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EXAMINATION OF FRACTURED REINFORCING RODS FROM MATSQUI INSTITUTION DRUG CENTRE, BRITISH COLUMBIA

by

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PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Following delivery of four reinforcing rods, which had fractured on site under the impact of hammer blows, a metallurgical examination was carried out in an attempt to determine the cause of failure.

Chemical analysis, tensile and bend tests, and metallographic studies showed that there was little intrinsically wrong with the material.

It was concluded that failure was probably caused by improperly bending the rods around pins of smaller diameter than that prescribed by specification. Such procedure is known to induce a brittle condition on the inside of the bends.

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INTRODUCTION

On February 25th, 1965, four fractured No. 11 steel reinforcing bars were submitted to the Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, by the Development Engineering Branch Testing Laboratories of the Department of Public Works, with a request to examine and determine the cause of failure.

These were representative of many other rods used in the construction of the Matsqui Institution Drug Centre at Matsqui, British Columbia. In a memo from the District Architect to the Development Engineering Branch, it was stated that trouble was first encountered when a bar, which a welder was preparing, fractured under the impact of his small chipping hammer. Subsequent investigation showed that many bars were "so brittle that they failed under the impact of a force of approximately 5 to 10 ft-lb".

VISUAL EXAMINATION

Each bar was received as a length of about 24-30 in. with a short section of about 7 in. bent at a 90 degree angle. It appeared that the long piece had been embedded in concrete up to the bend, and the short piece had been exposed to the atmosphere.

Visual examination of the bars and the fractures resulted in the following observations:

(a) The general location of fracture was the same in each case and occurred at the start of the bend, on the side which was not embedded in the concrete (see Figure 1).

(b) Each fracture was of the same completely brittle appearance (see Figure 2) and the markings showed that it originated on the underside of the bend, at the root of one of the transverse deformations. It was noted that at this point of origin, the deformation had been flattened, presumably during the bending operation.

CHEMICAL COMPOSITION

The bars were numbered 1 to 4 for reference purposes, and drillings for chemical analysis were taken at the end of each long piece. Results obtained are shown in Table 1 below:

TABLE 1

Results of Chemical Analysis (%)

Bar No.	C	Si	Mn	S	P	Al*	N
1	.35	.09	.46	.060	.010	.040	.008
2	.35	.08	.55	.054	.010	.060	.009
3	.35	.09	.46	.057	.010	ND	.009
4	.34	.08	.57	.058	.016	ND	.007

* Spectrographic analysis; ND-non-determinable.

These results show nothing unusual and are well within CSA Specification G30.1 (1954), which demands only that phosphorus should not exceed 0.05% for basic oxygen, open hearth, or electric furnace steel, and 0.08% for acid open hearth or electric furnace steel.

MECHANICAL TESTS

The rods were supplied to the Intermediate Grade of CSA Specifications G30.1 (1954). To determine whether the material under examination conformed to this, rods No. 1 and 2 were used for tensile tests and rods No. 3 and 4 for bend tests.

The results of the tensile tests are shown in Table 2, where it will be seen that the material was within specification.

The specification bend test for deformed bars, intermediate grade, required that they be bent at 90 degrees around a pin of 8-1/2 in. diameter, without cracking. This was performed successfully with no sign of cracks on the outside portion of each bar. A photograph of the test bars is shown in Figure 3.

METALLOGRAPHIC EXAMINATION

Longitudinal microspecimens were cut from rod No. 3 at the fracture and also at the extremity of the long piece, farthest from the fracture. The two specimens were examined in order to compare microstructure and so determine whether the fracture zone had been subjected to any localized treatment. As shown in Figure 4(a) and (b), both regions exhibited the same ferrite-pearlite structure and one which is considered normal for this composition of steel. Close examination of the edge of the fracture indicated that it was of a transgranular nature.

Prior examination in the unetched condition revealed the presence of some sub-surface defects and laps. These defects can act as initiation points for failure if the material is in a brittle condition.

Longitudinal sections through the centre of the fracture at the point of origin were cut from the small half-fractures, and deep-etched for macroexamination. The photographs of these sections, (Figure 5), illustrate the start of each fracture at the root of a deformation. (It would also appear that rod No. 2 was rolled from a billet possibly containing part of the ingot pipe.) The most significant observation, however, is that in three cases (No. 1, 2 and 3), a crack was present at the root of the next deformation down from the fracture, and on the same underside of the bend. It was noted that these deformations had been considerably flattened. Macroexamination revealed that these cracks propagated from a lap at the root of the deformation; as an example, that occurring in rod No. 3 is shown in Figure 6. Here, the directionality of the ferrite and pearlite grains clearly shows how the surface was 'lapped' into the rod, leaving the oxide-filled fissure from which a crack would start.

DISCUSSION

The results of the chemical analysis, tensile tests, and bend tests showed that the material received was acceptable according to CSA Specification G.30.1 (1954), albeit, that the requirements of this specification are not the most stringent. In this case, however, there was nothing unusual about the composition of the steel, although it should be mentioned that at sub-freezing temperatures, the notched impact resistance of steels of such carbon content, without alloy additions, can be fairly low. The transverse deformations on reinforcing rods provide many potential notches for fracture initiation. The Physical Metallurgy Division was verbally advised, however, that the failures occurred in the Fall, therefore low-temperature conditions can be ruled out.

"Laps" were discovered in the rods, but such defects need not necessarily be regarded as injurious if the material has sufficient ductility. From the evidence shown in Figures 5 and 6, it appeared very likely that they contributed to failure by acting as initiation points, but the material must first of all have been in a brittle condition. The successful bend tests indicated that no serious surface defects were present in the straight part of the rods and, therefore, suggested that perhaps the laps were a feature of the bend portion. In actual fact, each point of fracture, and the cracks shown in Figure 5, were observed at the root of a deformation that had been flattened. The flattening obviously occurred during the bending operation; therefore, it is very probable that the laps occurred as a result of this operation.

During bending of a rod, the outer 'fibres' are plastically deformed in tension and the inner fibres are plastically deformed in compression. Thus, in effect, the inside portion of the bend is prestrained in compression and it is a known phenomena that a reversal of plastic loads from compression to tension can result in brittle failure at lower than nominal yield strengths. Depending on the amount of prestraining, a rod may be damaged and its original ductility is exhausted so much, and in such a direction, that it cannot yield sufficiently at the inner radius of the bend, and especially at the roof of a notch.

Previous work on reinforcing rods at the Physical Metallurgy Division has shown that the above condition exists when rods are bent around pins of a smaller diameter than that prescribed by the specification. Attempted straightening of such bars, or striking them a modest impact blow, resulted in brittle failure at the bend (Physical Metallurgy Division Test Report PM-64-24).

Thus, here is a mechanism that can induce a brittle condition at a bend and it is felt that such improper bending was the cause of failure of the four rods. The fact that the origin of each fracture was observed at the same location, on the underside of the bend, supports this assessment. Also, the two bend test pieces, which were properly formed according to that prescribed in CSA Specification G-30.1, were able to withstand repeated impact blows without failure, while held in a vice.

A visual comparison of the inner radius of the above bends with that of each of the fractured rods suggested that the latter were of a smaller radius.

It is difficult to assess the exact influence of the 'laps' at the roots of the deformations on the underside of the bend. They undoubtedly contribute to failure by acting as stress-raisers and initiation points, but it is also quite probable that even when absent, the exhaustion of ductility of the material due to the prestrain is such, that fracture could occur with only the roots of the deformations acting as stress-raisers.

CONCLUSIONS

1. The material received was tested and found to conform to CSA Specification G-30.1 (1954): Intermediate Grade, in chemical composition, tensile test and bend test.

2. The compiled evidence suggested that failure was probably caused by a brittle condition at the bend, induced by improper bending.

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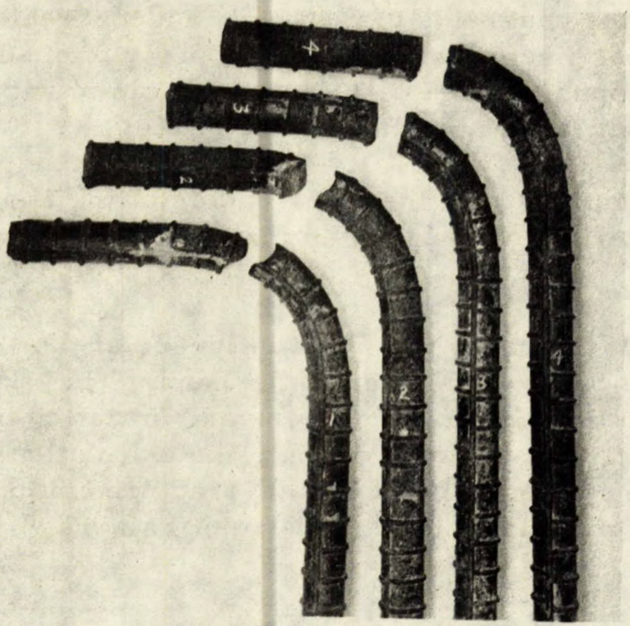


Figure 1. Photograph (approximately 1/6 actual size) of No. 11 reinforcing rod as-received. Note location of each fracture at the bend.

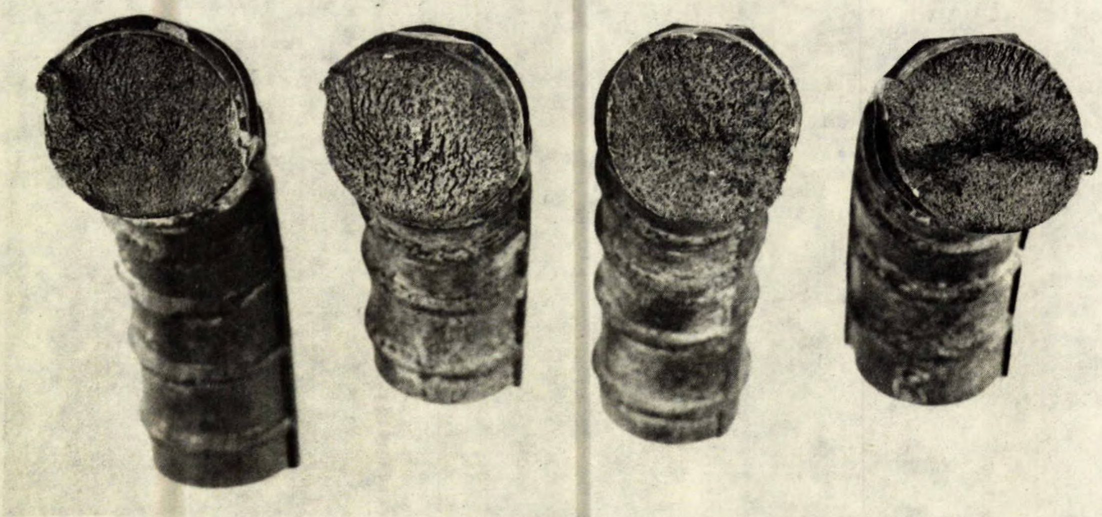


Figure 2. Photograph showing fractured surface of each rod. (approximately full size).

TABLE 2

Results of Tensile Tests

Rod No.	Yld Pt. kpsi	UTS kpsi	% El. on 8 in.
1	51.3	80.0	11
2	48.0	78.0	22
CSA Spec.	40.0 min	70-90	7 min

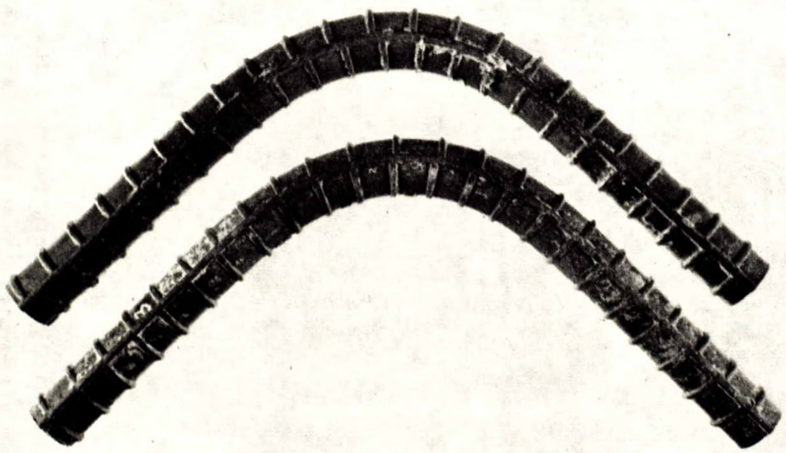
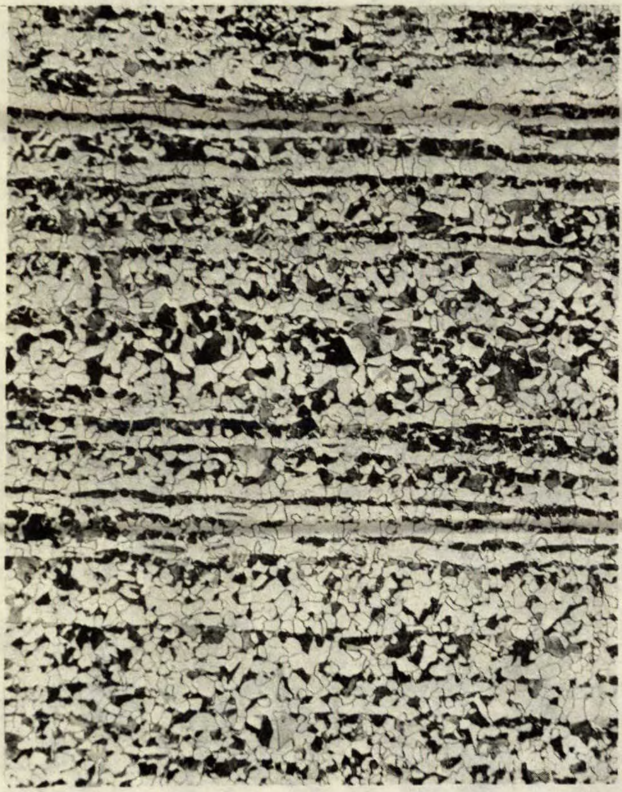


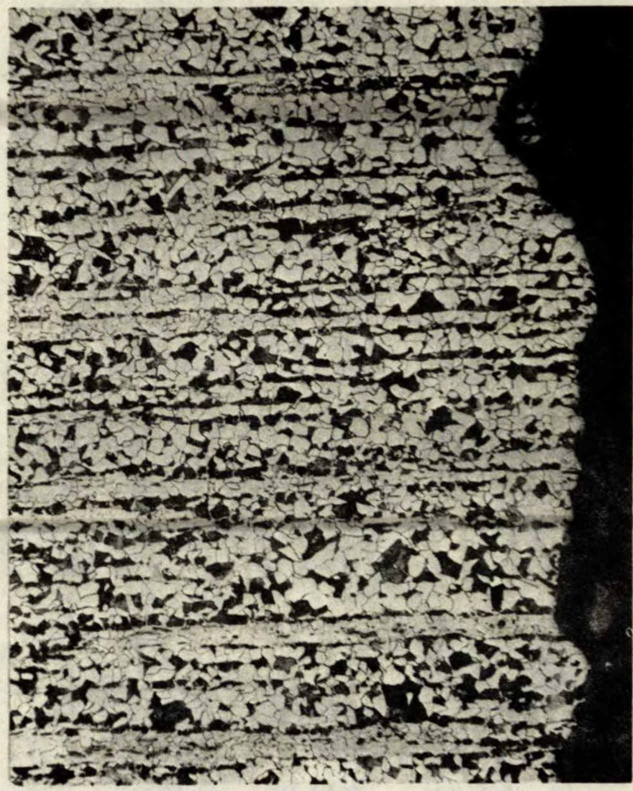
Figure 3. Photograph (approximately 1/5 actual size), showing results of bend tests.



X100

(a) At end farthest from fracture

Etched 2% Nital



X100

(b) At fracture

Figure 4. Photomicrographs showing same ferrite-pearlite microstructure at the fractured zone and at the end of rod No. 3 (longitudinal sections).

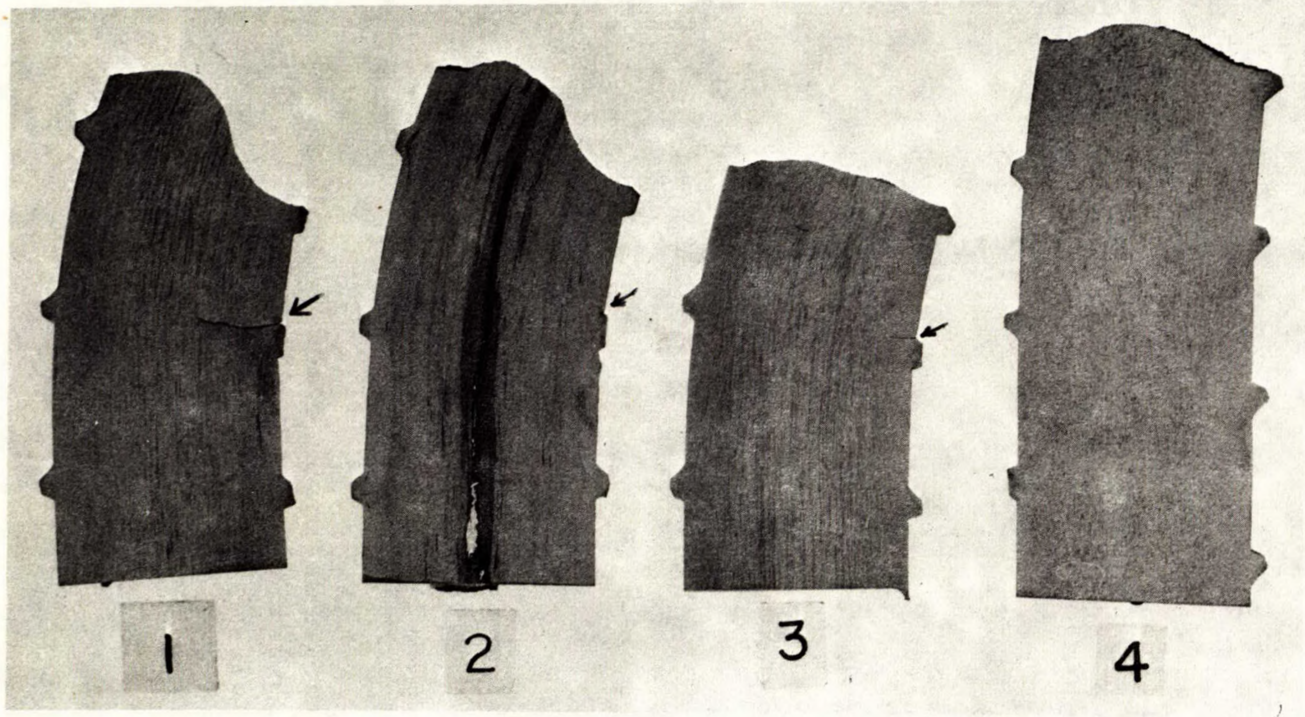
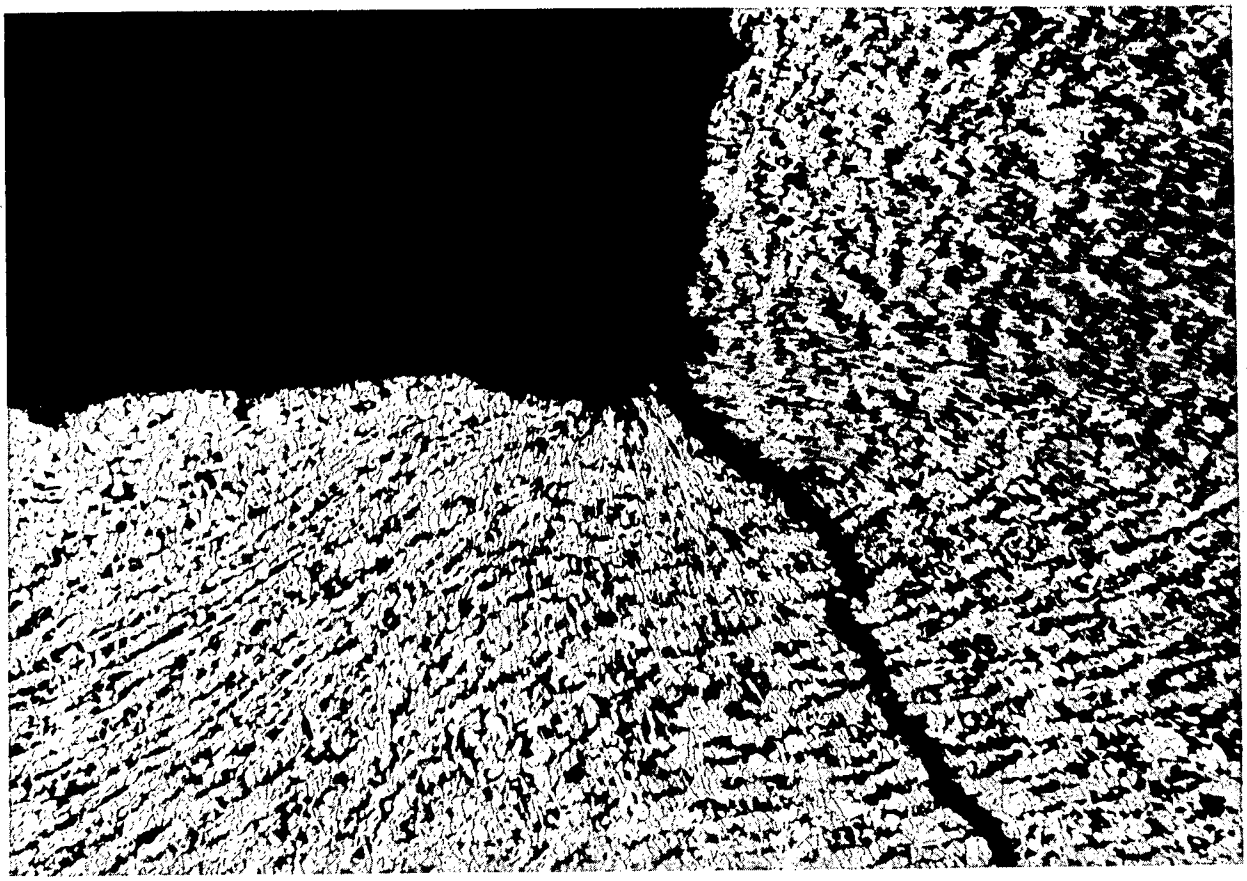


Figure 5. Photograph (approximately full size) of macroetched longitudinal sections through fractures. Note cracks at root of deformations.



Etched 2% Nital X100

Figure 6. Photomicrograph showing crack emanating from a lap at the root of a deformation (rod No. 3).