Duplex stainless steels in the pulp and paper industry

Craig Reid and Angela Wensley

ABSTRACT: Case histories are given of several applications of duplex stainless steels in pulp and paper mill services. Both successes and failures are reviewed. MacMillan Bloedel experience shows that duplex stainless steels are well suited to a range of applications owing to strength, fatigue, and corrosion resistance properties superior to the commonly used austenitic stainless steels. They have become an almost automatic maintenance replacement after failures of austenitic stainlesses. Examples are given of different levels of evaluation performed before selecting duplex stainless. All failures of duplex stainless steel experienced at MacMillan Bloedel have been due to misapplication rather than fabrication problems. Misapplications are inevitable because in many cases the actual service conditions are unknown. Often time is not available for adequate materials testing before material selection must be made. The results in service are compared with expectations.

KEYWORDS: Alloy steel, Canada, commonwealth, evaluation, failure, mechanical properties, mills (factories), North America, paper mills, performance evaluation, physical properties, plant departments, pulp mills, stainless steel, utilization, weldability.

Duplex stainless steels have been used in the North American pulp and paper industry since the 1960s. These uses, however, were for specialized applications such as liquor heater tubes, suction roll shells and pump shafts, impellers and bodies.

It was not until the mid-1980s that readily weldable nitrogen alloyed duplex stainless wrought products became available and could be considered as alternatives to austenitic stainless steel plate, sheet, and pipe. In general, however, the North American pulp and paper industry has been slow to make wide usee of the modern duplex stainless steels even though they apper to offer several advantages over common austenitic grades, such as types 304L, 316L, and 317L. These advantages are claimed to include superior mechanical strength, wear and cavitation resistance, fatigue strength, stress corrosion cracking resistance, and—in many cases—superior localized corrosion and general corrosion resistance. In addition, the thermal expansion of duplex stainless steels is a closer match with that of carbon steel than that of the austenitic stainlesses. Thus duplex stainlesses should be a good choice for lining carbon steel.

The slowness to adopt the duplex stainless grades has been due to inherent conservatism, fear of welding problems (real and imaginary), and to lack of information about their performance in real situations.

In 1986, the Metals Subcommittee of the TAPPI Corrosion and Materials Engineering Committee formed a task group to promote the informed application of duplex stainless steels in the pulp and paper industry. During task group meetings, it became clear that application case histories and practical fabrication guidelines were most desired. Several informal presentations on these subjects were given in task group meetings and documented in the task group minutes. It was then decided to reach a wider audience by means of an Engineering Conference panel discussion. The format chosen was that of a keynote paper to be included in the Conference Proceedings followed by short presentations by panelists and open discussion from the floor.

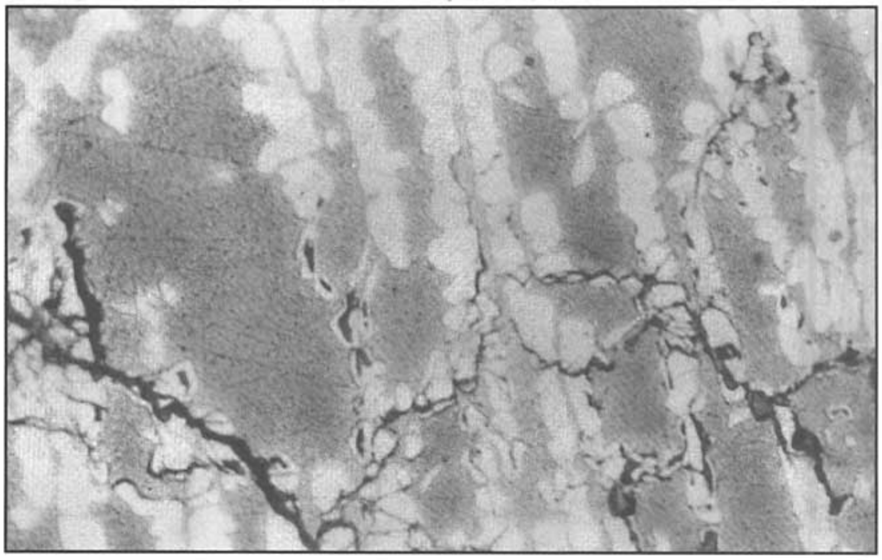
Reid is an engineering associate with MacMillan Bloedel, 4225 Kincaid St., Burnaby, BC, Canada V5G 4P5. Wensley is a consulting metallurgist with Bacon, Donaldson, & Associates, 12271 Horseshoe Way, Richmond, BC, Canada V7A421.

I. Weight loss corrosion rates in evaporative cooler

Alloy type mm/year	Weight loss corrosion rate, (mpy)
UNS NO6022	0.03 (1.1)
UNS NO8925	0.15 (5.9)
DIN 1.4565[a]	0.22 (8.8)
316L	0.56 (22)
UNS S32550	0.81 (32)
2205 duplex	0.97 (38)
ASTM A353 (9% Ni alloy steel)	2.4 (93)

[a]German material number. UNS number not available.

1. Stress corrosion cracking in austenite phase of 2205 type duplex stainless steel shaft cladding on screw conveyor in chip presteaming vessel (500X)



This keynote paper summarizes one company's successes and failures in the application of duplex stainless steels.

Use of duplex stainless steel in MacMillan Bloedel

Since our first large scale use of UNS S32550, in 1983, the use of duplex stainless has evolved from careful evaluation of all applications to general use by mill maintenance personnel where the traditional austenitic grades have failed. It is safe to say that our failures to date have resulted from misapplication rather than fabrication or quality problems with the duplex material itself. In fact, the duplex grades have become ensconced as an additional step in materials selection by successive failure. In our company the current general sequence is:

- Carbon steel
- Type 304L (preferred by most suppliers)
- Type 316 (preferred by most suppliers if 304L fails)
- Type 317L
- 2304-type duplexes
- 2205-type duplexes
- Super austenitics and super duplexes
- Nickel base alloys or titanium.

The sequence can, of course, be entered at any point, and assorted steps can be skipped depending on specific circumstances and background information available.

Two myths about duplex stainless steels do need to be clearly dispelled. These are:

- They are exotic and expensive.
- They are neither exotic (i.e., hard to get) nor expensive.
- They are hard to weld.

They are not hard to weld. Any welder competent to weld austenitic stainlesses will make a good weld in most duplex stainlesses if the correct heat input and filler metal are used. Welding costs are no different from the austenitics except for a slightly higher price per kilogram for filler metal. This applies to both shop and field welding.

One myth in development also needs to be dispelled. It is:

> The duplex stainless steels are "magic."

They are not magic. If a duplex stainless steel is misapplied it will fail just like any other material. For example, an application which destroys Type 316L austenitic stainless steel in a few months will likely do the same to a 2205-type duplex. The duplex may, however, last a bit longer.

Case histories

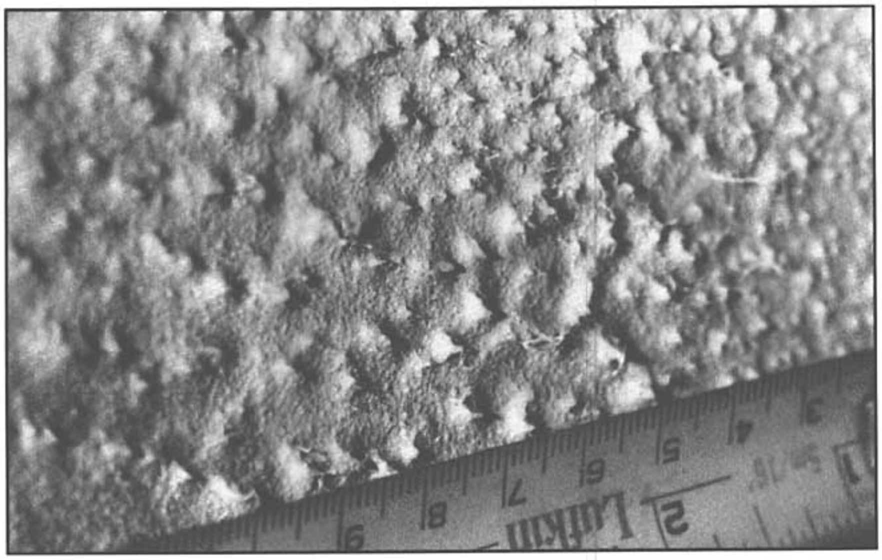
The following case histories outline some of our experience with informed, careful use of the duplexes and some not so careful or informed uses.

Lining of rotary dryers for hog fuel

In one of our coastal mills, bark (hog fuel) removed from sea-borne logs is dried with flue gas before it is burned in boilers. The hog fuel is passed through rotary cylindrical dryers where tumbling improves contact with the flue gas. Somewhat optimistically, the dryers and their extensive internal systems of lifting vanes were originally constructed from carbon steel. Severe corrosion thinning occurred immediately from startup, producing fatigue failures of lifters within six months.

On the basis of the performance of test lifters installed in various alloys, UNS S32550 superduplex stainless steel was selected over austenitic stainless steels for replacement of the corroded lifters and for internal lining of

2. Close-up view of 2205 duplex steel end plate of low-pressure feeder rotor



the dryers. The dryers were rebuilt in 1983 and have not experienced corrosion or cracking problems since.

Pulp machine cylinder mold

On a prehistoric pulp machine the pulp sheet is formed on a rotating cylindrical mold with perforated deck plates. In 1984, Type 316L deck plates failed due to transgranular stress corrosion cracking and fatigue cracking at punched holes in less than five years service. The environment was nominally 42°C, pH 6.8, 370 ppm NaCl, 6 ppm $Na_2S_2O_3$. Replacement deck plates were 2205 duplex stainless steel with drilled holes. The plates have now been in service for eight years with no cracking.

Flue gas ducting expansion joints and dampers

Flue gas ducting between hog fuel boilers and an electrostatic precipitator contained uninsulated carbon steel expansion joints and dampers which failed in less than four years due to dewpoint corrosion. Condensate collected while firing hog fuel had a pH of 2.6 and contained 40 ppm chloride ion. Nominal flue gas temperature was 260°C. Coupon testing confirmed 2205 duplex stainless steel to be resistant to corrosion in this environment (compared with a carbon steel coupon, which corroded at 0.6 mm/year). In 1987, this alloy was used extensively to line corroded carbon steel ducting. When inspection after seven months confirmed no corrosion, the expansion joints and dampers were replaced in 2205 duplex.

A floor lining of 2205-type duplex stainless steel installed below a cold stack in 1987 was found to be severely corroded after 14 months of service, showing preferential attack of the ferrite phase. Sulfuric acid condensate containing chloride ion had dripped from the fiberglass-reinforced plastic cold stack onto the 2205 lining. The relatively small failed area of the lining was replaced in a 6% molybdenum austenitic stainless steel.

Wet bottom precipitator bottom wall liner

Inspection of a recovery boiler electrostatic precipitator in a coastal mill, in 1988, revealed the Type 316L stainless steel bottom wall cladding to be severely corroded after less than 3 years service. It was replaced in 2205-type duplex stainless, without prior corrosion testing in this environment. After half a year, the 2205 cladding was found to be corroded in cold areas (such as near an access door) where dewpoint corrosion was no doubt a problem. Welds in particular experienced preferential corrosion. Analysis of deposits removed from the corroded cladding revealed mostly iron (41%), chromium (15%) and nickel (1.2%), with 12,400 ppm (1.24%) NaCl, 22,300 ppm Na_2SO_4 (2.23%), and pH 2.4 (1% solution). It is unlikely that any duplex alloy, even the superduplexes, could withstand this environment.

Evaporative coolers for recovery boiler flue gas

In another coastal mill, a pair of horizontal vessels are used for cooling recovery boiler flue gas from 425°C to 230°C, using a water spray at the vessel inlets. Carbon steel was the original material of construction, based on previous experience with vertical coolers and the belief that the vessel walls stayed dry. In reality, however, the vessel walls dissolved away rapidly. In the absence of coupon test data, 2205-type duplex stainless steel was used to line the coolers. The 2205-type duplex also suffered rapid corrosion. Subsequent coupon testing has revealed that a highly corrosion-resistant nickel base alloy is required; however, the 2205 is now accepted as a routine maintenance replacement by the mill, much to the delight of the duplex supplier. **Table I** summarizes weight loss corrosion rates from a coupon rack mounted at the discharge end of the cooler. The test time was six months.

Analysis of particulate deposits formed on a probe installed at the discharge end of the coolers was Na_2SO_4 (42%), NaCl (10%), insolubles (3.4%). A pH of 4.5 was produced by extracting a deposit sample in boiling water. Na_2SO_3 was also detected in the deposit.

In this aggressive environment, the duplex stainless steels were definitely not the solution. In fact, Type 316L would be a better choice for a sacrificial liner.

Chip prestreaming vessels for kraft continuous digesters

Chip prestreaming vessels are horizontal pressure vessels, approximately 2 m in diameter and 9 m long, typically operating at 120 kPa. Wood chips are moved through the vessel by an internal screw conveyor, with steam being supplied through nozzles along the bottom of the vessel. Originally, most chip steaming vessels were constructed from carbon steel plate. Because of wear problems along the bottom of the vessel, it became standard practice to install a wear plate of Type 304 stainless steel (which in actuality was little better in this regard than carbon steel).

Corrosion of the carbon steel shell and the austenitic stainless steel screw are chronic problems in many mills, particularly in coastal mills where the wood chips come from sea-floated logs. Other corrosives are wood acids released in the steaming process. Deposits scraped from corroded internal areas of these vessels gave pHs from 4.5 to 5.0 and had a water extractable sodium chloride content of 8000 ppm. Corrosion concerns prompted a trend in the 1980s to replace corroded carbon steel presteaming vessels with vessels constructed entirely from Type 304L stainless steel. Unfortunately, solid stainless steel vessels rapidly succumbed to stress corrosion cracking, both on the process side (especially the steaming nozzles) and externally beneath wet insulation.

Two chip presteaming vessels in MacMillan Bloedel mills have been replaced with new vessels constructed from clad plate. Use of clad plate allowed us to employ the superior corrosion, wear, and stress corrosion resistance of duplex stainless steel on the process side, and the beneath-insulation stress corrosion cracking resistance of carbon steel on the outside.

The first vessel to be replaced was in a coastal mill, and originally had been constructed from carbon steel roll clad with Type 304L stainless steel. After several years of service, inspection revealed that a large section of cladding in the top of the vessel had vanished exposing the carbon steel to corrosion. Only 2 mm (0.080 in.) of carbon steel remained in some areas.

The second vessel to be replaced was in an inland mill with no bleach plant. Nevertheless, Type 304L bottom steaming nozzles failed by stress corrosion cracking in less than one year of service. The solid 304L shell failed by external stress corrosion cracking within three years of service.

The clad plate for the first vessel was produced by roll cladding with AFNOR*°Z2 CND 25 7 AZ duplex stainless steel (25Cr-6.5Ni-3Mo-.18N). Clad plate for the second vessel was produced by explosive cladding using 2205. Out of concern for corrosion from high salt content wood chips, the process side welds in the first clad vessel were made using AWS ENiCrMo-3 filler. The process side welds in the second clad vessel were made with 25Cr-9Ni-Cu duplex stainless steel filler.

The first clad vessel went into service in 1987, it has not suffered any corrosion in four years of service. The second clad vessel went into service in 1991.

Screw conveyors for chip presteaming vessel

The internal screw shaft for the first clad presteaming vessel was loose-clad with 2205-type duplex stainless steel after the Type 316L loose-cladding on the screw shaft failed due to severe corrosion and stress corrosion cracking under deposits. Deposit analysis suggested the service environment was pH 3.15 and contained 2000 ppm Cl. Due to an error, the original manufacturer's material specification was reverted to when an emergency screw was ordered. The flights were made from Type 304 austenitic stainless steel. The error, however, was detected in time to clad the shaft with 2205 duplex. The flight-to-shaft welds, which included the connection to the 2205 shaft cladding, were made with Type 309 stainless steel filler. It was intended that these welds would be capped with AWS ENiCrMo-3; however, the capping did not cover all of the Type 309 stainless.

After a year of service, the 304 flights at the inlet end were severely stress corrosion cracked and pitted. The flight-to-shaft welds were found

II. Crevice corrosion data for duplex stainless steels in a chlorine dioxide bleach washer. Washer environment: pH 6–7, 70°C, 600 ppm Cl^-, 300 ppm ClO_3^-, 20–200 ppm ClO_2

UNS no.	LCR	Supplier	No.of Coup	Avg.actual data Initiation sites	Avg.actual data Max depth,mm	Normalized to 317L Initiation sites	Normalized to 317L Max depth, mm
S32304	25.1	A	3	26/40	0.91	1.8	2.8
"	25.3	B	1	40/40	1.40	1.1	3.7
S31500	28.0	C	1	14/40	0.20	1.6	0.8
S31803	33.3	D	2	27/40	0.15	2.0	0.5
"	33.4	B	3	19/40	0.20	1.0	0.6
"	33.7	E	1	11/40	0.36	0.8	0.4
"	33.9	F	2	27/40	0.91	1.9	3.0
"	34.1	"	6	13/40	0.43	0.9	0.9
"	34.0	A	2	34/40	0.25	1.8	0.7
"	34.2	G	2	23/40	0.28	1.1	0.8
"	34.2	C	1	20/40	0.33	0.7	1.1
"	34.1	H	3	8/40	0.18	0.8	0.5
"	34.1	"	4	16/40	0.30	0.9	0.8
"	34.4	"	1	1/40	0.03	0.2	0.1
S32950	34.5	I	2	17/40	0.23	0.7	0.6
S32550	38.6	B	5	7/40	0.10	0.6	0.2
"	38.8	J	2	25/40	0.20	1.2	0.2
"	39.3	"	4	13/40	0.05	0.7	0.1
"	39.8	G	1	28/40	0.10	1.8	0.4
S32750	42.9	A	3	6/40	0.01	0.3	0.02

*French designation. Nearest North American equivalent would be UNS S31200 with 3.0 % Mo minimum.

to be cracked and pitted, with the cracking extending into the 2205 duplex shaft cladding. In rebuilding the screw, the flight-to-shaft welds were ground away. We were able to obtain only a piece of adjacent 2205 shaft cladding. Metallographic examination of the piece of cladding revealed stress corrosion cracking propagating in the austenite phase of the duplex stainless steel microstructure (**Fig. 1**). The cracking apparently originated from the ground-away flight-to-shaft weld. It is suspected that the stress corrosion originated in the Type 309 weld, although initiation in the duplex HAZ cannot be ruled out.

The corroded areas of the shaft cladding were replaced with UNS N06022 which was also used to plate over the inlet end flights. The roll clad 25Cr-6.5Ni-3Mo-.18N duplex stainless steel lining in the vessel itself remained uncorroded.

Bottom wear plate for chip presteaming vessel

A severely corroded austenitic stainless steel liner in a chip presteaming vessel in another coastal mill was replaced with 2205-type duplex plate. After one year, the duplex plate showed some under-deposit corrosion in areas not swept clean by the moving chip mass. Test coupons of superduplex stainless steel and six molybdenum superaustenitic stainless steel have been installed in this vessel for evaluation.

Low pressure feeder for Kamyr digester steaming vessel

Low pressure feeders introduce chips into the steaming vessel. The feeder rotors were originally fabricated using 304L stainless steel. Stress corrosion cracking of the vanes and general corrosion of the rotor end plates sometimes required replacement of the rotor after service periods of only 2–2 1/2 years. The first metallurgical upgrade was Type 316L stainless steel, which did not outperform Type 304L. Corrosion rates of 316L rotor end plates were as high as 2.5 mm/year (100 mpy). Stress corrosion cracking of vanes still occurred. The general corrosion of the end plates, perhaps enhanced by pocket purge steam, seems to have removed surface at a greater rate than stress corrosion cracks could grow.

As the next upgrade, 2205 duplex stainless steel was tried. The end plates of the rotor shown in **Fig. 2** are in fact 2205 duplex after 2 1/2 years service. The corrosion rate was about 1.3 mm/year (50 mpy). Types 304L and 316L corroded in the same distinctive manner.

Moving up the ladder of materials selection by successive failure we now have two rotors in service fabricated from 6% molybdenum superaustenitic stainless steel. The performance of these full-size coupons will be monitored.

Corrosion testing in chlorine dioxide bleach washer

Beginning in 1982 and continuing to the present, we have carried out a series of corrosion coupon tests of two months duration in a chlorine dioxide (ClO_2) washer vat environment known to be aggresive to virtually all stainless alloys. The test program has included welded and unwelded coupons of 16 different duplex and superduplex stainless steel alloys (20 different heats), as well as a variety of austenitic, superaustenitic, and nickel-base alloys. The complete results have been reported elsewhere *(1, 2)*, so only the duplex stainless steel crevice corrosion data are reported here.

Table II gives the average crevice corrosion data for all duplex stainless steels tested. Alloys are listed in groupings by UNS number, and also generally in order of LCR (localized corrosion resistance *(3)*, also called PRE) number from 25.1 to 42.9. To account for test-to-test variations in corrosivity in this actual process environment, the data were "normalized" by dividing the numbers of sites of crevice corrosion initiation (40 possible per coupon) and the maximum crevice depths by the comparable data for a Type 317L austenitic stainless steel "standard" coupon included in every test. Normalizing the data not only gives the crevice corrosion performance of a given duplex alloy relative to Type 317L, it also enables comparison of the relative crevice corrosion resistance to be made among all the alloys tested.

The coupon test results demonstrate the beneficial effect of alloying (increasing LCR number) on crevice corrosion resistance, with the "2304"-type duplexes experiencing the most corrosion depth, the "2205" duplexes less corrosion, and the superduplexes the least. The duplex stainless steels also showed very well compared with other stainless alloys, as can be seen in the coupon test data summarized in **Table III**. Molybdenum-alloyed duplex stainless steels were found to be superior to Type 317L stainless steel in terms of normalized maximum depth of crevice corrosion. They were also superior on average to most 6% Mo superaustenitic stainless steels in this regard. However, the duplex stainless steels had on average more sites of crevice corrosion initiation than superaustenitic stainless steels. Nickel-base alloys containing 8% to 16% molybdenum did not experience crevice corrosion in this washer environment, but rather experienced pronounced general corrosion (up to 0.5 mm/year), likely due to transpassivation *(2)*.

Fabrication of chlorination stage bleach washer drum from 2205-type duplex stainless steel

Based on the results of the corrosion coupon test program, we selected 2205-type duplex stainless steel as the material of construction for new ClO_2 bleach washer drums, replacing Type 317L stainless steel drums, which were leaking due to advanced crevice corrosion. A superduplex alloy would have been the preferred material; however, Type 2205 was selected because it was perceived as a "within budget" improvement over Type 317L.

A first-stage chlorine dioxide washer drum fabricated from 2205 duplex in 1988 had experienced no corrosion. A decision was then made to consider 2205 for a first-stage chlorination washer drum which would operate between 50% and 100% substitution of chlorine dioxide for chlorine. There was no coupon test data to directly support this application.

We were concerned about possible corrosion of welds. Accordingly, test coupons of all welds to be made were provided to us, including:

- Deck plate welds (automatic GMAW)
- Internal piping circumferential welds (manual GTAW root; then pulsed GMAW)
- Internal piping longitudinal welds (automatic GMAW with root purging and copper backing)
- Repair welds (simulated by filling a grinder groove with a GTAW root and a SMAW cover pass).

Metallographic examination (Fig. 3) of the piping circumferential welds revealed excessive ferrite (77%) in the GTAW root, which appeared to have been produced when the pulsed GMAW second pass was done (unaffected root pass metal remaining on either side had a good austenite/ferrite balance). It was theorized that the pulsed GMAW cover pass had been made with too low heat input thus turning the root pass into a high ferrite heat-affected zone.

The automatic GMAW longitudinal piping welds had acceptable HAZ ferrite, despite the quenching effect of the copper backing. The simulated repair weld had 43% ferrite in the GTAW root (identical to the base plate) and 32% ferrite in the SMAW cover pass.

Pitting breakdown potentials of the high ferrite GTAW and acceptable ferrite GMAW weld roots were measured potentiodynamically in an Avesta Cell (*4*) containing a simulated worst case high substitution washer environment (60°C, 4000 ppm NaCl, 50 ppm Na_2SO_4, pH 1.8). Welds were ground flush to a 600 grit finish. The GTAW root experienced pitting breakdown at 650 mV vs SCE; the HAZ of the GMAW root experienced pitting breakdown at a higher potential, 879 mV. Both values were higher than the 440 mV measured for a comparable Type 317L GTAW weld.

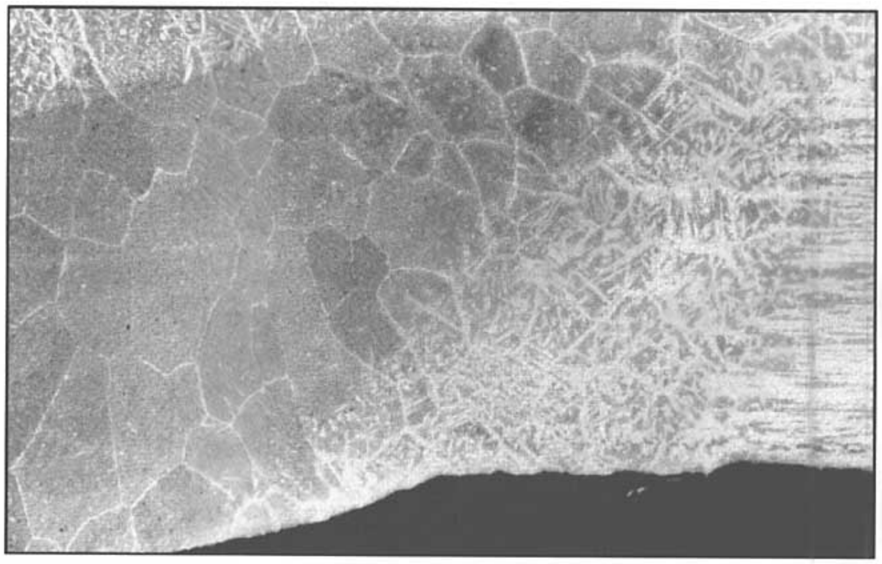
We should have known when to leave things well enough alone, but nonetheless decided to proceed with a second set of tests using the Avesta Cell, with specimens where the welds were left intact. The results of these tests were disconcerting: the GTAW root showed a very low pitting breakdown potential of -165 mV, the GMAW root showed no passivity whatsoever, experiencing severe crevice corrosion at rollover on the weld toes. This suggested the welds would spontaneously begin to corrode as soon as the washer went into service.

These disturbing results led to an investigation of post weld cleaning methods, and the Avesta Cell was again employed to obtain pitting breakdown potentials of intact GMAW deck plate weld specimens treated by various mechanical and chemical methods. The test results indicated that post weld cleaning is essential if the advantage of 2205-type duplex is to be maintained over type 317L stainless steel in this service. Grinding, grit blasting or glass bead blasting were found to be unsatisfactory by themselves, as the resultant breakdown potentials were lower than the 440 mV observed for Type 317L welds. A combination of pickling (with paste) and either grinding or grit blasting was required to ensure superiority over Type 317L. Longer pickling times (3 h) were best in terms of producing breakdown potentials which most

III. Normalized crevice corrosion data relative to type 317L

Alloy family	*Initiation sites*	*Max. depth*
Austenitic (317L)	1.0	1.0
Duplex (UNS S31803)	1.1	0.9
Superduplex	0.8	0.2
Superaustenitic	0.4	1.0
High-Nickel (30–50%Ni)	0.6	0.4
Nickel-Base (>50% Ni)	0.2	0.02

3. High ferrite GTAW root in circumferential piping weld specimen. Root was covered with pulsed GMAW filler pass. Note that the unaffected portion of GTAW root adjacent to the parent metal has acceptable ferrite (25X).



closely approached the 879 mV value measured for 2205-type welds ground flush to 600 grit. A fuller report of these tests has been published *(5)*.

Ultimately the welding procedure for the internal piping welds was modified to prevent the high ferrite heat-affected zone in the root pass from extending to the process side. The entire washer drum was sand blasted and pickled (with paste at the mill site). The drum has been in service for over one year, about half the time at 50% substitution and half the time at 100% substitution and there are no holes in it yet.

Coupons were cut from a production welded internal piping joint and exposed for 136 days in the washer vat. One coupon was left as welded the other was pickled with paste for three h. The normal environment was:

- T: 38°C (100°F)
- pH: 2.0
- Cl: 245–740 ppm
- ClO_3: 78–140 ppm
- SO_4^{2-}: 25–43 ppm
- Residual active chlorine: 0–100 ppm.

Crevice washers were placed on each specimen so that some of the crevice sites would lie on the weld HAZ. There was no crevice attack of the pickled coupon. The as-welded coupon was crevice corroded only in the weld HAZ.

Miscellaneous uses

As noted previously, 2205 duplex stainless steel has become an almost automatic replacement for failed Types 304L and 316L austenitic stainless steels. It is also being used as an upgrade for carbon steel or abrasion-resistant plate where it is not known whether corrosion or wear/erosion dominates the material-loss rate. Such miscellaneous uses include:

- Pump shafts (replaces 304L and 316L which fail in fatigue)
- Chutes for wet salty chips (replaces carbon steel)
- Batch digester blow tank target plates (replaces abrasion-resistant plate)
- Batch digester blow lines (replaces Type 304L)
- Screw conveyors (replaces Type 316L)
- Vibrating chip bins (replaces Type 316L).

Other duplex grades

With the exception of UNS S32550 used in the hog fuel rotary dryers and the 25Cr-6.5Ni-3Mo-.18N material used in one of the chip digester steaming vessels, Type 2205 duplex has been used for most applications. The 2304-type duplex with no molybdenum should be useful for all alkaline liquor applications but until recently availability has been a problem expecially with short lead time maintenance situations. Availability and price have limited the use of the higher alloy duplex stainless steels. We have, however, used some higher alloyed duplexes in bleach plant applications. For example, UNS S32550 was used for agitator seal rings in a high substitution, first-stage chlorination tower. The higher alloy duplex was chosen because of its good performance in chlorine dioxide and chlorination washer crevice testing. Whether that good performance will extend to the higher residual environment in the tower bottom remains to be seen.

UNS S32550 has been used for chip refiner plate bolts where high strength and resistance to stress corrosion cracking is required and for paper machine ventilation fans where high fatigue strength and corrosion resistance are needed.

Welding

With the exception of the chlorine dioxide washer internal piping noted above, welding has not been a problem with 2205-type duplex stainless steel. Shielded metal arc welding (SMAW), gas shielded metal arc welding (GMAW), gas tungsten arc welding (GTAW) and flux cored arc welding (FCAW) have all been used successfully by local fabricators and mill welders. Provided the correct filler metal and adequate heat input are used, austenite/ferrrite balance is not a problem. We generally try to use a heat input of 1–2 kJ/mm (25–50 kJ/in.) and would rather err on the high side than the low. We have experienced problems trying to use FCAW in the horizontal position for field welding under less than ideal conditions. We now allow FCAW only in the "downhand" position and only in shop fabrication.

In our experience, the biggest potential problem with welding the duplexes is with shops wishing to use low heat input, high productivity processes (pulsed GMAW, plasma arc welding), or with shops that cannot grasp the concept that minimizing heat input may be a bad thing. For severe environments, some suppliers now recommend the use of superduplex welding fillers for 2205. Use of an overalloyed filler (hopefully, with nitrogen content above 0.2%) might have avoided the high ferrite weld root described above in the section on chlorination washer fabrication.

According to local fabricators with experience in welding 2205 duplex, there is no increased welding cost over the austenitic grades other than the cost of consumables.

Cast duplex stainlesses

There are several grades of nitrogen alloyed cast duplex stainless steels available. These are now being offered as standard metallurgies by some pulp and valve manufacturers. These grades should offer the same advantages over the cast austenitics as wrought duplexes offer over wrought austenitics. However, for cast duplex there is some risk of unqualified foundries (e.g., without nitrogen analysis capability) producing the "recipe" rather than the desired product. There is also a risk that some foundries may shave the bottom end of the solution annealing temperature to maximize furnace life. The potential problems should be addressed by equipment manufacturers sourcing duplex castings. Pulp and paper companies sourcing their own duplex stainless steel castings need to ensure they deal with qualified foundries.

Conclusion

The case histories outlined above demonstrate that duplex stainless steels are not "cure alls" but do appear to have significant uses in the pulp and paper industry. They have certainly advanced beyond the stage of a metallurgist's hobby and should be viewed as established practical materials. The challenge for materials engineering in pulp and paper is to make informed cost-effective use of these steels.

Literature cited

1. Wensley, D. A. and Reid, D. C., NACE 1991 Corrosion Conference, Cincinnati, paper no. 3.
2. Wensley, D. A., Reid, D. C., Brown, D. J., *et al.*, TAPPI 1991 Engineering Conference Proceedings, TAPPI PRESS, Atlanta, p. 499.
3. Lorenz, K. and Medawar, G., Thyssen Forschung, 1(3): 97(1969).
4. Qvarfort, R., Corrosion Science 29(8): 987(1989).
5. Christie, D., 7th International Symposium on Corrosion in the Pulp and Paper Industry, Orlando, 1992. TAPPI PRESS, Atlanta, 1992, p. 87.

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