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EXAMINATION OF CRACKED AREA OF A TYPE 416 SUCTION ROLL

by

D.K. FAURSCHOU

PHYSICAL METALLURGY DIVISION

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SUMMARY OF RESULTS

Part of a suction roll from a papermaking machine was examined to determine why it had failed prematurely. The roll was made of process annealed steel equivalent to AISI Type 416. Multiple corrosion-fatigue cracks were observed in the suction holes where crevice corrosion had been active. Stress concentration at certain of these cracks in the region of highest stresses at mid-length caused the abrupt failure.

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

INTRODUCTION

On February 2, 1966, Mr. T. Foulkes, Chief Plant Engineer, The E. B. Eddy Company, Hull, P.Q., sent a piece of a fractured papermill roll shell to the Physical Metallurgy Division for metallurgical examination to determine the cause of failure. Specifically, we were requested to determine whether or not the roll failed due to fatigue or corrosion-fatigue.

It was stated that the roll had been used on the second press section of No. 8 paper machine - E. B. Eddy Job 87-5168. Previous rolls had been made of bronze. The failed roll was made of Firth Stainless Type FCS-1. This roll was in the form of a cylindrical shell having an outside diameter of 32 inches, an inside diameter of 28½ inches and a length of about 248 inches.

The E. B. Eddy Company has had no previous experience with stainless steel suction rolls. The use of stainless steel in suction rolls is a recent development being used to achieve higher operating pressures and speeds. The rolls are rubber-faced and drilled with about 5/32 inch holes on 5/16 inch centres. In operation a vacuum is created inside the roll to suck white liquor from the paper as it is squeezed between the suction roll and an upper pressure roll.

The results of analysis of a typical white sample were given as:

pH	3.7
Chloride Ion	8 ppm
Sulphate	109 ppm
Phosphate	nil
Mercury	nil

EXAMINATION

Macroexamination

Figure 1 (actual size) shows the fracture surface and the macrostructure of the metal on a plane parallel to the mean fracture plane. The fracture was reported to have occurred transversely at about the mid-length of the roll.

The fracture surfaces were not bright and clear. However, the appearance of the fracture surfaces still indicated that fatigue fractures had initiated at multiple sites in the outer (measured radially) 1/2 inch of the suction holes. In this 1/2 inch length there were dense adherent deposits about 0.035 inches thick, and beneath these deposits the metal was pitted and generally so corroded that no machining marks could be detected. In the inner $1\frac{1}{4}$ inch of each hole the dense deposits were thinner or non-existent and few pits were observed. Over this inner $1\frac{1}{4}$ inch the tool marks of the drills were clearly visible. Indeed, over this inner length some of the holes were only slightly tarnished. Many of the holes were filled with loose fibrous deposits.

Most of the fracture surface was characteristic of abrupt brittle failure.

The outer surface of the roll was roughened, presumably by pitting and general corrosion, to a greater extent than the inner surface of the roll.

In Figure 1, the deep etched section parallel to the mean plane of fracture indicates that the failure occurred roughly transversely to the principal planes of hot working which were longitudinal and circumferential. It is not known for certain whether or not the roll was fabricated from plate or forged directly from an ingot. Observations indicate that it probably was forged directly from an ingot and, therefore, the principal planes of forging spiral along the length of the roll.

Figure 2 (X9) shows a cross-section of some of the drilled holes at and close to the fracture. This section was located about 3/8 inch below the outer surface of the roll. In this section the fracture intersects the longitudinal plane of forging, as indicated by the inclusion stringers, at an angle of about 45 degrees. Two cracks are readily visible intersecting the inclusion stringers at about 15 degrees ("A") and at 90 degrees ("B").

The fracture was stated to be transverse i.e., circumferential and at mid-length of the roll. The 5-inch length of fracture indicated that the path of fracture followed a regular zig-zag path along lines of closest approach of drilled holes. The holes had been drilled regularly, probably in a slight spiral pattern, so that paths of weakness were formed. These paths intersected one another at 60 degrees since the holes were spaced to form sets of equilateral triangles. Over the 5-inch length of fracture, which had a mean circumferential path, the actual path of the fracture passed, via the shortest path in each case, through three holes cutting across the mean transverse path to the left; it then veered 60 degrees to the right across the mean transverse path and passed through seven holes; it then veered 60 degrees to the left through four holes; and then veered 60 degrees to the right through four holes.

Microexamination

The etched microstructure, as shown in Figures 3, 4 and 5 (X500) consists of spheroidized carbide in a matrix of ferrite.

Figures 3, 4 and 5 show more detail of the cracks marked "A", "B" and "C" in Figure 2.

Figure 3 shows the starting region of crack "A". Figure 4 shows the starting region of crack "B". It is evident that the cracks initiated in the corroded and pitted surfaces of the drilled holes.

Figure 5, taken along crack "C", shows that the crack paths are mostly intercrystalline with little tendency to propagate along multiple paths.

Hardness

The suction roll shell had a uniform average hardness of Rockwell "B" 85. This converts to Brinell 162.

Chemical Composition

The shell was stated to be made of Firth Stainless Type FCS-1. The composition limits for this grade were not available but an analysis of the roll was supplied. The specimen of roll was drilled between the existing suction holes, to avoid contamination of the drillings, and analyzed. The results of chemical analysis and the composition limits for AISI Type 416 stainless steel are given in Table 1.

TABLE 1

Roll Analyses and AISI Type 416 Limits

Element	Given Analysis, Wt %	PMD Analysis, Wt %	Type 416 Limits, Wt %
C	0.23	0.16	0.15 max
Mn	1.61	1.46	1.25 max
Si	0.39	0.38	1.0 max
S	0.165	0.24	0.15 min
P	0.010	0.024	0.06 max
Ni	nil	0.18	-
Cr	13.20	13.20	12.0/14.0
Mo	0.08	0.07	-

DISCUSSION

The roll shell was made of steel essentially conforming to the composition limits specified for AISI Type 416 stainless steel. This steel is hardenable but the microstructure and hardness show that the roll was in the process annealed condition. In this soft condition the steel is considerably stronger than the bronze alloys formerly used and has good machinability because of the added sulphur. However, the steel is in its poorest condition to resist corrosion because much of the chromium, especially in the vicinity of carbides, is combined with carbon to form spheroidized carbides. The sulphides, in the resulphurized steel, have also lowered the steel's resistance to general and pitting corrosion attack.

Chromium steels have their best corrosion resistance when the chromium is in solid solution. Thus, Type 416 stainless steel has maximum corrosion resistance in the as-quenched (fully hardened) condition. Stress-relieving up to about 700°F has little effect on corrosion resistance. Tempering above 1100°F causes a progressive loss of corrosion resistance as the temperature increases to process annealing and full annealing temperatures. The tempering temperature range between 700 and 1100°F is generally avoided in this type of steel because of embrittlement.

The failure of the roll is attributed to corrosion fatigue. In non-corrosive media, annealed Type 416 has a fatigue limit of about 40,000 psi. In corrosive media, the fatigue limit might be less than 20,000 psi.

It appears that the annealed Type 416 may have good corrosion resistance, if freely exposed in the white liquor. The most damaging general corrosion and pitting occur in the outer 1/2 inch length of the suction holes which become coated with a dense adherent deposit. Beneath this deposit, and to a lesser extent beneath the loose fibrous deposits in many of the holes, corrosion is of the accelerated "crevice" type. Any testing program to evaluate materials for this application should consider resistance to crevice corrosion as well as resistance to general corrosion.

The failure was initiated as multiple corrosion-fatigue cracks. The slow development of these cracks leading to the ultimate failure was not influenced materially by the presence of stringers of free ferrite. Pitting corrosion was definitely accelerated by the sulphides.

The appearance of most of the fracture surface was characteristic of sudden failure. This indicates that the mid-length of the roll was highly stressed in operation. This suggests that the roll should be made of higher strength material or have a redesigned section at mid-length for greater strength and rigidity. These are matters of concern to the designer and manufacturer.

Type 416 would have greater strength and corrosion resistance, with good machinability, if oil quenched and tempered at 1200°F rather than process annealed. Type 416 quenched and tempered at 1200°F would have a fatigue limit in a non-corrosive environment of about 55,000 psi. Alternatively, annealed Type 430F or 430F (Se) has about the same tensile properties as annealed Type 416 but because of lower carbon content (0.12% max) and higher chromium content (14.0 to 18.0%) they has superior corrosion resistance.

The problems associated with the use of stainless steel in suction press rolls can best be overcome if experience is pooled and if all concerned parties including the manufacturer are kept fully involved and informed.

CONCLUSIONS

Based on examination of a small part of the failed roll and the report that the failure was transverse and at mid-length, the following conclusions were reached:

1. The failure initiated as a result of crevice corrosion and pitting corrosion in the outer half-inch of the bored holes, combined with high alternating fatigue stresses. These factors produced multiple corrosion-fatigue cracks.

2. The roll was highly stressed at the region of failure. This was evident from the high proportion of the fracture surface which was characteristic of abrupt fracture.

3. The roll was made of steel essentially conforming to the composition specifications for AISI Type 416 resulphurized stainless steel.

4. The steel was in the process-annealed condition, having a hardness of Rockwell B85 (Brinell 162) and a microstructure of spheroidized carbide in a matrix of ferrite.

DKF/gm

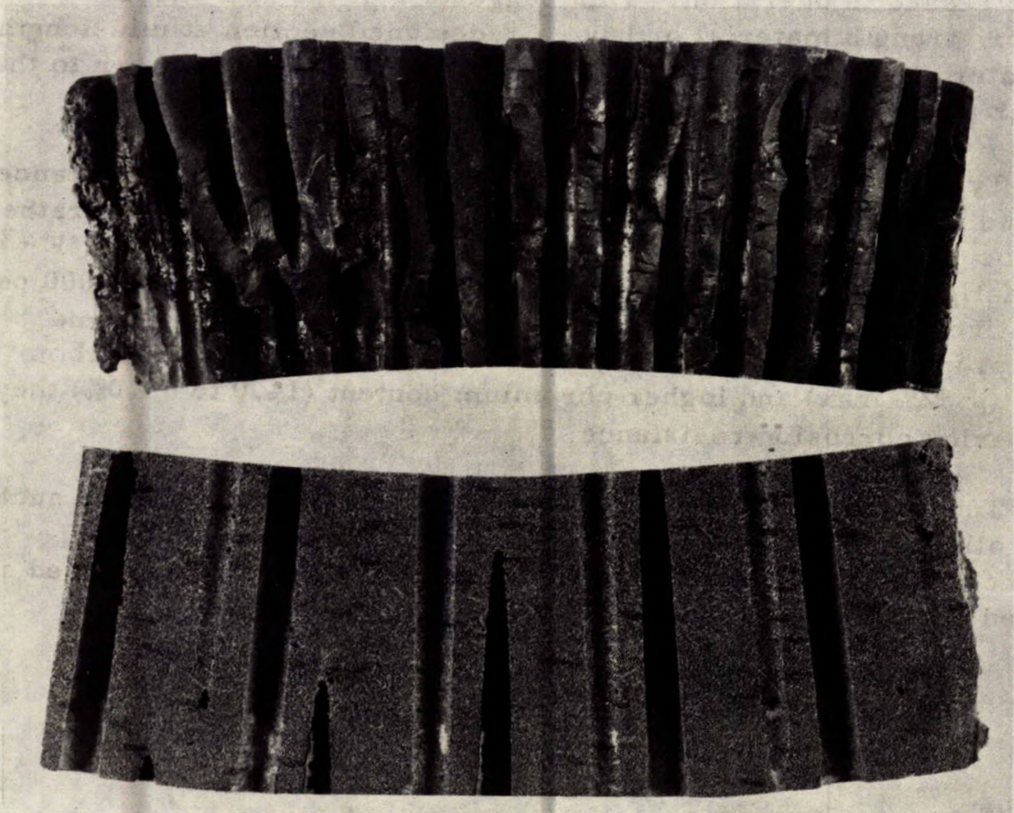

Figure 1. Portion of Failed Firth FCS-1 Stainless Steel Suction Roll - No. 8 Paper Machine - Second Press Section - E. B. Eddy Job 87-5168 (actual size)
Upper: Fracture Surface (transverse fracture at mid-length of the roll)
Lower: Macro-etched section parallel to the fracture surface.

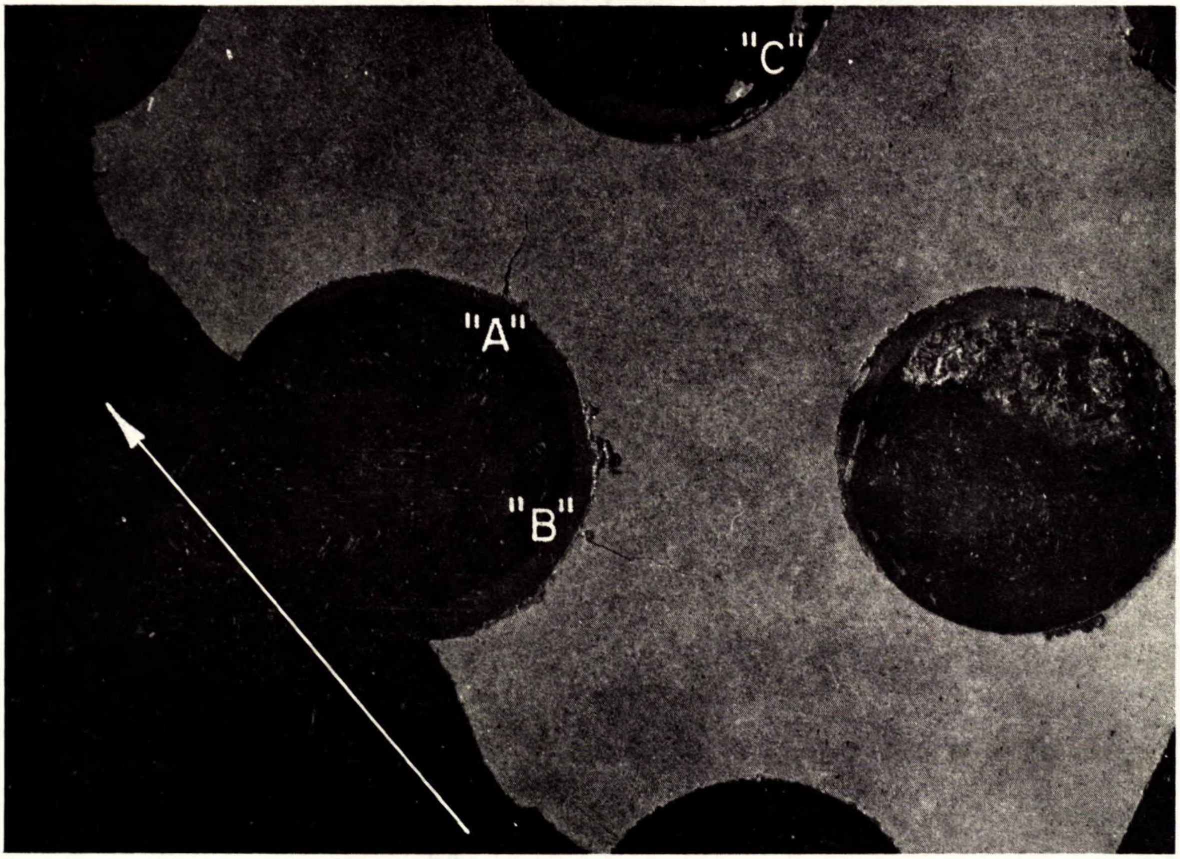

Figure 2. Macrophotograph showing corrosion pits and dense adherent deposits in the suction roll holes. The main fracture cuts across the lower left part of the field in the direction of the arrow. Small cracks are visible at locations "A", "B" and "C". Etched in Vilella's reagent. (X9)

Figure 3. Crack radiating from corrosion pits at location "A" in Figure 2. This crack started in the direction of inclusion stringers and then turned 90 degrees to the left to parallel the main fracture. Etched in Vilella's reagent. (X500)

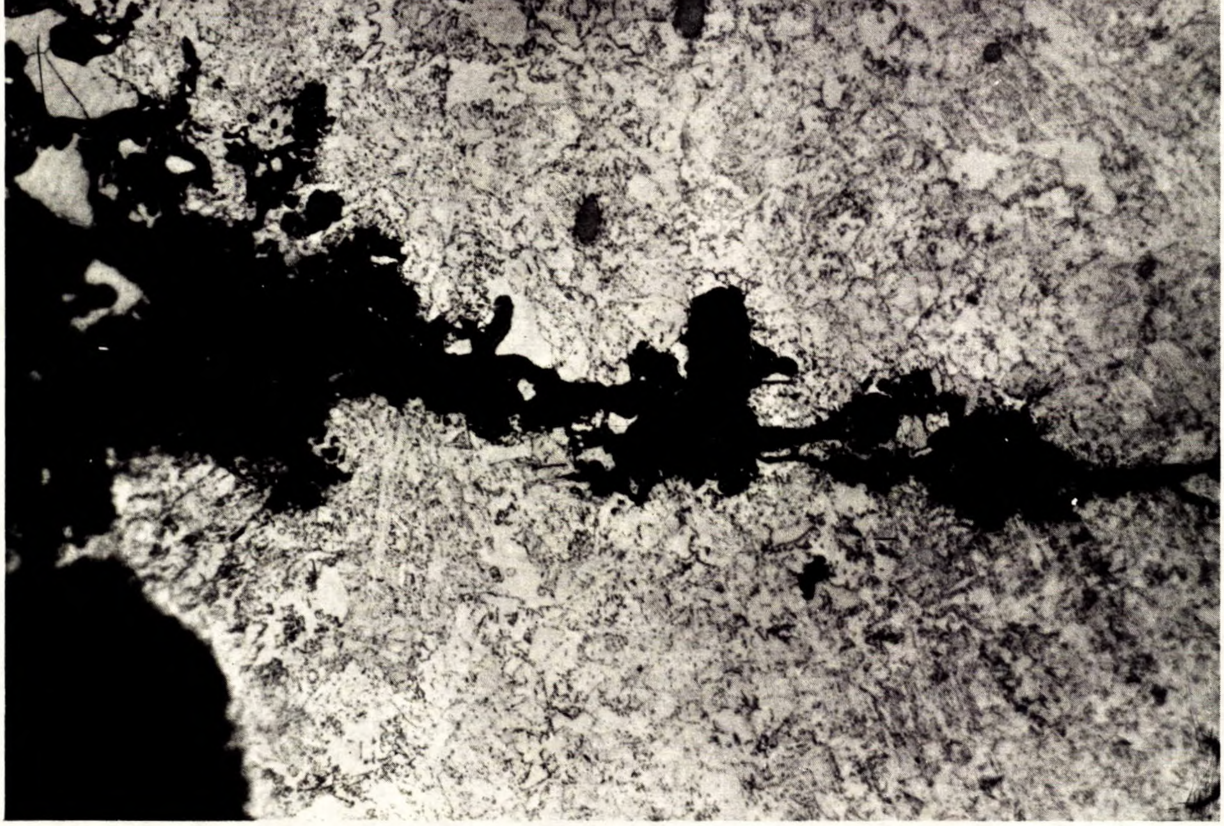

Figure 4. Crack radiating from corrosion pits at location "B" in Figure 2. The path of this crack is directly across the longitudinal forging direction. Pitting and general corrosion attack within the crack is evident. Etched in Vilella's reagent. (X500).

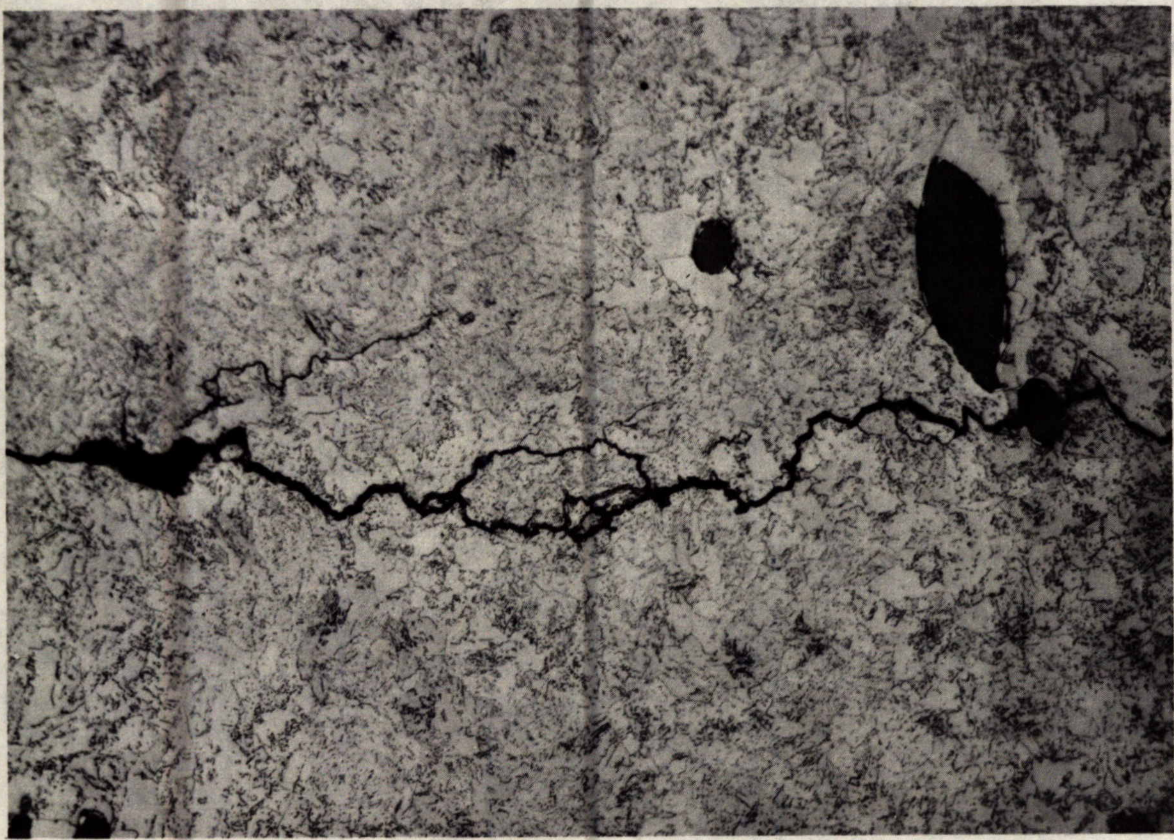

Figure 5. Photomicrograph of cracked region "C". This is a representative field, where the path of the crack has not been obscured by corrosion, showing that the cracks progressed intergranularly without many secondary cracks. Etched in Vilella's reagent. (X500)