surface, Figure 2. When stressed as a beam in a press, the sample broke readily into two pieces. As can be seen in Figure 3, there were three fatigue fractures in this sample. The only reason it had not separated when first cut free from the dipper stick was the fact that the fractures were not quite in the same transverse plane. The mechanical strength of the section across the cracks was virtually zero. As can be seen in Figure 4, the fracture in sample C originated as a fatigue crack. It is apparent that the fatigue crack penetrated the full wall thickness (as did those in sample A) before the occurrence of rapid fracture. Although not visible in the illustrations, there was a distinct lateral contraction at the end of the crack. Such contraction is typical of that which occurs at the arrest point of a brittle fracture. There was a longitudinal surface tear at the fracture origin, Figure 4(b).

CHEMICAL COMPOSITION

Drillings were obtained from samples B and D for chemical analysis. Results are shown in Table 1 along with the specified composition limits of ASTM A203, Grade B, for plate up to 2 inches in thickness and of firebox quality.

TABLE 1

Chemical Composition

Sample	Per Cent of Element					
	C	Mn	Si	S	P	Ni
B	0.20	0.78	0.31	0.013	0.015	2.62
D	0.19	0.77	0.31	0.011	0.015	2.61
A203 Gr B	0.21 max	0.70 max	0.13/ 0.32	0.04 max	0.035 max	2.03/ 2.57

Both manganese and nickel contents are slightly higher than the allowable limits on check analysis but this is not considered significant to the failures.

MECHANICAL PROPERTIES

Room temperature tensile tests were carried out on two 0.313 inch gauge diameter specimens prepared from sample C. As can be seen in Table 2, the tensile properties meet the requirements of ASTM A203, Grade B.

TABLE 2

Tensile Properties

Test	UTS kpsi	Yield Point kpsi	% El in 4XD (1.252 in.)
1	83.6	61.8	42.4
2	82.2	58.6	42.4
A203 Gr B	70/85	40 min	23 in 2 in.

Charpy V-notch impact tests were carried out on longitudinal specimens, notched normal to the surface so that fracture occurred in the same plane as the service fractures, i.e., circumferentially. Results are given in Table 3.

TABLE 3

Results of Charpy V-Notch Impact Tests

Sample	Test Temp. -°F	Absorbed Energy (ft-lb)	Sample	Test Temp. -°F	Absorbed Energy (ft-lb)
1	75	122	9	-40	21
2	75	118	10	-40	28
3	32	96	11	-80	26
4	32	44	12	-80	20
5	32	80	13	-80	34
6	32	94	14	-80	40
7	0	30	15	-120	9
8	0	41	16	-120	11

These results indicate a 25 ft-lb Charpy V-notch transition temperature of about -80°F (-62°C).

MICROEXAMINATION

Longitudinal sections were taken through two fracture origins in sample A and the single origin in sample C. Figure 5 shows a full section of sample A. It is notable that the fatigue fracture, right-hand edge of section, was not associated with the weld, although a small crack was found in the base of the weld adjacent to the interior surface of the tube. Three dark etching patches can be seen at the surface (top of the section) between the weld and the fracture. The right-hand patch is due to an arc strike, Figure 6(a), which resulted in the formation of at least six cracks. The other two patches were due to galling damage. One patch is shown in Figure 6(b). Figure 7 shows a portion of the section through two fracture origins in sample A. In both cases, fracture originated in cracks in brittle martensite which was formed as a consequence of high temperature generated in unlubricated sliding friction followed by self-quenching when motion ceased.

Figure 8 shows the fracture origin in sample C. In this case, no martensite was formed but the severity of shearing cold work, Figure 10, due to galling exhausted the ductility of the parent material and resulted in the formation of several surface cracks, one of which nucleated the fatigue crack.

The microstructure of the parent metal consisted of ferrite and semi-spheroidized pearlite, Figure 9. The structure is typical of that expected for such material in the normalized and tempered condition. The non-metallic inclusion content and distribution was deemed normal for standard commercial product. There is no evidence of metallurgical quality deficiencies in the original tube.

COMMENTS

The tensile properties of the specimens tested conform to the requirements of ASTM A203, Grade B. The chemical composition of samples B and D are within the limits specified by this standard except that the manganese and nickel contents are very slightly high. This is not considered to be of any significance with regard to the failure.

It is notable that all fatigue cracks originated in areas of surface damage due to lubrication failure. Obviously improvement to lubrication practice to eliminate this damage will also eliminate an extraordinarily fruitful source of fatigue cracks. It seems especially notable that all four fatigue cracks completely penetrated the tube wall prior to the final failure. In general, stress concentrations at fatigue crack notches are a ready source of brittle fractures and yet, in this case at least, damage was very extensive before final failure. Also, it will be recalled that a rapid fracture was arrested in sample C. These considerations, along with the results of the Charpy V-notch tests, suggest the material is not especially prone to brittle fracture in this service.

No fractures were found to be associated with the welds. Even the arc-strike cracks had not nucleated a fracture. This may well have been because of low surface stress in the particular area due to an adjacent pre-existing fatigue crack. In any event, it can safely be predicted that such arc-strike damage would cause failure in new dipper sticks where improved lubrication has eliminated galling damage.

The results of this investigation do not suggest that a change in material or heat treatment is called for at this time. The situation can be re-examined in the future in the light of experience gained with new sticks not so extensively damaged by lubrication failure.

CONCLUSIONS

1. Failure was due to fatigue cracks.

2. The fatigue cracks originated in surface damage due to lubrication failure.

3. No fractures were found associated with the welds.

4. In view of the extensive damage the unit suffered before failure occurred, it is considered the material is probably capable of meeting the service when the severe defects noted are eliminated.

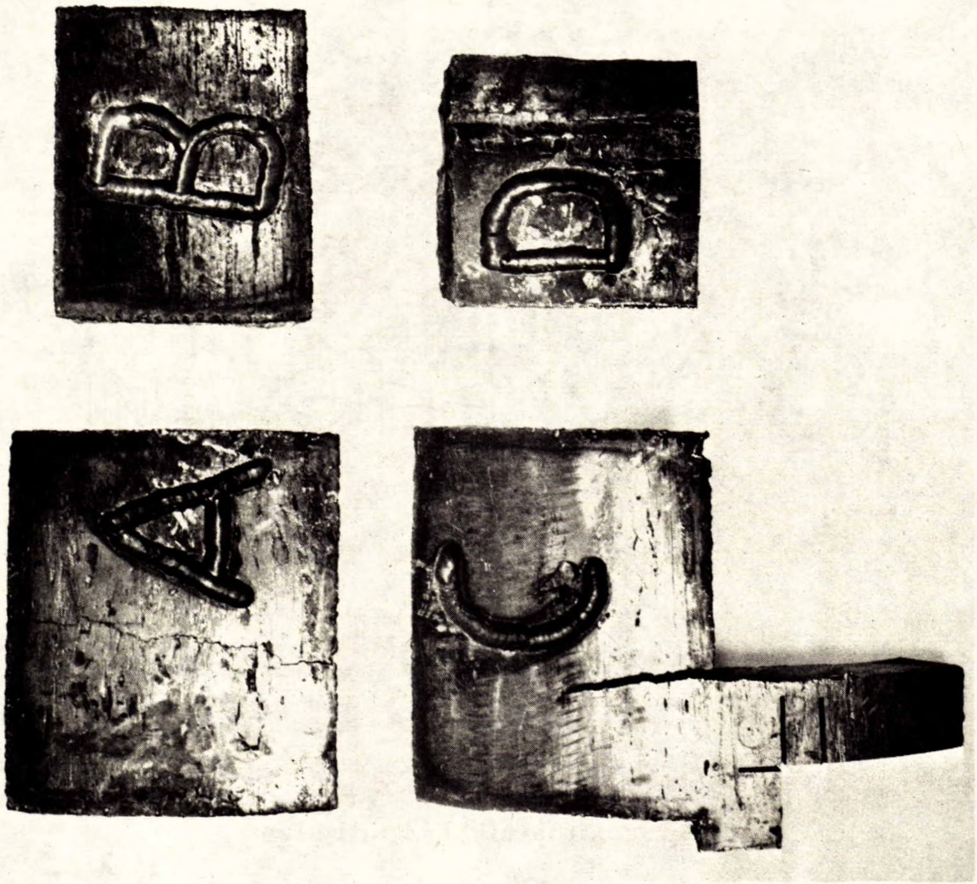
RECOMMENDATIONS

1. Lubrication should be improved to eliminate galling.

2. Accidental arc strikes should be avoided. If one occurs, the area should be repaired with a weld utilizing all the welding precautions relevant to the material and circumstances.

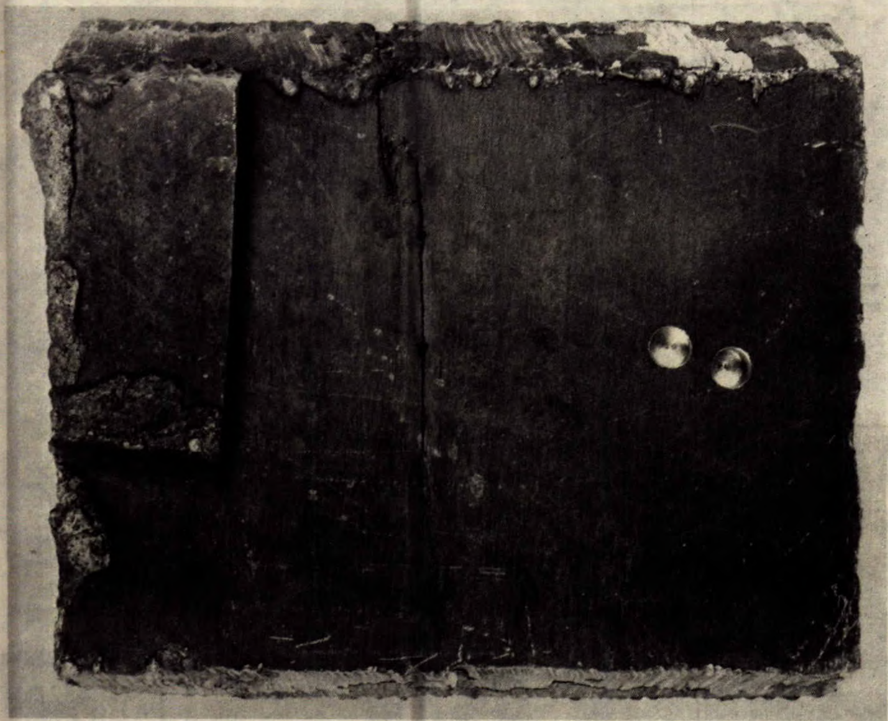
3. It is suggested the same material be used and the situation be reassessed following corrective action as per 1 and 2 above.

DRB/DAM/bb



Approximately 1/4 full size

Figure 1. Samples as received, except for portion removed from lower right corner of sample C.

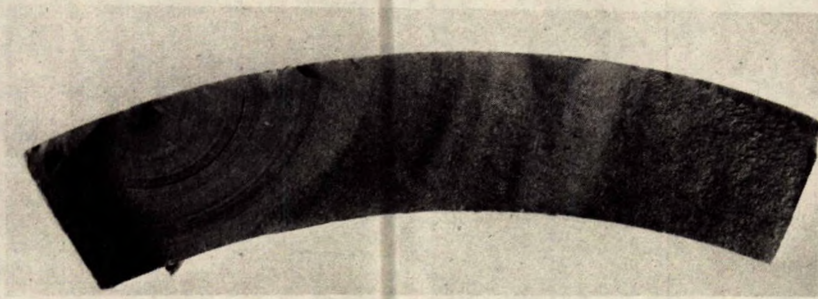


Approximately 1/2 full size

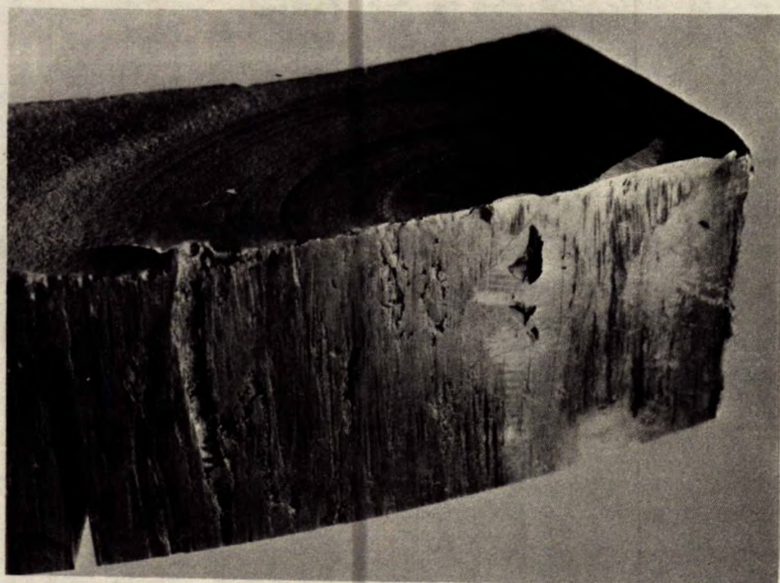
Figure 2. Interior surface of sample A, illustrating through-the-section penetration of crack shown on the opposite surface in Figure 1.

2/3 full size

Figure 3. Sample A after it was broken open, illustrating 3 fatigue fractures in this short length.



(a) Approximately 1/2 full size

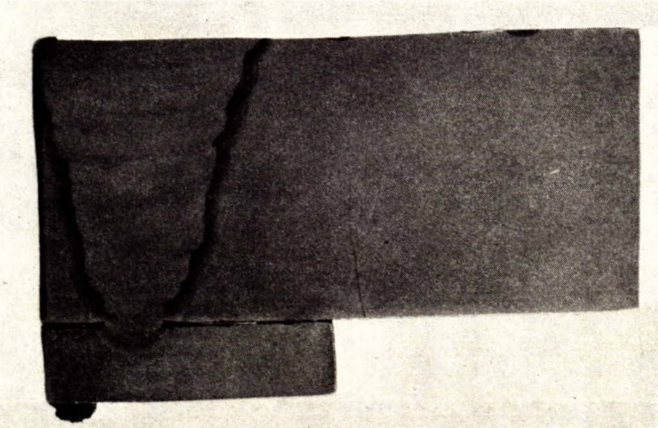


(b) Approximately full size

Figure 4. Sample C.

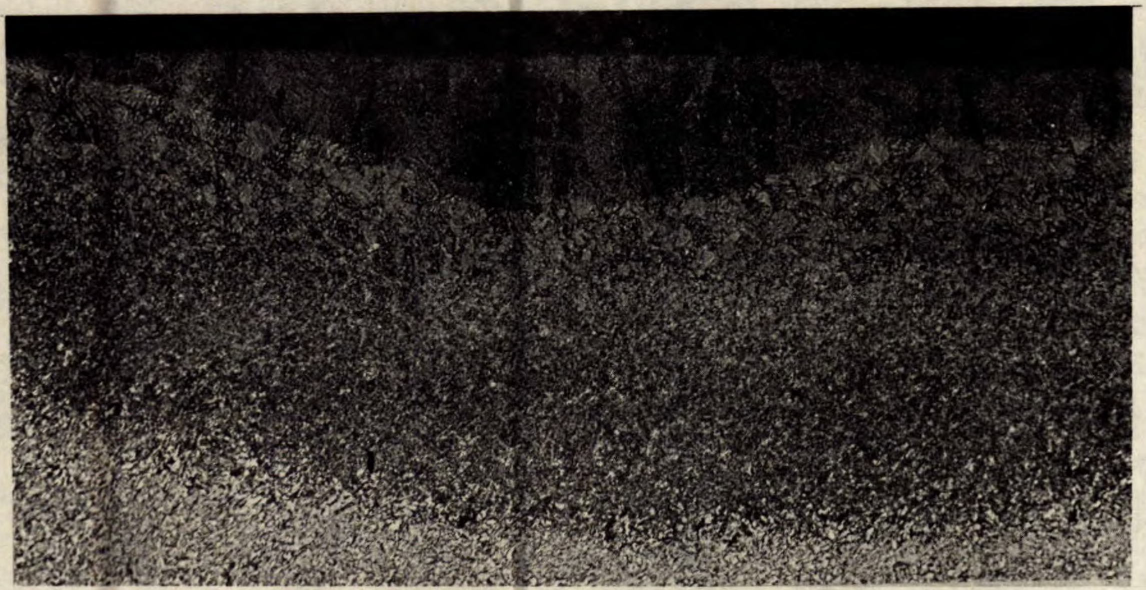
(a) Illustrating classic fatigue "beach" marks on fracture surface. Crack arrest occurred just beyond this portion to the right and the developing ductile "shear lip" can be seen at the upper right.

(b) Oblique view of fracture origin showing hollow formed when surface metal sheared due to galling following lubrication failure.



Approximately full size, etched in 6% nital

Figure 5. Full section through a fatigue fracture origin of sample A. The fracture, right edge, is not associated with the weld at the left. Note the three dark spots on the section at the upper edge between the weld and the fracture. The right hand one is an arc strike, Figure 6(a), while the other two are due to galling, Figure 6(b).



(a)

(b) X50, etched in 2% nital

Figure 6. Both same section as Figure 5.

(a) Illustrating arc strike containing at least 6 cracks.

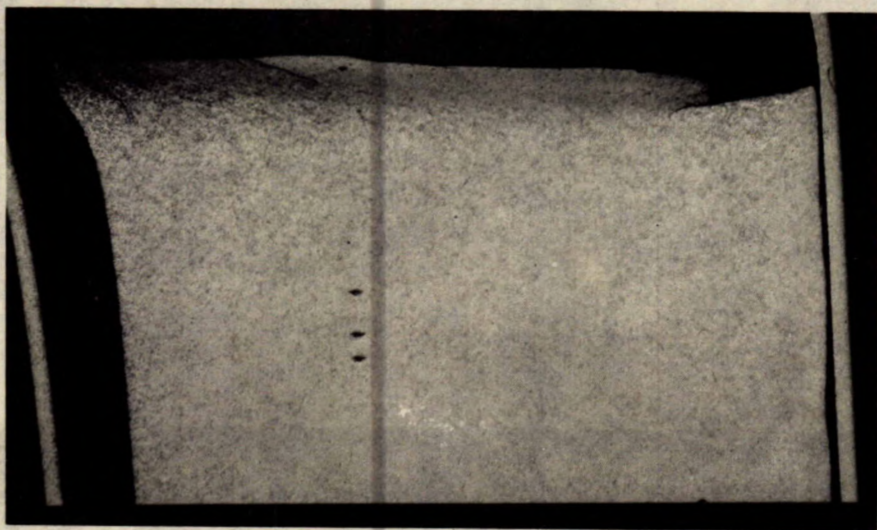
(b) Illustrating plastic flow and martensite generated at the surface due to lubrication failure.

Both structures are potential crack starters.

(a)

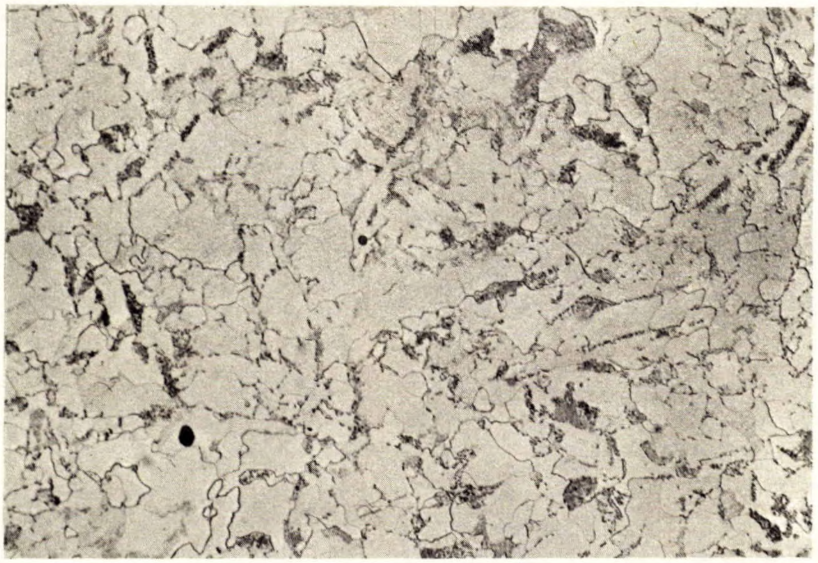
(b) X20, etched in 2% nital

Figure 7. Sections through fatigue crack origins in sample A. In each case galling has generated brittle martensite, which has cracked, thus serving as a fatigue crack nucleus.



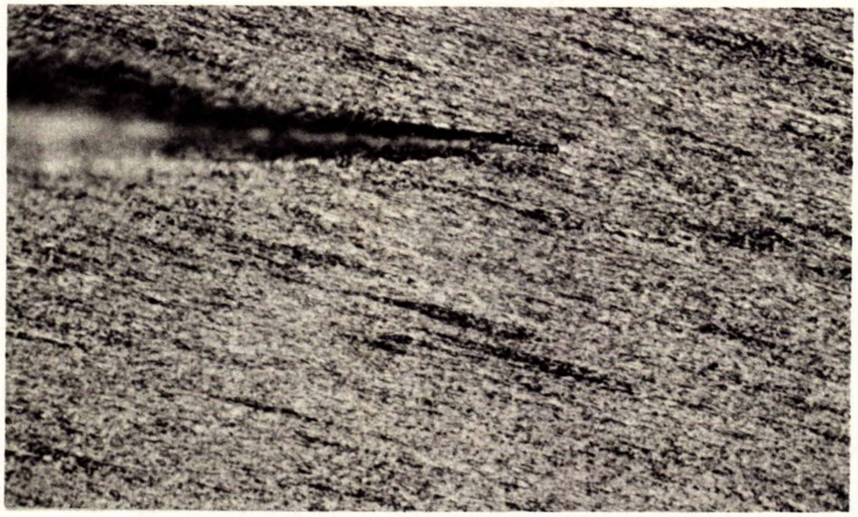
X8, etched with 2% nital

Figure 8. Section through fracture origin of sample C. Top surface is exterior surface and left edge is fatigue fracture, illustrating the other form of damage consequent to lubrication failure. In this case, galling has sheared the surface metal to a degree that exhausted all the ductility of the parent metal leading to surface cracking, which nucleated a fatigue failure.



X500, etched in 2% nital

Figure 9. Interior of sample C, same section as Figure 8. Typical original microstructure.
Hardness - Knoop 198 (approx. Rockwell B 89).



X1000, etched in 2% nital

Figure 10. Sheared surface of sample C, same section as Figure 8, illustrating the extreme cold work due to galling. The black pointed area in the upper left portion is part of a microhardness impression.
Hardness - Knoop 430 (Rockwell C 42).