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METALLURGICAL INVESTIGATION INTO THE FAILURE OF A BEATER ROLL BAR

by

G. P. CONTRACTOR

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

This investigation confirmed that the fractured beater roll bar was made to the required SAE Specification 1050. However, the bar showed appreciable decarburization and the presence of excessive amounts of inclusions. The surface condition of the bar was also poor.

The fracture surface was typical of brittle failure, with "herringbone" pattern pointing towards the origin of fracture which was initiated by a small fatigue crack in the fillet area. The cause of the fatigue crack may be attributed to a surface defect in the form of a scratch or a pit.

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* Senior Scientific Officer, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa, Canada.

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INTRODUCTION

In a letter dated January 3, 1958, Mr. K. E. Koreen, Supervisor of Engineering, Port Arthur Shipbuilding Company, Port Arthur, Ontario, requested an examination of the cause of failure of a beater roll bar, broken in service. A rough sketch of the drawing (#A-85) submitted by the company, showing the details of this steel bar, is reproduced in Figure 1.

Pertinent information from Mr. Koreen's letter is as follows:

i. The normal life of an average set of beater roll bars is 12 months. The number of bars required for each beater roll is 60.

ii. The bar in question is one of many which had broken in service after getting burred on the working edge in about one month's operation.

iii. The bar material is ordered in accordance with SAE Specification 1050 steel and is used in the "as rolled" condition.

PROCEDURE

The following procedure was adopted in the examination of the sample:

(a) Visual and magnaflux examination.
(b) Chemical composition.
(c) Hardness determinations.
(d) Macro-etch.
(e) Sulphur print.
(f) Metallographic examination.

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(a) Visual and Magnaflux Examination.

Figure 2 shows the fracture bar under investigation. The general surface condition of the bar was poor, being covered with patches of tightly adhering mill-scale, pitted areas, and long furrow-like markings localized near the fillet. Neither visual nor magnaflux inspection revealed the presence of flaws or cracks.

The working edge (Figure 3) showed a relatively smooth streaky surface, typical of flat metal parts rubbing against each other with particles of grit or hard foreign material in between. The smoothness of the working surface and the burred edges are indicative of relatively high pressure on the bar assembly during service.

The fracture surface showed a predominantly crystalline appearance, indicative of a brittle-type separation of metal (Figures 4 and 5). There was only a small zone of fracture, adjacent to the surface, which could be identified as fibrous. This was followed by a large typically crystalline fracture as shown in Figure 5.

There was no sign of beach or clam shell marks to fix the approximate location of the fracture origin. However, a searching examination revealed faint but definite evidence of the existence of "herringbone" marks (Figure 6) pointing toward the apparent source of failure in the fractured bar. It may be added that, although the markings in Figure 6 do not show a text-book picture, they were clearly visible with the naked eye. The general "herringbone" pattern tends to suggest that crack was initiated in the fillet area at the point marked by an arrow in Figure 6.

(b) Chemical Composition.

Drillings were taken from the fracture bar and chemically analysed. The elements copper and aluminium were determined spectrographically. The results are given in Table 1.

TABLE 1. - Chemical Composition of Fracture Bar

Elements	Composition, Per Cent	
	Sample	SAE 1050
Carbon	0.51	0.48-0.55
Manganese	0.70	0.60-0.90
Silicon	0.17	-
Sulphur	0.039	0.050 max
Phosphorus	0.029	0.040 max
Copper	0.2	-
Aluminium	0.005	-
Mn/C Ratio	1.37	1.25-1.63

Chemical analysis results show that the bar is made to SAE Specification 1050 steel composition. In regard to copper it may be added that although its presence is rarely reported in steel compositions, it is usually added for increased corrosion resistance in quantities up to about 0.2%. The general effect on the mechanical properties of as-rolled or normalized low or medium carbon steels is to increase tensile strength by about 1160 psi for each 0.10 per cent of copper. This increase will probably be accompanied by a slight decrease in ductility.

The reported aluminium content of 0.005 per cent is low and should produce no deleterious effect.

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(c) Hardness Determinations.

Hardness traverses were carried out using a Tukon hardness tester, with a 500 gram load, along the transverse section of the bar cut adjacent to the fracture. The results are given in Table 2. It will be seen that the hardness values of the decarburized zone, about 0.034 inch in depth, vary between $65R_B$ and $95R_B$. The hardness of the base metal is of the order of $20R_c$ - $25R_c$. Estimated values of tensile and fatigue strength are included to show how decarburization lowers the tensile strength of the material, and that it is accompanied by an appreciable drop in the resistance to fatigue.

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TABLE 2. - Results of Hardness Tests

	Distance from Surface of Bar, inches (a)	Hardness, Rockwell (b)	Hardness, Brinell (3000 kg load, 10 mm ball) (b)	Tensile Strength, psi (c)	Fatigue Strength, psi (d)
Decarburized zone	0.002	$65R_B$	116	-	-
	0.004	$79R_B$	147	71,000	33,500
	0.010	$83R_B$	159	77,000	36,000
	0.014	$83R_B$	159	"	"
	0.018	$83R_B$	159	"	"
	0.022	$88R_B$	176	85,000	40,000
	0.026	$88R_B$	176	"	"
	0.030	$95R_B$	210	101,000	47,500
	0.034	$95R_B$	210	"	"
Base metal	0.038	$20R_c$	223	106,000	50,000
	0.042	$20R_c$	223	"	"
	0.046	$20R_c$	223	"	"
	0.050	$20R_c$	223	"	"
	0.100	$22R_c$	235	110,000	52,000
	0.25	$25R_c$	255	120,000	56,000
	-	-	-	121,530*	-

(a) Thickness of the bar - approximately 0.5 in.

(b) Converted from Tukon Hardness readings.

(c) Estimated values calculated on the basis of Brinell hardness numbers, using conversion factor of X480.

(d) Estimated values calculated on the basis of Endurance ratio of 0.47.

* Tensile strength calculated on the basis of chemical analysis, using the formula: T.S. = 38,800 + C(650 + 4 Mn) + 90 Mn + 1,000 P. In using this formula the decimal point is dropped from the percentages of carbon, manganese and phosphorus. (Reference: "The Metallurgy of Quality Steels", by C. M. Parker, Reinhold Pub. Corp., New York, 1946.)

(d) Macro-Etch.

A transverse section of the bar was etched in 1:1 HCl at 165°F for about 30 minutes. The results showed a relatively clean, uniform structure with only a small zone of segregation in the centre (Figure 7).

(e) Sulphur Print.

Sulphur printing of a 4 1/2 inch long transverse section did not show any major localized segregation (Figure 8). However, the pattern shows uniform distribution of sulphides over the entire surface, with small areas showing relatively higher concentration.

(f) Metallographic Examination.

Longitudinal and transverse sections of the fracture bar were cut, mounted in bakelite, and polished for examination under a metallographic microscope. The unetched sections showed the presence of a fairly large amount of non-metallic inclusions in the form of stringers of oxides and sulphides (Figure 9). The amount present is considered to be in excess of the normal distribution found in commercial steels. These inclusions may initiate fatigue cracks. Furthermore, numerous large inclusions greatly reduce the ductility of the material (especially in the transverse direction) and this, in turn, adversely affects the impact strength.

Following the above microexamination the sections were etched with 2 per cent nital. The microstructure (Figure 10) consisted of pro-eutectoid ferrite and lamellar pearlite. The grain sizes of the steel were relatively coarse, indicating the possibility that there had been a high finishing temperature of rolling. Furthermore, the surface of the bar showed appreciable decarburization (Figure 11); that is, there had been a loss of carbon from the surface during heating and rolling operations. The presence of a decarburized layer also substantiates the possibility of high finishing temperature, referred to previously.

Figure 12, a microstructure of a section taken across the fracture surface, shows distortion of grains. This would seem to indicate a ductile behaviour of base metal under certain conditions of stressing.

DISCUSSION

The chemical composition of the steel is within the limits of SAE Specification 1050 and is satisfactory in regard to its sulphur and phosphorus contents.

Metallographically, however, the steel is dirty with large stringers of oxide and sulphide inclusions. It also shows appreciable decarburization on the surface and has a relatively coarse-grained structure. In addition, the surface appearance of the bar is poor, being covered with mill-scale, pits, and deep-seated scratches. All of these characteristics are detrimental to the quality of the material, in spite of the fact that it satisfies the chemical requirements.

Presence of "herringbone" markings on the fracture surface, and its coarsely crystalline appearance, suggest brittle failure, initiated by a small fatigue crack in the fillet area. The cause of the initial fatigue crack may be attributed to the presence of a pit or a scratch on the surface.

It may be added here that the fatigue crack can be non-propagating in a material of good notch ductility, if stress conditions giving rise to fatigue cracks are reduced. In the present case, it appears that the conditions were favourable to rapid propagation because of the presence of an excessive amount of non-metallic inclusions and a coarse-grained structure. In other words, these conditions appreciably increased the notch-sensitivity of the material so that even at low strain levels the velocity of crack propagation was rapid, eventually rupturing the bar with a typical brittle fracture.

Although decarburization is not considered directly responsible in the present case, it greatly reduced the fatigue resistance of the metal, since fatigue cracks almost invariably start at the surface. In this connection it must be mentioned that laboratory tests (Trans. Am. Soc. Metals, vol. 39, p. 45, 1947) on homogeneous and decarburized specimens have indicated that the fatigue strength of the fractured material is reduced approximately 50% by decarburization. Applying this finding to the present case, the fatigue limit of the fractured bar (see Table 2) may be of the order of 36,000 psi, compared with 56,000 psi had the bar been homogeneous, i.e. not decarburized.

CONCLUSIONS

1. The fractured bar was made to SAE Specification 1050. However, it showed appreciable decarburization and contained excessive amounts of deleterious non-metallic inclusions.

2. The fracture surface was typical of brittle failure, with "herringbone" pattern pointing towards the origin of fracture which was initiated by a small fatigue crack in the fillet area. The surface condition of the bar was poor.

3. The cause of the initial fatigue crack may be attributed to a surface irregularity in the form of a scratch or a pit. The presence of other undesirable conditions, mentioned in conclusion 1 above, increased the rate of propagation of the crack which eventually ruptured the bar.

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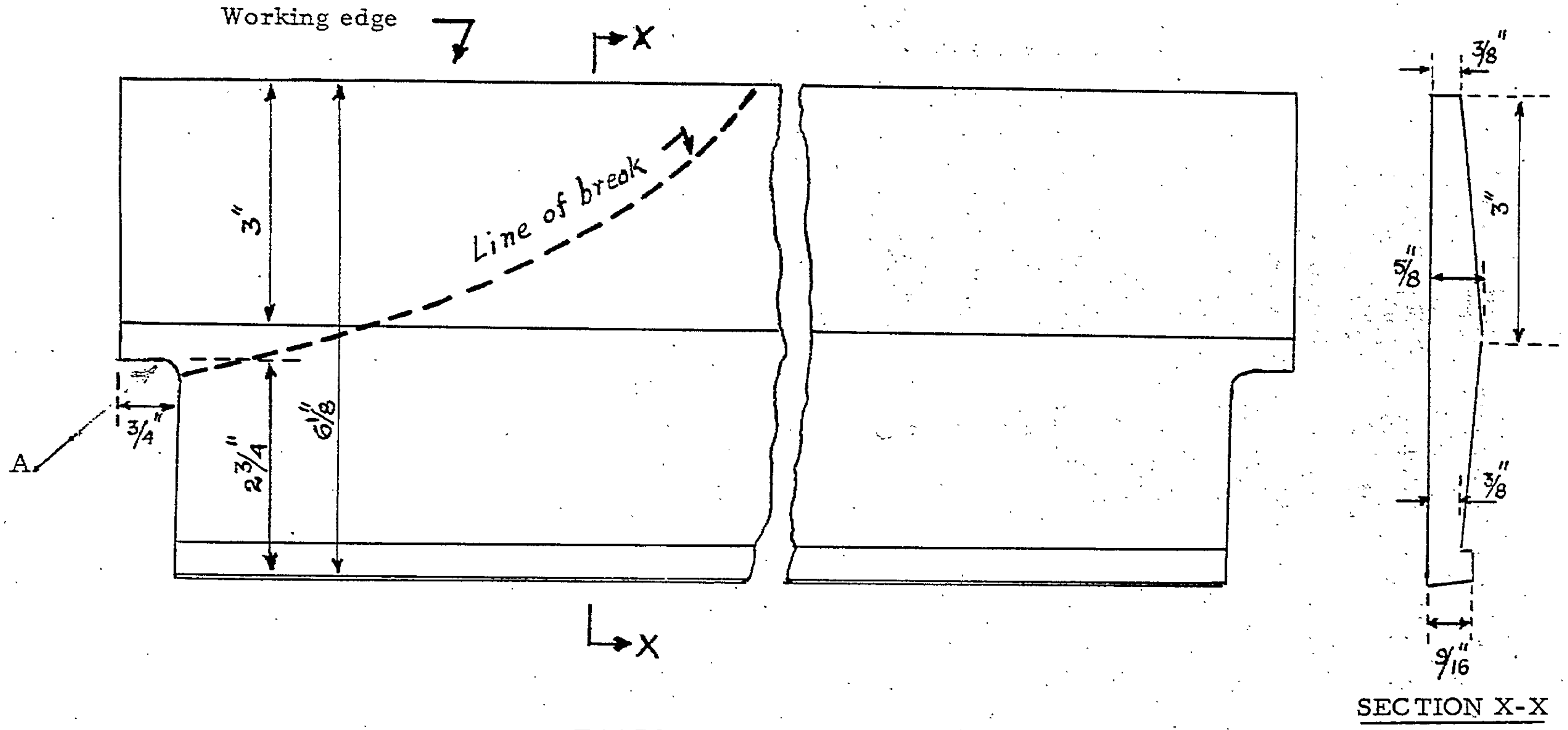
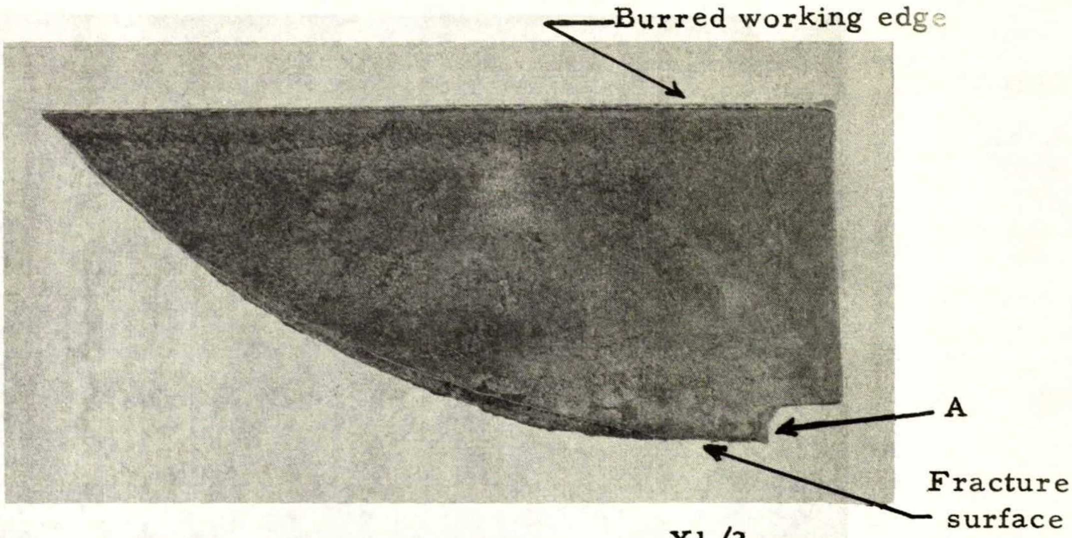
GPC:(PES)VB

(Figures 1 to 12 follow,)
(on pages 10 to 16.)



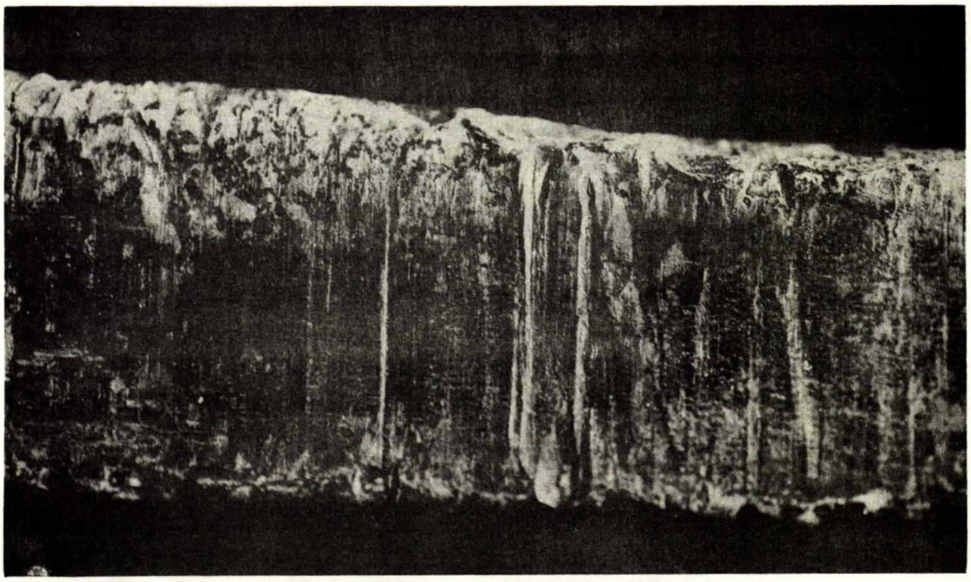
PASCOL - BEATER FLY BAR

Fig. 1. - Drawing A-85.



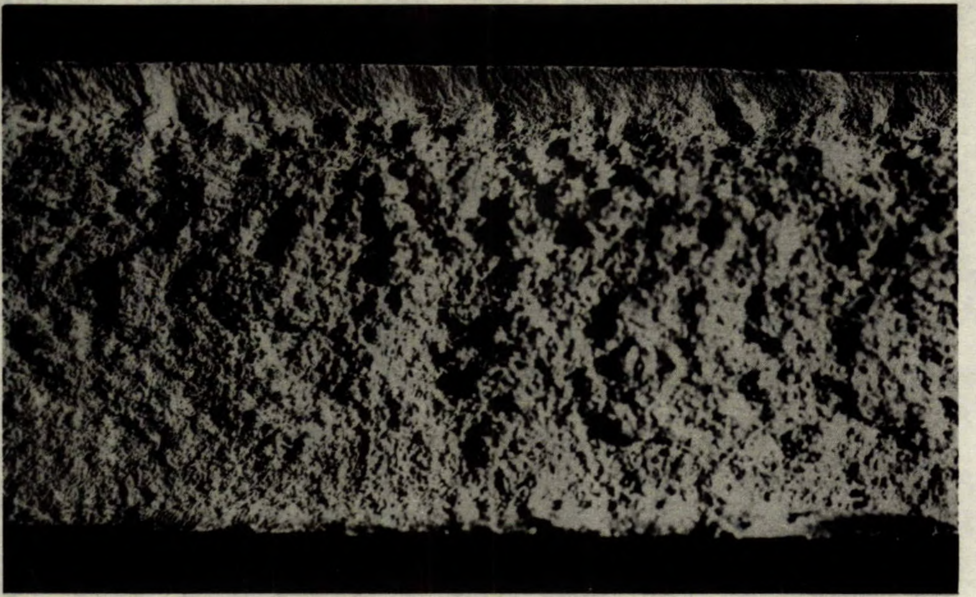
X1/2.

Fig. 2. - Photograph of fracture bar. Note the poor surface appearance. (A = starting point or nucleus of initial fatigue cracks.)



X4.

Fig. 3. - Working surface of fracture bar. Note burred edges and streaky appearance of the surface.

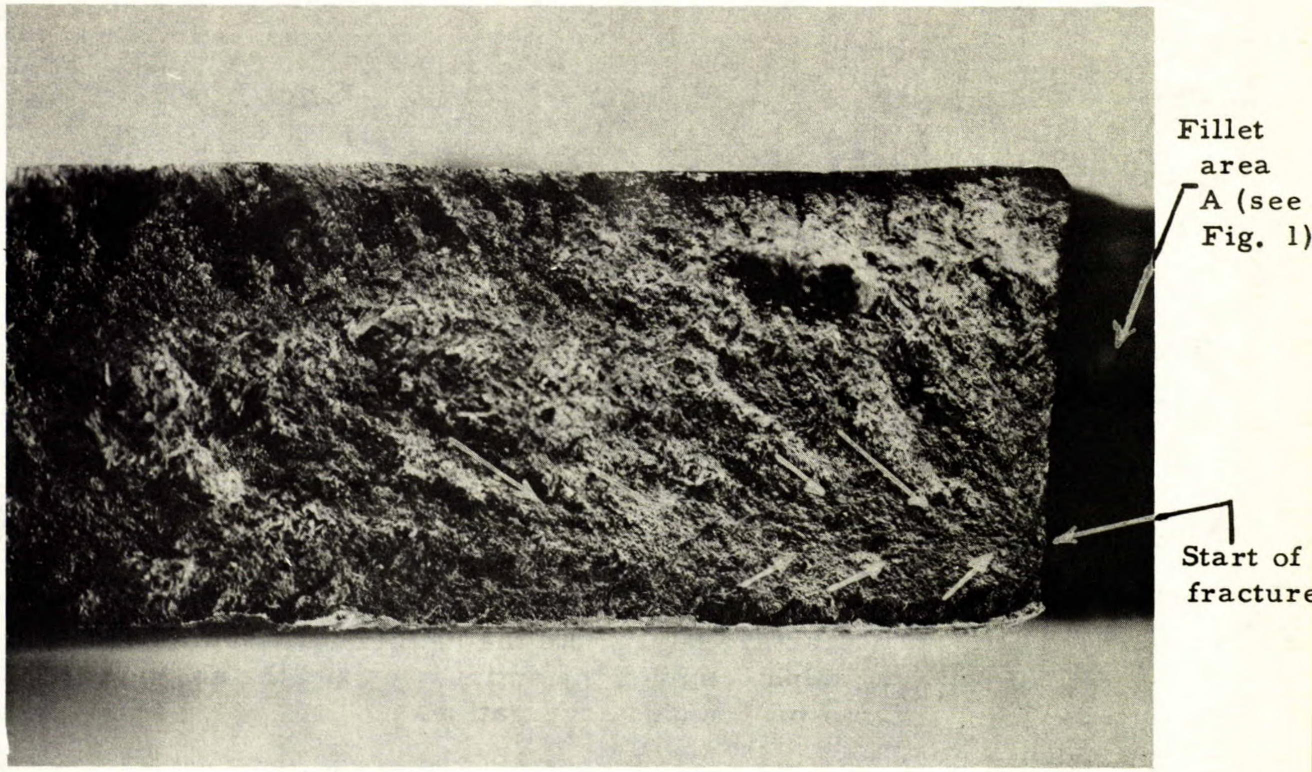


X4.

Fig. 4. - Longitudinal view of fracture surface. It shows a fine to coarse gradation in fracture grain size. Note the relatively small zone of fibrous fracture on the top.

X3.

Fig. 5. - Same as Fig. 4, but the fracture surface is more coarsely crystalline.



X4.

Fig. 6. - Longitudinal view of fracture surface, showing "herringbone" pattern (marked by small arrows) pointing towards the origin of the fracture.

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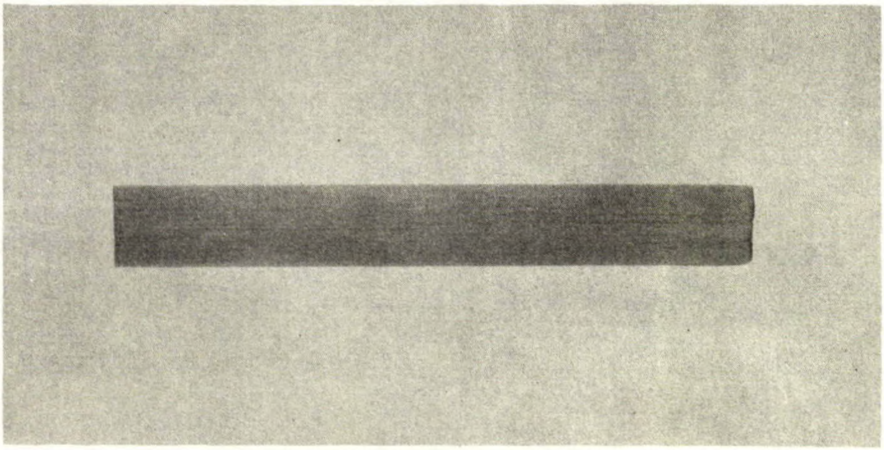

X 2/3.

Fig. 7. - Transverse section deep-etched in 1:1 HCl.

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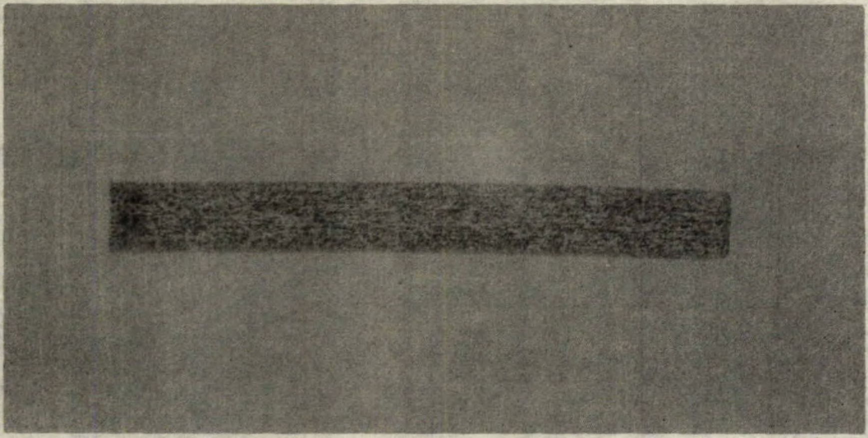

X 2/3.

Fig. 8. - Sulphur print of transverse section of the fracture bar. Note the uniform distribution of sulphides over the entire area and the absence of pronounced segregation.

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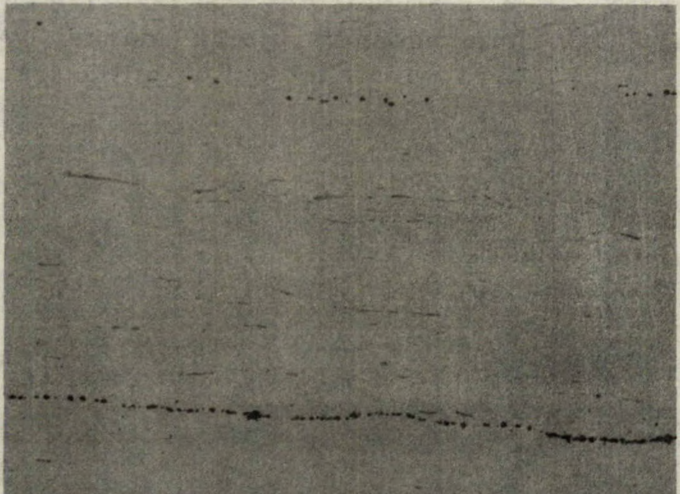

X100.

Fig. 9. - Note the dark stringers of oxide and light grey sulphide particles.

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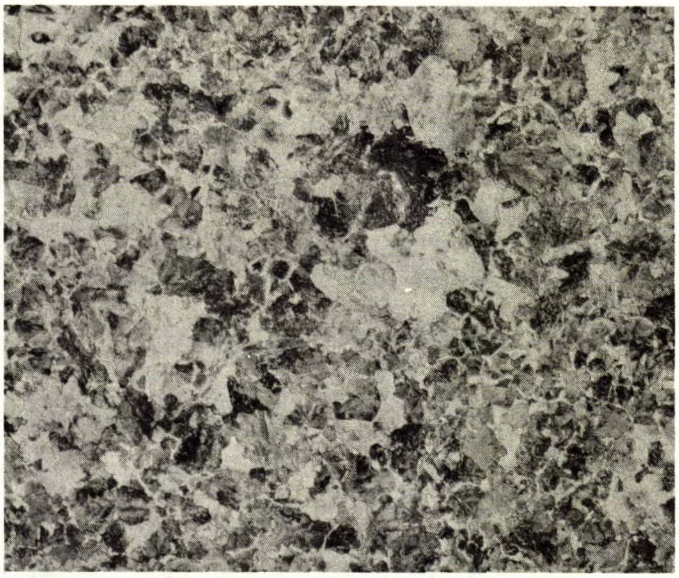
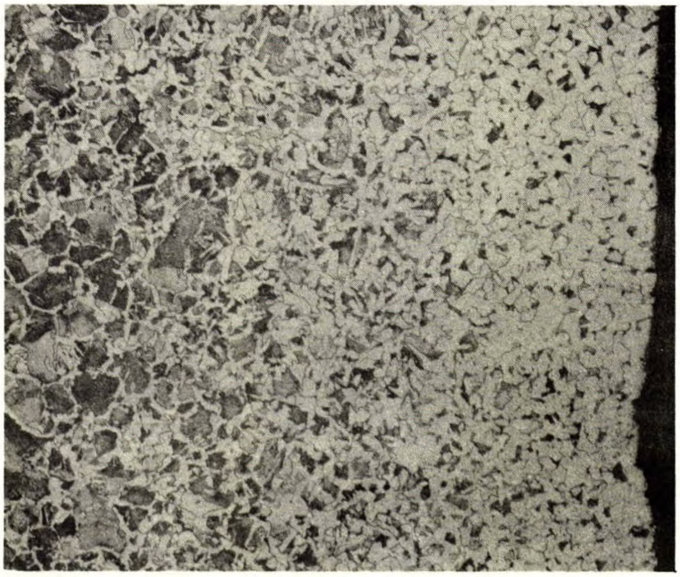


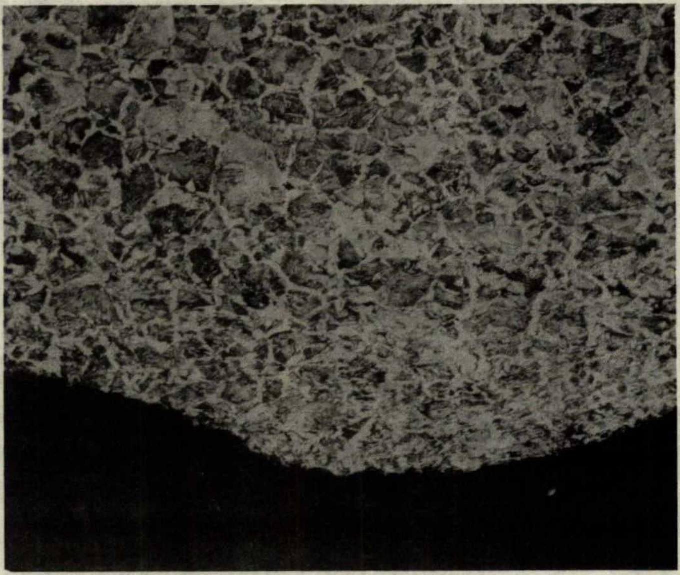
X100.

Fig. 10. - Photomicrograph of bar, showing network of ferrite (light) and dark lamellar pearlite.



X100.

Fig. 11. - Same as Figure 10, but showing decarburized surface (right) gradually merging into base metal (left).



X100.

Fig. 12. - Photomicrograph of bar across the fracture surface. Note elongated ferrite grains (bottom) as a result of plastic deformation.

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