Dealing with localized corrosion of paper machine felt-roll journals

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As paper mill white waters lean toward higher corrosivity and paper machine sizes, speeds, and felt tensions increase, there will be increasing demands on materials for roll journals.

MacMillan Bloedel Ltd. wanted to ensure the safe operation of felt-roll journals at one of its pulp and paper mills. Failures of low-alloy steel journals and 17-4PH‡ stainless steel journals had occurred, causing equipment damage and downtime. Journal damage also constituted a possible safety hazard.

Failure analysis identified corrosion fatigue as the cause of failure of UNS G41400 journals. Fatigue failure of 17-4PH stainless steel journals (UNS S17400) initiated at pitting and crevice corrosion. Evidence of stress corrosion cracking also was found at the failure origin.

Laboratory corrosion testing was performed to evaluate candidate alloys for replacement journals. The study established criteria for replacing failed journals and protecting others in service from corrosion attack.

This paper reviews early materials performance, then summarizes the findings of the investigative research.

Journal failures

Existing rolls were reused as part of a paper machine rebuild, but the journals were changed from 1020 carbon steel because higher journal stresses were expected. Journals made of 4140 alloy steel began to fail by corrosion fatigue within one year after the rebuild. The journal stresses calculated for the 19 rolls involved ranged from 4760 psi to 18,106 psi. The design allowable stresses were 8250 psi for 1020 and 16,850 psi for 4140. Four of the 19 rolls were expected to experience tensile stress above 14,000 psi. The first three failures, however, occurred in a roll position where the design stress was only 10,210 psi.

The journals were again changed as part of a subsequent roll replacement program. The journal design was modified to reduce stress concentrations at radiused steps in diameter. The maximum bending stress for the new design was calculated to be less than 10,000 psi. To increase corrosion resistance, 17-4PH precipitation hardening martensitic stainless steel was used for the new journals.

The precipitation hardening stainless steel had the strength of the alloy steels it replaced. Based on published data, we thought that the 17-4PH journals would resist the corrosive deposit/spray environment of the paper machines. The 17-4PH journals were phased in on three paper machines beginning in 1986, and we believed the problem was solved.

In 1990, however, a 17-4PH journal failed after only 10 months of service. The roll position was the second highest stressed on the paper machine (but, as noted earlier, the journal's nominal stress was less than 10,000 psi). The failed journal had been painted, but had experienced widespread pitting. The machined surface was very rough despite a specification for polishing of radiused surfaces. The failure initiated at a small (approximately 1/16-in. diam.) corrosion pit. Scanning electron microscopy showed the pit was bordered by a semicircular halo of stress corrosion cracking (SCC). Beyond this small halo the fracture surface had characteristics of both fatigue and SCC. Visually the fracture appeared to be pure fatigue.

Investigation showed the journal had not received the specified H1100 heat treatment but had been left in the solution annealed condition A. Condition A material is known to have lower fatigue resistance.

Small samples were cut from all 17-4PH journals to check the heat treatment. The failed journal was the only one with improper heat treatment.

A 5-wt% solution of fiber deposit found on the journal yielded a pH of 2.9. The water extractable chloride ion content of the deposit was 170 ppm(expressed as ppm of the o.d. deposit).

In 1991, another 17-4PH journal failed after about one year of service. The failed journal had received the correct heat treatment and had not been painted. The machined surfaces had not been polished but did not have the rough machining marks of the previous failure.

I. Typical room-temperature mechanical properties of alloys considered for felt-roll journals

Alloy	Heat treat condition	Tensile strength, ksi	Yield strength, ksi	Ductility, %	Hardness (Brinell)	Charpy V-notch (ft.-lb.)
17-4PH[a]	H1100	150	135	17	332	45
15-5PH[a]	H1100	150	135	17	332	45
PH13-8Mo[a]	H1100	160	150	18	331	60
2205 DSS	Annealed	90 min.	65 min.	25 min.	290 max.	74 min.
Custom Age 625 PLUS[b]	Double aged (1350°F/1150°F)	181	130	30	375	74

[a]Registered trademark of Armco Inc.
[b]Registered trademark of Carpenter Technology Corp.

The fatigue/SCC causing failure initiated at a band of crevice corrosion under the edge of a cast-iron bearing flinger.

We felt that the deposits formed on the rolls had become more corrosive (*i.e.*, lower pH) since 1989 due to changes in the pulping and bleaching process. We also suspected that some journals were seeing higher loads due to intermittent high felt tensions. Procedures were implemented to monitor felt tension and to clean the journals regularly. A journal inspection program using shear wave ultrasonics and wet fluorescent magnetic particle examination was also begun. However, inspection was not viewed as a permanent solution because of the expense and downtime involved. An increase in journal diameter to further reduce stresses was not possible.

Laboratory study

A laboratory study was undertaken at MacMillan Bloedel Research to evaluate candidate replacement alloys and provide the means to protect the existing 17-4PH journals. The investigation consisted of cyclic polarization crevice corrosion testing, potential monitoring, and slow strain rate testing for SCC resistance.

Electrochemical tests

Electrochemical tests (cyclic polarization) were carried out at 60°C in an aggressive simulated white water environment containing 400 ppm NaCl and 200 ppm Na_2SO_4 at pH 2.9 to determine the localized (crevice) corrosion resistance of 17-4PH and several alloys considered as replacement materials. This type of attack occurs under pulp pads, damaged paint coatings, and flinger assemblies. Our test solution approximated the environment under a pulp pad.

All of the potential replacement alloys showed significantly higher resistance to crevice corrosion attack than that offered by 17-4PH.

Potential monitoring

Potential monitoring was done to determine the feasibility of protecting existing journals to achieve a reasonable service life. Journals would be replaced with a higher alloy as required. To this end, 17-4PH electrodes were coupled with zinc or aluminum to depress the corrosion potential of 17-4PH below the value where crevice corrosion could occur. Three 17-4PH electrodes were prepared and fitted with a Viton O-ring to form a reproducible crevice. One specimen was coupled to a zinc anode, another to an aluminum anode, and the third was tested unprotected. All tests were carried out in the aggressive white water environment simulating that under a pulp pad.

A platinum anode also was used for redox potential monitoring. The platinum electrode was used to indicate whether potential fluctuations observed for the test electrodes were due to corrosion processes or environmental changes.

Tests with the unprotected 17-4PH electrode confirmed field observations that 17-4PH stainless steel has insufficient resistance to crevice corrosion attack in aggressive paper machine white waters.

The potential of the 17-4PH electrode coupled with aluminum was steady and low, well below the value where there is danger of crevice corrosion.

The 17-4PH specimen coupled with zinc pitted under the crevice O-ring. At 60°C—close to the maximum journal operating temperature—zinc can become cathodic relative to 17-4PH, thereby causing it to corrode at an accelerated rate.

Slow strain rate testing

Slow strain rate testing (SSRT) was conducted to determine the possibility of hydrogen embrittlement occurring in cathodically protected 17-4PH. A control specimen was tested in air to establish baseline strength and ductility. Failure occurred in 10 days.

A second SSRT specimen was fitted with a Viton O-ring to produce a crevice, then immersed in the aggressive white water solution. It suffered localized attack and failed in less than five days. Failure initiated at a site of crevice corrosion under the O-ring. From this site, stress corrosion cracking then propagated.

Ultimate failure of the specimen was due to ductile overload, after SCC had progressed enough to weaken the speci-

II. Breakdown potentials of possible felt-roll journal alloys

Alloy	*mV vs. standard calomel electrode*
17-4PH	85
15-5PH	205
PH13-8Mo	529
2205 DSS	646
Custom Age 625 PLUS	Immune (no breakdown)

men. This sequence is similar to the mechanism that occurred in both felt roll-journal failures where pitting led to SCC, which propagated via fatigue crack growth and final ductile failure.

A third SSRT specimen was fitted with a Viton O-ring and held at –400 mV vs. SCE (as if coupled with aluminum) using a potentiostat. Hydrogen embrittlement did not occur. The area beneath the crevice ring was unaffected, and no signs of either crevice or general corrosion were evident.

Alternative alloys

Four alloys were considered as possible alternatives to 17-4PH. To qualify as an acceptable replacement material, an alloy had to have better corrosion resistance than 17-4PH and comparable mechanical properties. **Table I** shows typical mechanical properties of alternative alloys for felt roll-journal service.

Evaluation showed that 15-5PH‡, a "clean" version of 17-4PH, had somewhat greater resistance to localized attack than 17-4PH. However, its resistance to such attack was found to be insufficient for aggressive white water service.

Tests were also conducted on PH13-8Mo‡, a modification of 17-4PH containing molybdenum as an alloying addition. Molybdenum imparts increased resistance to localized corrosion. This alloy was found resistant to localized corrosion in aerated white water. However, it could not be ascertained that the alloy would be immune to corrosion in more severe under-deposit environments.

Further testing showed that 2205 duplex stainless steel (DSS) exhibited good localized corrosion resistance in white water environments. This alloy, however, was not considered a good replacement material because its mechanical strength is not as high as the precipitation hardening stainless steels. The yield strength of 17-4PH in condition H1100, for example, is about twice that of annealed and quenched 2205 DSS.

The final material evaluated was Carpenter Technology's Custom Age 625 PLUS‡ alloy. This precipitation hardenable nickel-base alloy, with its minimum 7% Mo composition, was found to be immune to corrosion in the tested white water environment. In the age hardened (high strength) condition, Custom Age 625 PLUS alloy offers exceptional resistance to stress corrosion cracking, as well as general pitting and crevice corrosion.

Breakdown potential values determined by cyclic polarization for each of the alloys are summarized in **Table II.**

A yield strength (0.2% offset) above 120 ksi (827 MPa) can be obtained by aging Custom Age 625 PLUS alloy without prior warm or cold working. In the "double aged" (1350°F + 1150°F) condition, this newly developed alloy has mechanical properties comparable or superior to 17-4PH stainless steel in condition H1100.

In addition, the fatigue properties (**Fig. 1**) of Custom Age 625 PLUS alloy are slightly better than those of other precipitation hardening alloys. It has a fatigue endurance limit of 50% of yield, compared with 45% for pH stainless steels.

Custom Age 625 PLUS alloy can be machined in either the solution-treated or age-hardened condition. As with all nickel-base alloys, a high work hardening rate dictates careful attention to machining parameters. Equipment must have ample power and be very rigid.

Cutting tools must have smooth finishes and be very sharp. A continuous smooth cutting action should be maintained. Light feeds should be avoided. An ample supply of coolant must be maintained. In general, machining procedures similar to those used for Alloy 718 are suggested.

For its immunity to localized corrosion, its excellent mechanical properties, and peace of mind, Custom Age 625 PLUS alloy was the replacement material recommended.

Protecting existing journals

To get as much service as possible from existing 17-4PH stainless-steel journals, methods were investigated to prevent the initiation and propagation of localized corrosion. Using zinc for galvanic protection was ruled out because of its unstable anodic/cathodic behavior at 60°C. However, we found that using aluminum as a sacrificial anode would provide enough galvanic protection to prevent crevice corrosion of 17-4PH.

Aluminum could be applied in several ways to provide protection against localized corrosion. Aluminum thermal spray coating was determined to be the most practical method for protecting 17-4PH journals. But this process presented a downside to be considered.

Applying an aluminum thermal spray coating would require removal of rolls from service. Journals would have to be prepared with a fine-grit blast then, after thermal spraying, receive a protective coating to prevent general corrosion of the aluminum layer. An organic paint coating or wax tape covering would protect the aluminum from corrosion.

Special care would be required after coating to avoid coating damage. Flingers would have to be modified to prevent damage when tightening set screws. Wire rope slings could not be used to remove the rolls because they could damage the journal top coat.

It was believed inevitable that gouging or chipping of the coated surface would occur in normal service. Any surface damage would have to be repaired as soon as it became apparent.

Aluminum foil could be used to protect the journal surface by acting as a physical barrier and also provide galvanic protection if the journal were to come in contact with the white water. However, it is difficult to apply foil under the flingers, which are prime areas for crevice attack. In addition, mill exposure tests indicated that aluminum foil would have limited useful life in white water service because it suffered heavy general corrosion. Additional protection such as wax tape coating would be required.

Finally, the feasibility of replacing cast-iron and mild-steel flingers with an aluminum alloy was considered. Aluminum bearing flingers would help guard against crevice attack in this vulnerable area. However, protection would not extend to exposed journal surfaces where pulp pads could form. Complete protection would require aluminum thermal spray coating of the journal.

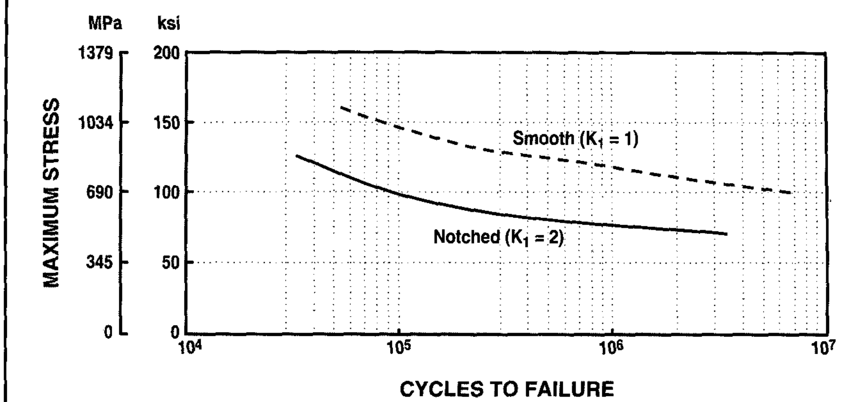
At the conclusion of the study, a recommendation was made to remove 0.025 in. of stock from existing 17-4PH journal surfaces (0.050 in. from the diameter) of each felt roll removed from a paper machine. This would remove the localized corrosion attack in most cases, while not significantly impairing mechanical properties. The journals would then be metallized with aluminum in accordance with the procedures outlined previously. If the localized corrosion was not eliminated after 0.025-in. stock removal, the safest course would be to scrap and replace the journals.

After consideration of these results, the mill opted for replacement of critical service journals (highly stressed, corrosive spray environment, cracked journals) in Custom Age 625 PLUS alloy. The operator's preference is naturally for a material that requires a minimum of care and inspection.

The use of aluminum for galvanic protection was not viewed favorably because of questions about its durability and because any form of coating could interfere with magnetic particle testing and shear wave ultrasonics.

1. Axial fatigue properties of Custom Age 625 PLUS alloy

Solution treated and aged 6.0-in.-diam. (152 mm) bar.
Heat treatment: 1900°F (1038°C) 1 h. air cooled + 1350°F (732°C) 8 h. furnace cooled to 1150°F (621°C) 8 h. air cooled. Longitudinal mid-radius specimens.
Frequency = 1750 cpm. R-Factor = 0.05.
130 ksi yield strength, 181 ksi tensile strength, 35% elongation, 55% reduction of area.



As paper mill white waters lean toward higher corrosivity and paper machine sizes, speeds, and felt tensions increase, there will be increasing demands on materials for roll journals. Custom Age 625 PLUS alloy has been viewed as the "ultimate solution," but we must caution that no material should be considered forever immune to failure in dynamic service.

Journals on the paper machines in question here run at about 600 rpm and can thus see up to 3×10^8 cycles per year. Fatigue strength data at 10^9 or 10^{10} cycles would thus be needed to fully support materials selection. Unfortunately, such data is almost never available when practical decisions must be made. Therefore, paper machine journals could be considered as large fatigue test coupons to determine the true long-term fatigue strength of a material as influenced by corrosion and surface condition.

For this reason, regular inspection at appropriate intervals is still required to prevent in-service failures. TJ

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