

A suction-roll shell material with improved corrosion-fatigue strength

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ABSTRACT: Alloy 86 is a patented duplex stainless steel that has high corrosion-fatigue strength and enhanced pitting corrosion resistance in highly corrosive acidic white waters containing chloride and thiosulfate anions.

KEYWORDS: Alloy steel, corrosion, corrosion mechanisms, corrosion resistance, electrochemistry, evaluation, fatigue resistance, force, loads, machine components, mechanical properties, notches, performance evaluation, pitting, rolls, sensitivity, shells, stainless steel, steel, stresses, tensile stress, vacuum rolls, waste waters, white water.

Papermaking technology is continually undergoing change which requires the development of new and improved corrosion and corrosion-fatigue resistant suction-roll shell materials. In recent years, paper machine speeds for some paper grades have increased dramatically. Some tissue machines are operating in excess of 1800 m/min (5906 ft/min), and a few newsprint machines are operating in excess of 1200 m/min (3937 ft/min). It has become necessary to double-nip suction-roll shells to maintain press section efficiency in faster machines. This change will increase the number of load cycles a suction-roll shell experiences per revolution and in a given period of time. Faster paper machines can result in increased nip loading requirements in the press section.

Machine widths have been increasing, requiring longer suction-roll shells of increased diameter. Longer shells will experience increased bending

loads. Obviously, the papermaker requires suction-roll shell materials with high corrosion-fatigue strength to optimize suction roll performance.

In addition to increasing operating load requirements, suction-roll shells are being subjected to white waters of increasing corrosivity. Pulping and brightening of virgin fiber and deinking of secondary fiber can result in the introduction of thiosulfate anions into the wet end of the paper machine. Recent technical articles have revealed how the thiosulfate anion, in conjunction with sulfide, chloride, and hydronium ions (from use of alum and various acids), has promoted increased pitting and crevice corrosion of many suction-roll shell and paper machinery structural materials (1-11). Other recent technical articles demonstrate how the thiosulfate anion, in conjunction with other corrosive ions, reduces the corrosion-fatigue strength of suction-roll shell materials (12) and adversely af-

fects fatigue-crack growth-rate characteristics (13). White water corrosivity can be expected to increase further as a result of white water system closure (14, 15) and microbiological activity (16, 17). Felt and shell cleaning practices, as well as wire-life-extension chemicals, also may promote increased corrosion of suction-roll shell materials.

An important factor which cannot be overlooked is that a successful suction-roll shell material, in addition to having increased general corrosion resistance and high corrosion-fatigue strength, also must have very low tensile residual stresses. Tensile residual stresses are produced in a suction-roll shell as a result of nonuniform cooling after any thermal processing step. High tensile residual stresses, in addition to normal operating loads (stresses), have been shown to be detrimental to the operating life of Alloy 63, a highly corrosion-fatigue-resistant material (18). The effect that high tensile residual stress can have on the performance of a material can be modeled by applying a mean stress in fatigue testing.

Alloy 75, a duplex stainless steel, was introduced in 1975 and was developed to take advantage of the increased strength and crack growth resistance characteristics of duplex stainless steels. The chemical composition of Alloy 75 allows this material to be slowly cooled to produce the lowest tensile residual stresses contained in any duplex stainless steel suction-roll shell material in the industry. Although this material has had an excellent operating history, in recent years pitting has been reported in a few mills containing

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Corrosion

a high level of the thiosulfate ion in white water process streams.

A duplex stainless steel suction-roll shell material that is superior to Alloy 75 should demonstrate improved resistance to localized forms of corrosion, such as pitting, in more corrosive white waters. Pitting acts as a stress raiser and can promote early crack initiation under cyclic-loading conditions. The material also should have the lowest tensile residual stresses attainable to promote longer life under increasing cyclic-load requirements. Therefore, the new material, like Alloy 75, should be able to be relieved of harmful tensile residual stresses by a slow-cool heat treatment without formation of unacceptable brittle phases (19). The material also should have improved corrosion-fatigue strength and demonstrate increased resistance to fatigue-crack initiation and growth in corrosive white waters. The material should not be notch sensitive.

For example, cracking of suction-roll shells has occurred under normal operating conditions as a result of grooves being introduced on their inside surfaces from scoring under normal operating conditions. These grooves acted as stress raisers, and cracking was observed to initiate at the base of the grooves.

Alloy 86, a duplex stainless steel, was developed to satisfy the needs and requirements described in previous paragraphs. Initial pitting-resistance test results and R. R. Moore corrosion-fatigue strength data in simulated corrosive white waters have been reported earlier (19). Alloy 86, as a result of its chemical composition and proprietary stress-relieving heat treatment, has very low tensile residual stresses, comparable to those levels determined in Alloy 75.

In this paper, we present the results of corrosion-fatigue tests involving axially loaded Alloy 86 and Alloy 75 materials with and without various levels of mean stress. Notch sensitivity was investigated under axially loaded conditions. Additional electrochemical studies were conducted to further evalu-

I. Typical chemical composition and tensile properties

Alloy	Chemical composition, wt%						
	C	Cr	Ni	Mn	Si	Cu	Mo
86	0.02	26.0	6.8	0.8	0.75	2.0	...
75	0.02	26.0	6.8	0.8	0.50	...	...

Alloy	Tensile properties		
	0.2% Offset yield, MPa (ksi)	Ultimate tensile strength, MPa (ksi)	% Elongation in 51 mm (2 in.)
86	403 (58.5)	759 (110.1)	17
75	430 (62.3)	778 (112.8)	20

ate the pitting resistance of these materials.

Suction-roll shell lifetime may be divided into two segments: time to crack initiation and the time required for a crack to propagate to a critical crack length whereupon catastrophic failure occurs. This paper includes the results of evaluation of the fatigue-crack growth rate characteristics of Alloy 86 and Alloy 75. The evaluation of Alloy 86 and additional suction-roll shell materials by other investigators is cited to confirm our results.

Experimental procedures

Materials

Test specimens were machined from centrifugal castings in these studies. Table I contains typical chemical composition data and tensile properties of the test materials.

Three types of tests were performed: axial-loading corrosion-fatigue, corrosion-fatigue crack propagation, and electrochemical pitting resistance. Test procedures employed in each experiment are described in the following subsections.

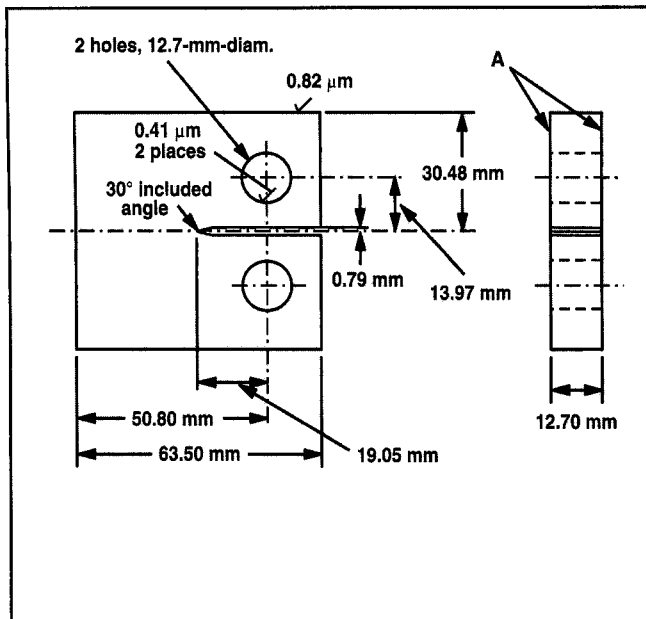
Axial-loading corrosion-fatigue experiments

Specimens were machined from near the outside surface of rings cut from production centrifugal castings and were oriented so that their longitudinal axis was in the same direction as the longitudinal axis of the centrifugal casting. Two types of corrosion-fatigue specimen configurations were evaluated: smooth specimens were used to measure the inherent corrosion-fatigue resistance of the materials, and notched specimens were used to evaluate the effect of stress concentration on corrosion-fatigue resistance.

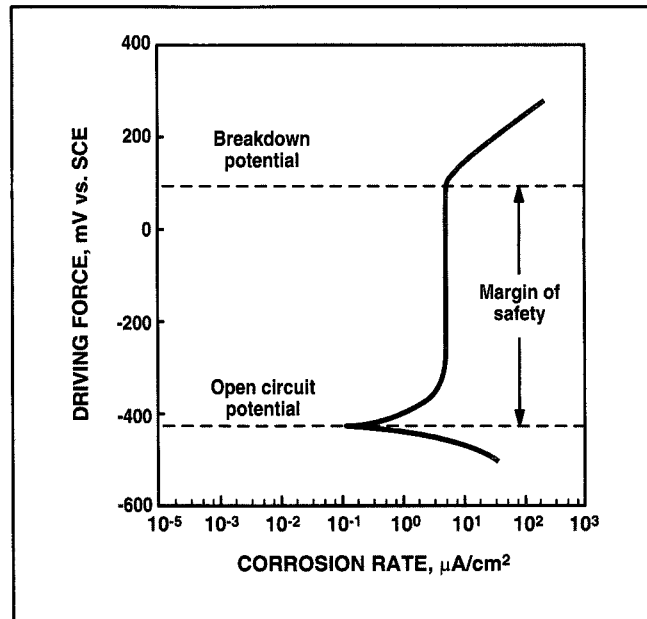
Smooth and notched specimen configurations and surface preparations are discussed in the original paper on this subject (20).

Smooth specimens had a 6.35-mm (0.250 in.) gauge-length diameter test section with no notch. The theoretical stress concentration (K_t) for the smooth specimen was equal to 1.0 (21). Notched specimens had a 7.30-mm (0.288 in.) gauge-length diameter with a circumferential notch at the midspan. The minimum diameter of this specimen at the root of the notch was 6.35 mm (0.250 in.), and the notch-root radius was 0.81

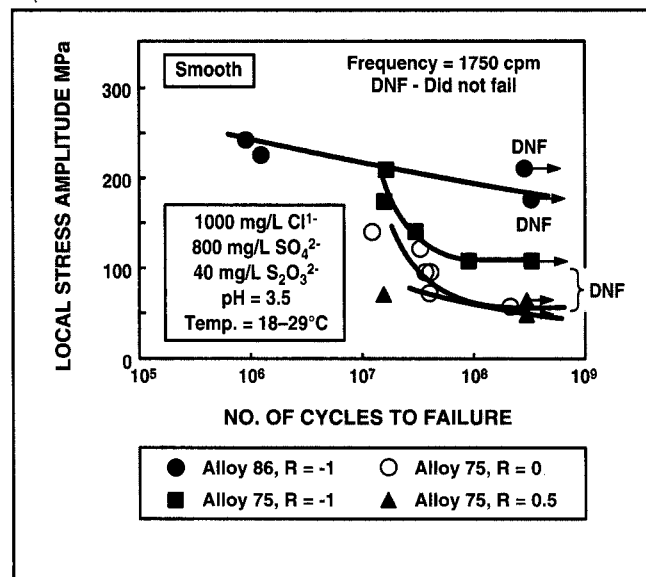
1. Fatigue-crack-growth-rate specimen configuration. "A" surfaces should be perpendicular and parallel as applicable to within 0.10 mm.



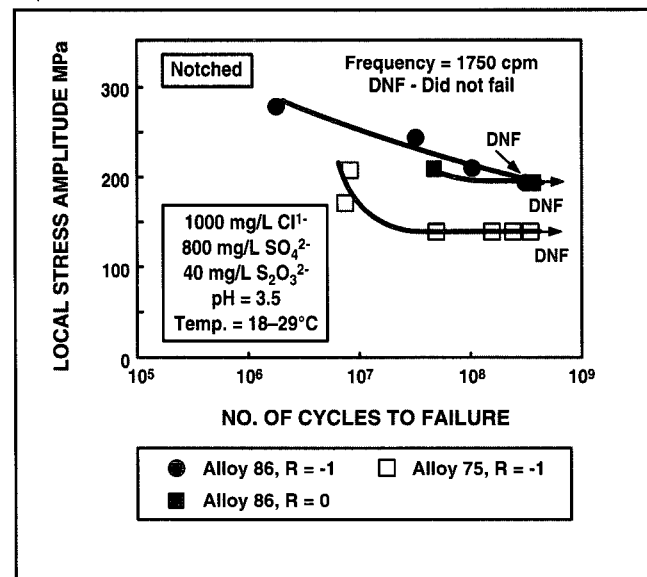
2. Typical pitting polarization scan



3. Axial corrosion-fatigue test results for Alloy 86 and Alloy 75 smooth ($K_t = 1$) specimens



4. Axial corrosion-fatigue test results for Alloy 86 and Alloy 75 notched ($K_t = 2$) specimens



mm (0.032 in.). Based on these specimen dimensions, K_t was equal to 2.0 (21).

Axial-loading corrosion-fatigue experiments were performed using Krouse axial mechanical testing machines operated at approximately 1750 rpm. These machines produced a sinusoidal stressing pattern with a frequency of approximately 1750 cycles

per minute. With these machines, the mean load could be varied to apply a mean stress to the specimen to simulate the effects of tensile residual stress or mean loads that may be encountered under actual service conditions, or both. Stress versus number-of-cycles-to-failure (S-N) curves were developed for specimens tested at three values of stress ratio (R): $R = -1$, $R = 0$, and $R =$

0.5, where R is the ratio of the minimum to maximum applied stress.

Specimens were cycled until complete fracture occurred, at which point the test machine and load cycle counter shut off automatically, or until a test was stopped without failure. During each test, a solution of simulated white water at room temperature was sprayed onto the vertically oriented

II. Axial corrosion-fatigue best-fit constants

Alloy	Test conditions		Best-fit constants in Eq. 2			Standard error of estimate
			b_1	b_2	b_3	
A86	Smooth, $K_t = 1$	$R = -1$	51.76	-19.18	0.00	0.98
A75		$R = -1$	8.28	-0.54	102.29	0.24
		$R = 0$	8.56	-0.64	49.53	0.15
A75		$R = 0.5$	16.74	-4.99	0.00	0.48
A86		$R = -1$	39.46	-13.54	0.00	0.26
A86	Notched, $K_t = 2$	$R = 0$	8.12	-0.40	192.96	...
A75		$R = -1$	7.71	-0.48	137.80	0.32

test section of the specimen every 60 seconds, which was sufficient to ensure that the metal surface remained wetted throughout the test. Fresh solution was prepared about twice a week and excess solution that was collected after it dropped off of the specimen was discarded (it was not recirculated). The simulated white water solution was prepared in the same manner as described in the previous work of Jaske and Castillo (12).

Corrosion-fatigue crack-growth-rate studies

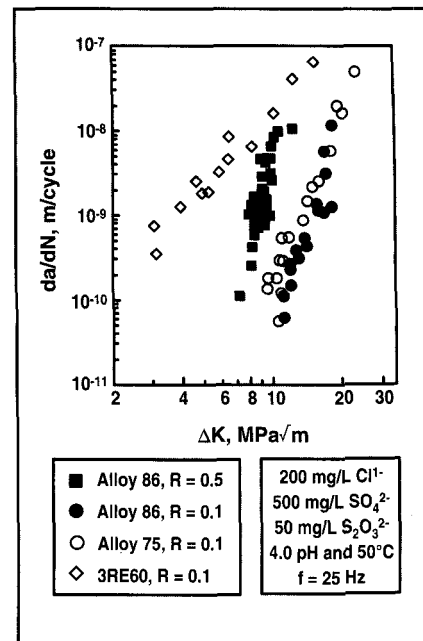
Alloy 86 specimens were taken from rings cut from production centrifugal castings and were oriented so that their loading axis was in the same direction as the longitudinal axis of the original casting and the direction of crack propagation was in the circumferential direction of the original casting. This crack-plane orientation is commonly designated by the code L-C (22) and corresponds to the most likely direction of crack propagation in an actual suction-roll shell. After completion of machining, the specimens were thoroughly degreased using reagent-grade

acetone followed by rinsing with ethyl alcohol before testing.

Near-threshold corrosion-fatigue crack-growth-rate studies were performed using 12.70-mm-thick (0.500 in.) by 50.80-mm-wide (2.000 in.) standard compact-type specimens. Specimen configuration details are shown in Fig. 1. The experimental procedures were in accordance with American Society for Testing and Materials (ASTM) E647 (23) and patterned after those used by Yeske (13, 24). An electrohydraulic testing system, operating in closed-loop load control, was used to perform the tests. The load was controlled to follow a sinusoidal waveform with a cyclic frequency of 25 Hz and a constant value of either $R = 0.1$ or $R = 0.5$. Load shedding (that is, periodically decreasing the load range) was used to gradually reduce the rate of crack growth and obtain meaningful data in the near-threshold region. A digital computer was used to acquire the crack-length data and to control the sequence of load shedding.

The crack length during testing was measured by use of a Krak-Gage[®] cemented to one face of the specimen, rather than by using optical readings,

5. Near-threshold corrosion-fatigue crack-growth-rate test results for Alloy 86, Alloy 75, and 3RE60



as in the work of Yeske (25). The output of the Krak-Gage was verified by making a few optical readings of crack length on the opposite face of the specimen and by measuring the final crack length at the end of the test. In some experiments, the dc electrical potential method also was used to measure crack length and provide backup data to the Krak-Gage measurements. These crack-measurement procedures allowed the tests to be automated so the specimens could be cycled continuously.

During load shedding, each reduction in load range was to a value 10% below the prior load range. When the load range was decreased in this manner, there was a slight retardation of crack growth until the crack grew through the crack-tip plastic zone associated with the previous load range, and the data were not considered valid until the crack had grown beyond this zone. The Irwin estimate of the plane-strain plastic zone size (r_p) was used to screen out the data considered to be invalid. The equation for estimating

*Krak-Gage is a registered trademark of Hartrun Corp., 88 Riberia St., St. Augustine, FL 32084.

III. Critical crack length corresponding to threshold for corrosion-fatigue crack growth (cyclic stress range = 55 MPa)

Alloy	ΔK threshold, MPa $\sqrt{m}$	Critical crack length 2a, mm
86	11	25.40
75	10	21.00
3RE60	3	1.89

IV. Critical stress corresponding to threshold for corrosion-fatigue crack growth (crack length = 2.54 mm)

Alloy	ΔK threshold, MPa $\sqrt{m}$	Critical stress, MPa
86	11	174.1
75	10	158.3
3RE60	3	47.5

plastic zone size is:

$$r_p = (1/3\pi)(K_{\max}/YS)^2 \quad (1)$$

where

$K_{\max}$ = the maximum stress intensity factor

YS = the 0.2% offset yield strength.

Thus, after a load-range decrease, the data were not considered valid until the crack grew an additional length greater than the value of r_p associated with the value of $K_{\max}$ at the previous load range. For example, if $K_{\max} = 22$ MPa $\sqrt{m}$ and $YS = 386$ MPa, then:

$$r_p = (1/3\pi)(22/386)^2 = 0.34 \text{ mm}$$

This indicates that an additional 0.34 mm of crack growth would be required before the data would be considered valid for the lower applied load range. The stress intensity factor range (ΔK) is $(1 - R)K_{\max}$; thus, for $R = 0.5$ in the above example, $\Delta K = (1 - 0.5)22 = 11$ MPa $\sqrt{m}$. The valid crack length (a) versus number-of-cycles (N) data were analyzed in accordance with the procedures of ASTM Designation E647 (23) to produce cyclic-crack-growth-rate (da/dN) versus ΔK data.

In some of the experiments, an additional strain gauge was secured to the back face of the specimen. The output from this gauge provided an indication of whether or not crack closure was occurring during a test.

Tests were conducted in the following simulated white water: deionized water containing 200 mg/L chloride ion, 50 mg/L thiosulfate ion, and 500 mg/L sulfate ion. The pH of the test solution was adjusted to 3.5 by sulfuric acid addition at room temperature. Tests were conducted at 50°C. This environment was used in Yeske's work (22).

Electrochemical studies

An electrochemical method was used to evaluate the pitting corrosion resistance of Alloy 86 and Alloy 75. Cylindrical test specimens were removed from production centrifugal castings, machined, and then polished as described in an earlier paper (20).

Anodic potentiodynamic polarization scans were conducted in a deaerated, corrosive simulated newsprint white water as described earlier (20). Additional pitting resistance electrochemical studies were conducted in a

simulated deinked newsprint white water solution. The solution was prepared by adding reagent-grade chemicals to deionized water and contained 100 mg/L chloride, 25 mg/L thiosulfate, 50 mg/L sulfite (SO_3^{2-}), and 320 mg/L sulfate anions. The pH was adjusted to 4.0 by sulfuric acid addition at 25°C. Testing was performed at 50°C. Pitting corrosion resistance was determined by obtaining breakdown and open circuit potentials and then algebraically determining a margin of safety value from each polarization scan, as shown in Fig. 2.

Alloys that have higher margins of safety possess greater pitting corrosion resistance.

Results and discussion

Axial-loading corrosion-fatigue studies

Results of the axial corrosion-fatigue tests of Alloy 86 are shown in Figs. 3 and 4, together with comparable results for Alloy 75.

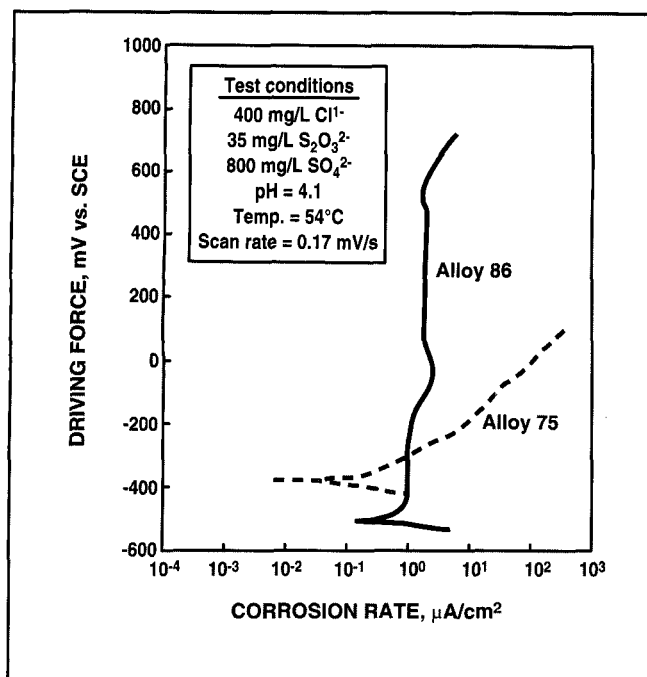
Figure 3 presents the data that were obtained from tests of smooth ($K_t = 1$) specimens, whereas Fig. 4 presents the data that were obtained from the tests of notched ($K_t = 2$) specimens. The data are plotted in terms of the local stress amplitude, which was equal to the nominal stress amplitude for the smooth specimens and was equal to twice ($K_t = 2$) the nominal stress amplitude for the notched specimens.

In both figures, each plotted symbol represents data obtained from a single specimen. Arrows associated with a specific symbol indicate that the specimen did not fail. Each trend line through the data represents a best-fit S-N curve for the associated set of data points. Best-fit S-N curves were obtained by linear least-squares regression analysis as described earlier (12).

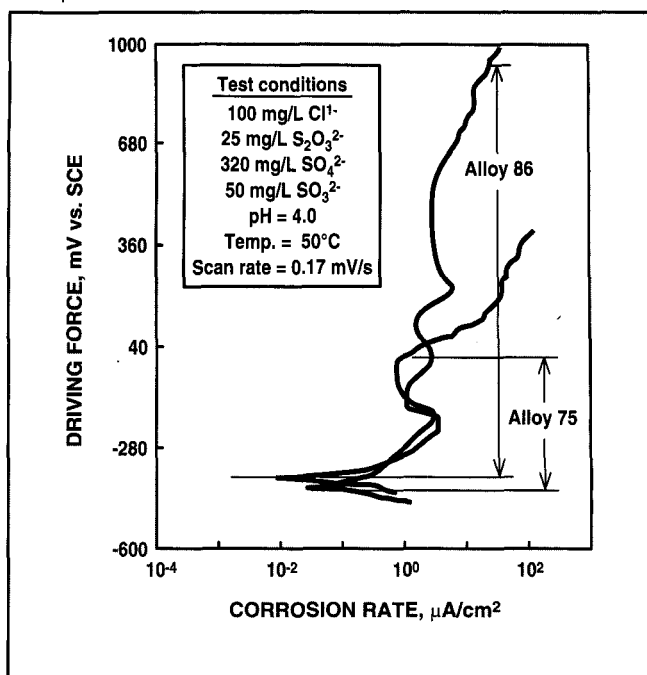
Best-fit values of b_1 , b_2 , and b_3 , in addition to the calculated standard error of estimate (standard deviation) values, are summarized in Table II.

The information in Table II can be used to estimate suction-roll shell ma-

6. Polarization scans for Alloy 86 and Alloy 75 in simulated corrosive newsprint white water



7. Polarization scans for Alloy 86 and Alloy 75 in simulated corrosive newsprint-deinked white water



terial average life for a given design stress or an estimated average design stress for a required average life. The design engineer must also include a safety factor in a final calculation to obtain a more conservative answer.

For example: Estimate the average life (N_f) for Alloy 86 at $R = -1$ and $K_t = 1$, for a stress (S) of 55.16 MPa (8 ksi).

Employing the equation

$$\log_{10} N_f = b_1 + b_2 \log_{10}(S - b_3) \quad (2)$$

one obtains

$$\log_{10} N_f = 51.76 - 19.18 \times \log S$$

$$\log_{10} N_f = 51.76 - 19.18 \times \log 55.16$$

$$\log_{10} N_f = 18.36$$

$$N_f = 2.27 \times 10^{18} \text{ load cycles.}$$

The design engineer must calculate a more conservative life estimate (N_f) by incorporating the suction-roll material safety factor.

The effect of a notch can be incorporated in the calculation by use of design factors greater than unity. This would have the effect of reducing a given material's average life.

Using Eq. 2, the design engineer can also estimate the maximum aver-

age stress a material can experience when an average-life value is required; just solve for S and calculate the answer using the appropriate regression constants.

As shown in Fig. 3, data at $R = -1$ are available for smooth specimens of Alloy 86, whereas data at three stress ratios ($R = -1$, $R = 0$, and $R = 0.5$) are available for Alloy 75. The evaluation of Alloy 86 is continuing. Alloy 86 has greater axial corrosion-fatigue strength at $R = -1$ than Alloy 75 (compare filled circles with open circles in Fig. 3). For Alloy 75, increasing the value of R , which corresponds to increasing the mean stress, clearly caused a decrease in corrosion-fatigue strength. A similar reduction in corrosion-fatigue strength performance is expected with Alloy 86 and other duplex stainless steels as the R value or mean stress level is increased. For this reason, it is very important that the R value or operating mean stress level of suction-roll shells be kept to a minimum in actual service applications. The impact of increasing R value also shows that tensile residual stresses, in addition to operating mean stresses, if kept

to a minimum, will maximize the service life of suction-roll shell materials.

The corrosion-fatigue strength of Alloy 86 was greater than that of Alloy 75 for the notched specimens, as illustrated in Fig. 4. Most of the data for the notched specimens were for fully reversed loading ($R = -1$). Specimens of Alloy 86 which were evaluated under an imposed mean stress condition at $R = 0$ (filled squares) exhibited similar corrosion-fatigue strength compared to values obtained under a zero-mean stress condition of $R = -1$ (filled circles).

Comparing Fig. 4 with Fig. 3 shows that notched Alloy 86 and Alloy 75 specimens had about the same or slightly higher corrosion-fatigue strength performance (in terms of local stress amplitude) than did the same materials evaluated in the smooth condition at $R = -1$. These results indicate Alloy 75 and Alloy 86 have good corrosion-fatigue resistance at stress concentration sites. The stress concentration factor can be used by design engineers to conservatively estimate the corrosion-fatigue strength in the presence of a notch for these two materials in cases where only smooth speci-

Alloy	Margin of safety, mV	
	Simulated newsprint	Simulated newsprint-deinked
Alloy 86	1084	> 1200
Alloy 75	0	425

mens have been evaluated. These notched-specimen results are significant because the potential sites for corrosion-fatigue-crack initiation in suction-roll shells are at stress concentrations such as drilled holes, grooves, and localized corrosion (pitting) sites.

Corrosion-fatigue crack-growth-rate studies

Results of the near-threshold corrosion-fatigue crack-growth-rate tests for Alloy 86 versus two other materials are presented in Fig. 5.

Figure 5 is a logarithmic plot of the cyclic-crack growth rate versus the range of the stress intensity factor. Data for Alloy 86 were developed at $R = 0.1$ (filled circles) and $R = 0.5$ (filled squares). The data for Alloy 86 are compared with past data on Alloy 75 at $R = 0.1$ (open circles) and wrought 3RE60 at $R = 0.1$ (open diamonds) from the work of Yeske (24). In that work, Yeske found that Alloy 75 had the highest crack-growth resistance of five alloys (Alloy 75, Alloy 63, VK-A171, VK-A378, and 3RE60) that he evaluated, whereas wrought 3RE60 had the lowest crack-growth resistance.

The current results show that Alloy 86 has slightly higher fatigue-crack-growth resistance than Alloy 75. Test procedures employed by Sandusky were identical to procedures used by Yeske, with additional features. Recently Yeske (26) has reported similar findings from his tests of Alloy 86. Thus, Alloy 86 has outstanding corrosion-fatigue crack-growth resistance as well as improved corrosion-fatigue strength.

Also observed in Fig. 5 is the effect the stress ratio has on the performance of Alloy 86. Increasing the R value to 0.5 clearly decreased the corrosion-fatigue crack-growth resistance of Alloy 86 as compared with the data at $R = 0.1$ (filled squares versus filled circles). Again, this result indicates the importance of minimizing applied and tensile residual stress levels imposed on a working suction-roll shell to optimize service performance.

Two additional features—monitoring of load versus back-face strain gauge readings and examination of fracture surfaces after testing—revealed no significant evidence of crack closure. Thus, the crack-growth data were not significantly influenced by crack closure, and the values of ΔK do not have to be reduced to determine an effective ΔK . Yeske (26) also has reported no evidence of significant crack closure effects in his fatigue-crack growth resistance evaluations of the six previously mentioned suction-roll shell materials.

Material fatigue-crack-growth-rate characteristics are important and useful. The design engineer and papermaker can utilize fatigue-crack-growth-rate test results to estimate the performance of suction-roll shell materials under cyclically loaded conditions in a corrosive environment.

In considering crack initiation and growth under cyclic-loading conditions, we know that crack growth depends on the instantaneous crack length, geometry of the cracked component, and the magnitude of the cyclic loading. These three factors are combined in a quantity called the cyclic stress intensity range, ΔK (13). In an

infinite sheet or component containing a crack of length $2a$, the expression for the cyclic stress intensity range is

$$\Delta K = \Delta \sigma \sqrt{a} \sqrt{\pi} \quad (3)$$

Following Yeske's example and in the absence of a better formula for the stress intensity of a crack in an actual suction roll, Eq. 3 will be used to demonstrate the usefulness to the design engineer of fatigue-crack-growth-rate data.

At the threshold conditions we know that

$$\Delta K_{th} = \Delta \sigma \sqrt{a_{crit}} \sqrt{\pi} \quad (4)$$

where

ΔK_{th} = cyclic stress intensity range at threshold

a_{crit} = 1/2 the critical crack length or the critical flaw size for fatigue crack growth

$\Delta \sigma$ = range of the applied cyclic stresses.

Table III contains threshold data obtained from Fig. 5 for Alloys 86, 75, and wrought 3RE60 at the stress-ratio condition of $R = 0.1$. Assuming a suction-roll shell operating at an applied cyclic stress range of 55 MPa (8 ksi), further calculation shows that Alloy 86 can have a sharp crack of 25.40 mm (1.00 in.) before crack growth can begin, whereas a crack length of only 1.89 mm (0.07 in.) is necessary in wrought 3RE60 for crack growth to commence.

What if a crack length is known and the design engineer or papermaker wants to estimate the critical range of applied stress that will cause crack growth to commence in a suction-roll shell material? Theoretically, ΔK_{th} can be used to estimate the stress (load) a suction roll can experience without causing a pre-existing sharp crack or flaw to grow.

Table IV contains critical stress values for Alloys 86, 75, and wrought 3RE60, given the fact that a small sharp crack of 2.54 mm (0.10 in.) exists in each material. Based on threshold data obtained at $R = 0.1$ in Fig. 5, Alloy 75 and Alloy 86 can withstand 3.3 to 3.7

times greater cyclic stresses before crack growth commences than wrought 3RE60.

Examples of crack growth in these materials, based on critical flaw size, have been given earlier (24, 25). In the examples just described and cited, a material's resistance to fatigue crack growth is based on the fact that it has a high ΔK_{th} in a corrosive environment. The duplex stainless steels, Alloy 86 and Alloy 75, have high ΔK_{th} values. The determination of correct and accurate material ΔK_{th} values, by empirical means, is extremely important. Thus, it is critical that proper experimental procedures be employed, documented, and reported.

Electrochemical polarization studies

Figure 6 illustrates the enhanced pitting corrosion resistance of Alloy 86 versus Alloy 75, as determined by anodic polarization scans, in a corrosive simulated newsprint white water. The excellent pitting resistance of Alloy 86 is demonstrated by the 1084 mV margin of safety value obtained and shown in **Table V**. In separate studies at Sandusky, the pitting resistance of Alloy 86 was greater than that determined for molybdenum containing 3RE60 material, in the same simulated corrosive newsprint white water.

The excellent pitting resistance of Alloy 86 versus Alloy 75 is further demonstrated in a corrosive simulated newsprint-deinked white water in **Fig. 7**. Thiosulfate and sulfite ions are formed in the white water as the direct result of chemical decomposition of sodium hydrosulfite which is used in a post-bleach deink pulp-brightening step. Corresponding margins of safety for both materials in the newsprint-deink white water are listed in **Table V**. The Alloy 75 is observed in this instance to have improved pitting resistance versus its performance in the simulated newsprint white water seen in **Fig. 6**.

The enhanced pitting resistance of Alloy 86 is attributed to the formation of a copper-rich oxide on the surface of the metal when exposed to the corro-

sive newsprint white water containing thiosulfate anions. The copper-rich oxide provides an effective passive film barrier which protects the base metal from the combination of chloride, thiosulfate, and hydrogen ions.

Conclusions

Alloy 86 has improved corrosion-fatigue strength versus Alloy 75 in a very corrosive acid-chloride simulated newsprint white water containing 40 mg/L thiosulfate.

Alloy 86 and Alloy 75 have good notched corrosion-fatigue strength, which is an important characteristic of these materials when considering their use as suction roll shells. Drilled holes, localized corrosion, or shell-surface grooving, a service related problem, are stress concentration areas and are potential sites for corrosion fatigue or stress-related crack initiation.

Based on this work and past crack growth studies conducted in the same environment (24), Alloy 86 and Alloy 75 have greater resistance to corrosion-fatigue crack growth in an acid-chloride white water containing 50 mg/L thiosulfate than Alloy 63, VK-A378, VK-A171, and wrought 3RE60 suction roll shell materials.

Alloy 86 has improved pitting resistance in simulated newsprint and newsprint-deink acid white waters containing chlorides and the highly corrosive anion, thiosulfate. This enhanced pitting corrosion resistance is obtained by the presence of 2 wt % copper in the alloy and without the addition of molybdenum. ■

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The authors wish to thank Sandusky International Inc. for the opportunity to conduct these studies and for their permission to publish the results.

Received for review Feb. 14, 1992.

Accepted May 20, 1992.

Presented at the TAPPI 1991 Engineering Conference.