PEER REVIEWED

Chromizing for near-drum corrosion protection

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ABSTRACT

During the past decade, many pulp mills have experienced severe corrosion of generating bank tubes in the vicinity of the lower drum of two-drum–style kraft chemical recovery boilers. This phenomenon has been labeled "near-drum" corrosion. In 1994, a trial mill developed a plan to test various products and applications for controlling and ultimately eliminating this problem. The use of chromized tubing has so far produced encouraging results and, as a result, further development of this tubing has been initiated to specifically address the application. This paper includes the test plan and the results, and reviews the chromizing developments made specifically to combat near-drum corrosion.

Application:

The information provided in this paper will be useful to owners of two-drum kraft chemical recovery boilers that are considering generator retubing due to near-drum corrosion.

THE PHENOMENON OF NEAR-DRUM thinning in generator bank tubes of kraft chemical recovery boilers is a very widespread and costly problem. The purpose of this paper is to discuss what is believed to be a new approach that has been tested at one mill to combat the problem. It is not the intention of this paper to further discuss the causes of the problem. The causes have been widely discussed, and many papers on that subject have previously been published. The cause is generally accepted to be chemical corrosion.

The process of chromizing, which has been available since the Second World War, has been used in water walls, superheater areas, and water-cooled smelt spouts of kraft chemical recovery boilers since 1985. This paper describes the use of chromized tubing in the generator section of a trial boiler and is believed to be a unique case.

The case mill is a brownstock kraft linerboard and sack paper mill in northern British Columbia that began production in July 1970. Its recovery boiler is designed for 5168 kPa (750 psi) steam pressure and 400°C (750°F) steam temperature. Steam production is designed for 232,000 kg (510,000 lb) per hour and a capacity of 1544 metric tons (3.4 million lb) per day of black liquor solids. The unit is still "non-low odor" and operates with direct-contact cascade evaporators. Black liquor solids are generally fired at about 68%. The generator tubes have the following characteristics:

- SA-192 steel
- 63.500-mm (2.50-in.) outside diameter (OD)
- 4.191-mm (0.165-in.) wall thickness
- Swaged to 50.800-mm (2.00-in.) OD at the drums.

BACKGROUND

In the early 1980s, this mill became aware that others were beginning to find serious generator tube thinning in the vicinity of the drums. In 1982, the recovery boiler experienced several generator tube leaks. At the next shutdown, tests were conducted, and this mill was also found to have a very serious case of this tube thinning. A number of tubes were plugged, and plans were made to retube at the next opportunity. Retubing was done in 1983, with the entire rear or cold half of the generator bank being replaced, except for the outer tubes. The outer tubes on both sides are the "structural" tubes, which are welded into the drums. Generally, these tubes are known to thin at a slower rate.

Over the ensuing years, as the nondestructive testing industry developed better test devices, the mill began a regular program of a complete generator tube thickness survey with the wet immersion probe ultrasonic method. It was discovered that the rate of metal loss averaged about 0.381 mm (0.015 in.) per year—and sometimes higher. In some years, a few tubes had lost up to 0.610 mm (0.024 in.) of wall thickness in a single year. Also, from year to year, certain tubes would suddenly slow their thinning rate, while others would dramatically increase their rate. **Tables I–IV** illustrate tubes with high rates of metal loss over the period 1992–1997 in various areas of the generator.

Table V shows the nondestructive examination (NDE) data from two tubes between 1994 and 1996 and illustrates that the rate of thinning often increases once a tube is less than about 2.540 mm (0.100 in.) in wall thickness.

Such high thinning rates mean that a tube with an original wall thickness of 4.191 mm (0.165 in.) could be down to 2.286 mm (0.090 in.) wall thickness in only 5 years. ASME Code minimum tube wall thickness for this boiler is 1.854 mm (0.073 in.) at the swaged portion

Row	Tube	1992 thickness, mm	1993 thickness, mm	Loss, mm
3	9	2.82	2.34	0.46
3	35	2.95	2.46	0.48
4	18	2.97	2.51	0.46
22	13	3.48	2.92	0.56

I. Generator tube thickness loss. 1992–93 ultrasonic testing (UT) data—high thinning rates.

Row	Tube	1994 thickness, mm	1995 thickness, mm	Loss, mm
3	43	2.69	2.49	0.20
3	46	2.59	2.41	0.18
9	46	2.46	2.31	0.15

II. Generator tube thickness loss—right-rear section. 1994–95 UT data—average thinning rates.

Row	Tube	1995 thickness, mm	1996 thickness, mm	Loss, mm
3	43	2.49	2.18	0.31
3	46	2.41	2.16	0.25
9	46	2.31	1.98	0.33

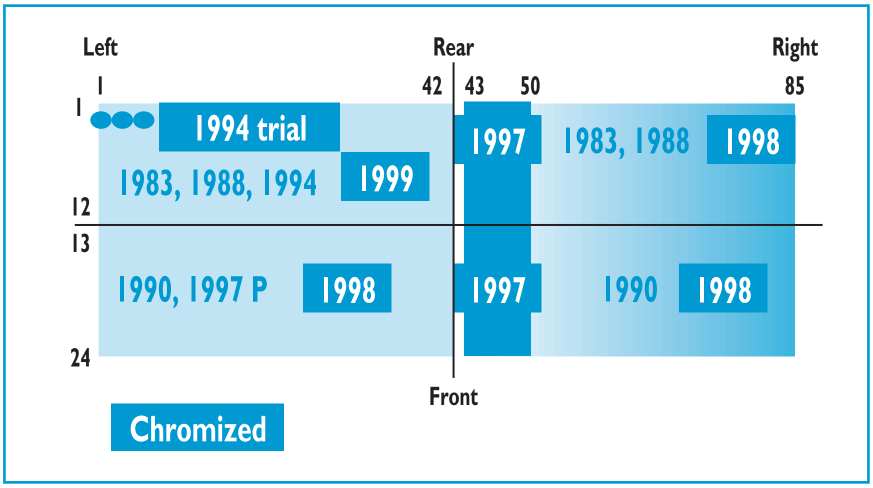
III. Generator tube thickness loss—right-rear section. 1995–96 UT data—high thinning rates.

Row	Tube	1996 thickness, mm	1997 thickness, mm	Loss, mm
3	59	2.54	2.24	0.30
4	1	2.51	2.08	0.43
16	42	2.44	2.18	0.26

IV. Generator tube thickness loss—random tubes. 1996–97 UT data—high thinning rates.

Row	Tube	1994 thickness, mm	1995 thickness, mm	Loss, mm	1996 thickness, mm	Loss, mm
3	43	2.69	2.49	0.20	2.18	0.31
3	46	2.59	2.41	0.18	2.16	0.25
9	46	2.46	2.31	0.15	1.98	0.33

V. Generator tube thickness loss. 1994–1996 UT data of the same tubes illustrate that thinning can increase when tube thickness falls below 2.540 mm (0.100 in.).



1. Generator tube layout and retubing history location of three 1994 chromized trial tubes

where the thinning occurs. To be safe, tubes were plugged at 2.261 mm (0.089 in.) and smaller. As a result, the rear half was again replaced in 1988, and the entire front half was replaced in 1990. Prior to 1993, this boiler was shut down semiannually for inspection and maintenance, so annual loss rates of up to 0.601 mm (0.024 in.) could be safely tolerated. However, since 1993, only annual maintenance shutdowns have been taken, so the inspections became more critical, and the tolerance for the annual loss rate was lowered to about 0.406 mm (0.016 in.) per year, if tube plugging were to continue at 2.261 mm (0.089 in.).

MAGNITUDE OF THE PROBLEM

This particular kraft chemical recovery boiler contains 1830 tubes in its generator bank, including the 48 outside "structural" tubes, which are welded into the drums. The tubes are numbered in 24 rows from the rear to the front, and 85 tubes are across the width from the left side to the right. The front five rows only have 43 tubes per row. Every other tube is omitted to allow for the water distribution to the downcomers, which feed the water walls. To date, this boiler has had 4692 tubes replaced in six separate projects. This amounts to replacing the entire generator over 2.5 times since 1983.

2. March 1994 installation of ceramic shields during generator tube installation

3. April 1995 ceramic shields starting to break off after only 1 year of service

Year	Generator section	No. of tubes
1983	Rear half	996
1988	Rear half + structural	1008
1990	Front half	785
1994	Left-rear quadrant	492
1997	Partial: front and right-rear	293
1998	Balance of front and right-rear	1118
1999	Left-rear quadrant, including structural	504
TOTAL		5196

VI. Generator retubing chronology

If the planned retubing of the final section in 1999 is included, the total will amount to 5196 tubes, or over 2.8 retubings. The total retubing, including that in 1999, also includes replacing the left-rear 12 structural tubes twice. These are the side wall tubes that are welded into the drums. **Figure 1** shows the tube layout, with a map of the history of the retubing and the location of the three chromized trial tubes that were installed in 1994. **Table VI** shows a chronology of the retubing projects from 1982 to date and the number of tubes replaced each year.

TEST PROGRAM

By 1993, plans were underway to replace one-quarter of the generator on the left half of the rear or cold side for the third time. With such frequent retubing, it became obvious that something drastic had to be done to slow the rate of corrosion. Metal arc spraying was considered. However, this technique was rejected because the coating should not be put on the portion that is expanded inside the drum, and it would be impractical to completely coat the tubes after the expansion was completed. Annual maintenance of an arc-sprayed coating would also be impractical due to the tight spacing of the tubes. Two other solutions were selected for further consideration. The two options that were chosen for trials were (a) ceramic or stainless steel shields or collars and (b) chromizing.

Ceramic shields

Ceramic shields, 50.8 mm (2 in.) long, were made to allow for a gap of 0.254–0.635 mm (0.010–0.025 in.) between the outside diameter of the cold tube and the inside diameter of the ceramic shield to allow for thermal expansion. Thirty-two of the shields were installed during the tube-stabbing process, and after the tube expansion, the shields were grouted into place at the drum. **Figure 2** is a photo of the 1994 installation of some of the ceramic shields.

Figure 3 shows the ceramic shields after only 1 year of service and illustrates that most of the shields had already started to break and fall off in that time. Even though most of the shields failed, they still provided a few years of significant protection. However, because most of them broke or fell off within the first few years, the method was considered a failure.

Stainless steel shields

In 1996, a brief trial was made with stainless steel shields. These were formed to fit to the bottom 25 cm (10 in.) or so of the tube, from just above the swaged section down to the mud drum. These shields were placed on about 60 trial tubes on row 1 at the rear of the generator and rows 23 and 24 at the front, only across the left half, as historically this half had the highest rates of metal loss. Installation was limited to the rear row and the front two rows due to access difficulties with the tight spacing of the tubes.

Since a number of these tubes were removed after only 1–2 years of service, in the 1997 and 1998 tube replacements, no significant data have been gathered as to their effectiveness. Between 1997 and 1998, the average rate of metal loss for tubes with the stainless steel tube shields still in place in row 1 was about 0.051 mm (0.002 in.). However, two tubes did experience losses similar to those suffered in 1992–1993 before the last retubing in this area, when they were still unprotected. **Table VII** shows the rates of metal losses for these two tubes from 1992 to 1993,

Row	Tube	1992 thickness, mm	1993 thickness, mm	Loss, mm
1	5	3.25	2.90	0.35
1	6	2.82	2.51	0.31
Row	**Tube**	**1997 thickness, mm**	**1998 thickness, mm**	**Loss, mm**
1	5	4.30	3.99	0.31
1	6	4.24	4.11	0.13

VII. 1997–98 UT data (with shields) compared to the 1992–93 UT data (no shields) for the same tubes illustrate that the thinning rate is similar with or without the stainless steel shields.

when they were unprotected, and then from 1997 to 1998 after the 1994 retubing and the 1996 installation of the stainless steel shields. The conclusion is that stainless shields likely offer little protection and have the downside of allowing corrosion products to accumulate between the shield and the tube, perhaps eventually accelerating the corrosion. This method was not tried again, and all remaining shields will be removed with the 1999 retubing of the left-rear quadrant.

Chromizing

The other trial choice selected for 1994 was chromizing. Three sections of tube, each about 3.66 m (10 ft) long, were made up to match three positions in the second row at the rear of the generator. This area was chosen because it has a history of high thinning rates. One end was swaged to 50.800-mm (2-in.) OD, and the tubes were then bent to match the pattern for the intended row. The three tubes were then chromized for their entire length, including the swaged portion. During the generator retubing, matching lengths were cut off of three nonchromized tubes for row 2. The chromized portions were then field-welded onto the main section of the tubes. These trial tubes were then installed into row 2 in tube positions 2, 3, and 4, as measured from the left side of the boiler.

It became evident that if nothing were done, the rear section of the generator would require retubing about every 5 years on the left half and about every 8–9 years on the right half. The front section would also require retubing about every 8–9 years. The right-rear quadrant had been last retubed in 1988 and the front in 1990. Thus, the NDE data from the 1995 and 1996 maintenance shutdowns was very important to provide an early indication whether the three 1994 chromized trial tubes would provide any protection. Fortunately, NDE results from these 2 years indicated that the chromizing was providing greatly increased protection against the rapid thinning.

Row	Tube	1994 thickness, mm	1995 thickness, mm	Loss, mm
2	2	4.19	4.14	0.05
2	3	4.19	4.14	0.05
2	4	4.19	4.29	+0.10*
4	3	4.19	3.73	0.46

*"Growth" due to UT error.

VIII. 1994–95 UT data on 1994 trial tubes compared to adjacent nonchromized tubes

Row	Tube	1995 thickness, mm	1996 thickness, mm	Loss, mm
2	2	4.14	4.17	+0.03*
2	3	4.14	4.17	+0.03*
2	4	4.29	4.11	0.18
4	3	3.73	3.28	0.45

*"Growth" due to UT error.

IX. 1995–96 UT data on 1994 trial tubes compared to adjacent nonchromized tubes

Row	Tube	1996 thickness, mm	1997 thickness, mm	Loss, mm
2	2	4.17	4.11	0.06
2	3	4.17	4.11	0.06
2	4	4.11	4.22	+0.11*
4	3	3.28	3.05	0.23

*"Growth" due to UT error.

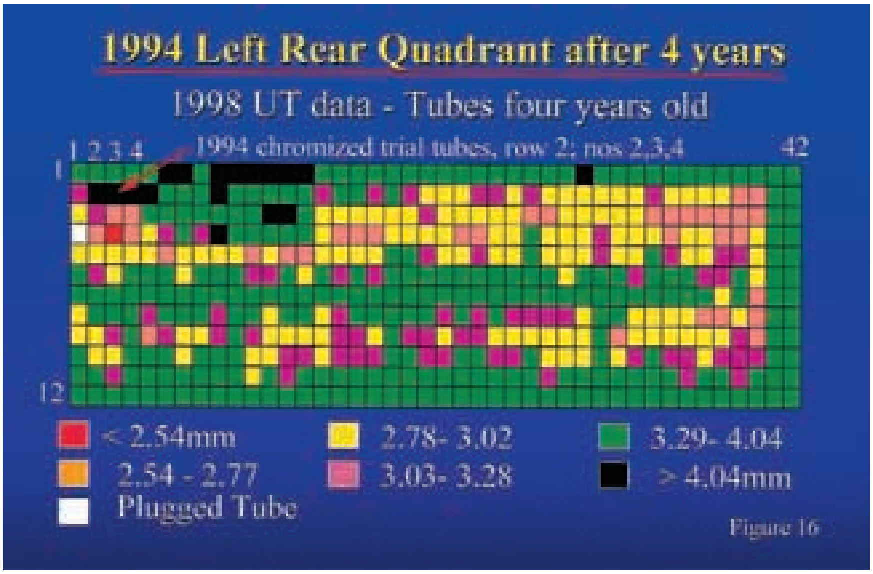
X. 1996–97 UT data on 1994 trial tubes compared to adjacent nonchromized tubes

Row	Tube	1997 thickness, mm	1998 thickness, mm	Loss, mm
2	2	4.11	4.11	0
2	3	4.11	4.17	+0.05*
2	4	4.22	4.22	0
4	3	3.05	2.49	0.56

*"Growth" due to UT error.

XI. 1997–98 UT data on 1994 trial tubes compared to adjacent nonchromized tubes

Tables VIII and IX show the nondestructive examination measurements from 1995 and 1996 for the three trial tubes compared to an adjacent nonchromized tube. The



4. 1998 UT data on the left-rear quadrant (retubed in 1994) illustrate that most other tubes have thinned considerably, compared to the three trial chromized tubes in row 2, positions 2, 3, and 4.

Row	Tube	Chrome, %
1	49	46
2	49	45
3	49	41
7	50	75
8	50	67
12	51	41

XII. 1998 surface analysis data of chromium content for 1997 chromized tubes

data illustrate that there was essentially no detectable metal loss on either of the three trial chromized tubes, whereas the unprotected tubes continued to thin at a rate of 0.457 mm (0.018 in.) per year.

By 1996, it was clear that the right-rear quadrant, which was last retubed in 1988, and most of the front section, which was last retubed in 1990, would soon need further retubing. Since the 1997 shutdown was to be fairly short, only 293 tubes were replaced in a pattern that dealt with the worst areas. If no retubing had been done in 1997, a large number of tubes would have required plugging. Since there were a number of clusters of six to eight or more thin tubes together, plugging that many tubes so close together could have caused boiler circulation problems. For this reason, a small number of tubes were replaced across the left-front section, although mill personnel recognized that these tubes would have to be chromized (redone) the next year. The plan was to again replace these 121 tubes, which were made of standard carbon steel, in 1998 with chromized ones. This was done to minimize downtime and because of access problems to narrow tube lanes. A particularly bad section through the center of the generator was replaced with 172 chromized tubes, installed from front to rear in positions 43 through 50.

TEST RESULTS

Table X shows the 1997 NDE wall thickness test results of the three 1994 trial chromized tubes compared to the same adjacent tube as before. The results again show no noticeable metal loss after 3 years, whereas the nonchromized tubes lost an additional 0.229 mm (0.009 in.). On this basis, mill personnel decided it was time to fully commit to chromizing, and in May 1998, they replaced 1118 tubes—all with the lower 30 cm (12 in.) chromized. This installation completed three-quarters of the generator bank with chromized tubing, except for the 48 outer structural tubes. **Table XI** shows the 1998 NDE wall thickness test results of the three original 1994 trial tubes again compared to the same nearby nonchromized tubes.

The difference is dramatic. In 4 years, all three of the original chromized trial tubes have retained almost all of their nominal thickness, whereas the worst-case nonchromized tube has lost over 1.651 mm (0.065 in.) of wall thickness, or over 0.406 mm (0.016 in.) per year. **Figure 4** shows an overview of the 1998 NDE results of the left-rear generator section, which is now only 4 years old. It is clear that many of the tubes around the chromized trial tubes are now severely thinned, including some that were part of the 1994 ceramic shield trial. It is also obvious that the left-rear quadrant, where the chromizing trial began, needs to be retubed for the fourth time. The plan is to replace this quadrant in 1999. This will finish the entire generator with chromized stubs at the mud-drum end, except for 36 of the outer structural tubes: 12 on the left-front section and all 24 on the right side. To date, of the 48 structural tubes, only the 12 left-rear ones have experienced significant thinning.

A chromium content of at least 30% at the surface of a boiler tube is known to provide good corrosion protection in many applications. During the May 1998 maintenance shutdown at this mill, a portable surface test instrument was used to evaluate the surface of a number of the chromized tubes that were installed in 1997. The test results show that after 1 year of service, these tubes have maintained a very high surface content of chromium. **Table XII** shows some of these test results. Unfortunately, the three 1994 original trial tubes are all in one row from the rear and are spaced too close together to allow surface test measurements. All of the chromized tubes from the 1997 installation were also tested with the internal wet immersion probe ultrasonic method. The wall thickness results for these tubes were also very good, with none of the tubes showing any significant metal loss. **Table XIII** shows typical wall thickness readings of these tubes.

When the complete left-rear quadrant, including the 12 outer structural tubes, is retubed in 1999, the original three chromized trial tubes will be removed for destructive analysis. This will confirm their remaining chrome thickness and wall thickness. This will allow a better estimate of the ultimate life expectancy of the chromized tubes.

CHROMIZED TUBING DETAILS*

Chromizing is the diffusion-controlled enrichment of a component's surface to produce a chromium-rich layer that is highly resistant to a wide range of corrosive media. The process is accomplished by placing the parts to be chromized in a steel box, or retort, that is filled with a chrome-bearing powder, a parting agent, and a halide activator. The box is sealed, and air is evacuated from the retort. The retort is then placed into a specially designed furnace and heated to a specified temperature for the time required to produce a diffusion layer of the desired thickness. To monitor the quality of the chromizing, control coupons are placed at strategic locations throughout the retort. Once the processing is complete, the coupons are removed and destructively analyzed to verify that the chromized layer is of acceptable quality (i.e., having a uniform thickness in the protected area, no excessive porosity, etc.).

Because of the relative ease of diffusion, the bulk of the chromizing that has been performed on pressure-part materials has been on the lower-carbon tubing materials, such as SA-192, and the low-alloy grades of SA-213, in particular, T11, T12, T22, T9, and T91. The processing of these materials produces a chromized layer that typically consists of a very thin outer layer of chromium carbide, which has a thickness of 0.0254–0.0508 mm (0.001–0.002 in.). Although the chromium content of this carbide layer exceeds 70%, it is not considered to be a part of the chromizing protection, because it is relatively brittle and will not always remain intact during handling.

The chromium-enriched layer will vary in thickness from approximately 0.203 mm (0.008 in.) to as much as 0.610 mm (0.027 in.) for special applications. The layer is relatively soft and ductile with a hardness comparable to that of the unprocessed base material. This relative ductility of the chromized layer is obviously critical for generating bank tubes, since the layer must flow readily during the sealing operation to form an effective bond between the tube and the drum. Of equal importance for generating bank tubes is the fact that the chromized layer is an integral part of the base material; the layer cannot spall or separate from the substrate, even under conditions of severe mechanical deformation.

The surface chromium content of the soft diffusion layer is 30–35%, with the chromium concentration dropping gradually to the etching boundary (i.e., the boundary between the original base metal that transforms to austenite during processing and the ferrite-stabilized, chromium-rich layer), where the chromium concentration will be approximately 13%. Below the diffusion layer, a decarburized layer of moderate thickness will form in the base metal. This decarburized layer develops during processing due to the high affinity of the carbon for

Row	Tube	1998 thickness, mm
1	45	4.34
2	45	4.31
3	45	4.29
4	45	4.34
5	45	4.29

XIII. 1998 UT data on 1997 chromized tubes

chromium. Extensive testing has demonstrated that, when properly controlled, the decarburized layer, which is an inevitable part of the process for commercial chromizing applications, does not effect the ASME Code calculated strength of the tubing. This layer can, however, result in a slight overall softening of the material relative to the original bulk material hardness.

The condition of the outer layer of a chromized component is typically slightly rougher than the original surface condition of the tubing. This is due to some particle adhesion to the component surface that occurs during the diffusion process. However, this surface roughening is easily removed by light grinding, and a smooth surface suitable for rolling can be produced with minimal removal of material.

With annual monitoring of the surface chromium content, a qualitative indication of the remaining chromized layer thickness can be obtained, thereby providing an estimate of component life expectancy. The chromized tubes installed in the trial boiler in 1997 and 1998 are all expected to have an average chromium layer thickness of approximately 0.457 mm (0.018 in.), as determined from the control coupons that were placed in the retort with the tube stubs. The thinnest layer measured was 0.406 mm (0.016 in.) thick, and the thickest layer was 0.508 mm (0.020 in.) thick.

Although a standard chromized component will be highly resistant to corrosion, for the reasons previ-

*Henry, J. F. and Daoust, N., *TAPPI 1994 Engineering Conference Proceedings*, TAPPI PRESS, Atlanta, p. 435.

ously discussed, it will be no more resistant to abrasive erosion damage than will the base material. Therefore, the use of standard chromizing in areas subjected to aggressive abrasive erosion is not recommended. (There is a variation of chromizing in which a very hard and wear-resistant chromium carbide layer is produced on the surface during processing; this wear-resistant chromized layer has operated successfully in a number of nonpressure-part applications.) Chromizing has been used successfully in recovery boilers to protect furnace walls, superheater assemblies, and water-cooled smelt spouts since 1985.

For the generating bank tubes that were to be rolled into the mud drum on the test unit, the standard chromizing process was modified to achieve a slightly greater chromized thickness—an average layer thickness of 0.457 mm (0.018 in.) vs. the typical average thickness of 0.305 mm (0.012 in.)—and to minimize the influence of grain boundary carbides that can form in the chromium-enriched layer under some processing conditions. These modifications were based on information obtained from a series of rolling tests conducted by the manufacturer at its manufacturing facility. In the tests, a number of chromized tube ends were mechanically sealed into mock drum plates so that the influence of the sealing operation on the integrity of the chromized layer could be evaluated. The sealing methods tested included both traditional mechanical rolling and hydraulic sealing. These tests demonstrated that when processed properly, the chromized tubes exhibited excellent ductility during the sealing process, permitting an effective bond to be obtained between the tube and the drum with no risk of cracking, even when subjected to what would be considered severe "over-rolling" conditions.

The generator tubes for the trial mill are SA-192, 63.500-mm (2.50-in.) OD, 4.191-mm (0.165-in.) wall thickness, swaged to 50.800 mm (2.000 in.) OD at the drums. This boiler has not experienced a problem at the steam drum, so the chromizing is only applied to the mud-drum ends. The three 1994 trial tubes had about half of their total length chromized and involved a field weld. Since the problem area is extremely localized within 1–5 cm of the mud drum, the chromizing of subsequent tubes was kept to as short a length as possible. The chromized portion was thus limited to the lower 30 cm (12 in.), including the portion expanded into the drum.

The manufacture of the chromized tube ends was carried out in the following manner. First, straight tubes were cut to length and then cold hydraulically swaged at both ends. After swaging, the tubes were stress-relieved. A 30-cm section was cut from the end of the tube that would be rolled into the mud drum, and these stubs were shipped to the manufacturer for chromizing. After chromizing, the stubs were returned to the tube shop, where they were reattached to the parent tube using an automatic gas tungsten arc (GTA) weld process. The welding procedures used to reattach the chromized stub were identical to those that would have been used for a bare stub; no special joint preparation, such as "peel back," was required to make a satisfactory joint. Once the stubs were reattached, the tubes were bent to their final configurations.

The three trial tubes installed in 1994 had been normalized and tempered after chromizing so that they exhibited a smooth, dull black appearance compared to the nonchromized portion of the tube. When these tubes were expanded into the drum, minor surface cracking was observed in the over-roll area just outside of the drum surface. This superficial cracking was expected and involved only the thin outer carbide layer previously described. As a result, the corrosion resistance of the chromized layer was not compromised as demonstrated by the ultrasonic thickness readings taken on the tubes over the past 4 years. The chromized tubes installed in 1997 and 1998 had a bright, shiny appearance with a slightly roughened surface. The difference in the surface appearance was due to the fact that these tube stubs had not been normalized and tempered after chromizing, so the original chromized surface was preserved.

In 1997, 293 generator tubes were replaced. Of this number, 121 were nonchromized and 172 were chromized. The tubes were expanded into the drums by conventional air-powered rolling equipment. After the installation was completed, the boiler was hydrostatically tested to its design pressure of 5168 kPa (750 psi). During the first hydrostatic test, the nonchromized tubes were tight, but a large number of the chromized tubes exhibited slight leaks at the mud drum and required additional rolling. The reason for this was that after chromizing, the chromized tubes were somewhat softer than the nonchromized tubes. This was in part due to the fact that the tubes had not been normalized and in part due to the decarburization effect discussed previously.

As a result, the chromized tubes required additional rolling to achieve the required amount of work hardening that provided a satisfactory seal. All tubes were tight following the second hydrostatic test. During the 1998 installation, the tube rolling was carefully monitored with calipers, and a 15% wall thickness reduction in the expanded section was targeted. A portable, single-tube hydrostatic test device, which was on site, was used to monitor the expanding. This device allowed single tubes to be quickly hydrostatically tested in the drum portion of the tube during the installation. With careful tube expanding and monitoring, the 1998 installation of 1118 tubes was watertight on the first hydrostatic test.

SUMMARY

The three original chromized trial tubes that were installed in 1994 at this mill and the 172 chromized tubes that were installed in 1997 have lost no significant wall thickness as measured by the internal, wet-immersion probe ultrasonic method. In addition, a reasonable test portion of the 1997 tubes have shown that in 1 year, their surface chrome content has remained very high. We recognize that additional information is required from surface metallurgical testing and destructive testing to conclusively state how many years of corrosion protection the chromizing can be expected to provide It is also recognized that other solutions for near-drum thinning may deal directly with the chemical problem. However, since in many cases this could require a costly low-odor conversion, we feel that at the trial mill, the installation of chromized tubes can provide significant corrosion protection and life extension without the costly conversion. **TJ**

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