Selection guidelines help mill engineers select alloys to resist corrosive chloride, abrasion and acidic bleach plant applications

Selecting Correct Valve/Pump Depends on Right Match of Alloy and Application

F E A T U R E

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Engineering

Pulp and paper mill engineers must be concerned with the corrosion resistance, abrasion resistance and quality of the cast stainless steels used for pumps and valves. These products obviously play a very important role in pulp and paper mills due to the tremendous amount of water, chemicals and other materials that a typical mill processes. However, much less information is published or readily available on the use of these cast alloys compared to the extensive literature on wrought alloys. This article provides guidelines for addressing these three cast stainless steel properties, and choosing the correct material for various mill applications.

CAST STAINLESS STEEL COMPARED TO WROUGHT MATERIALS. Data on the chemical composition of the principal cast stainless steels used for pumps and valves in the pulp and paper industry are shown in table 1. Information provided includes the cast designation, mechanical properties and pitting resistance equivalent number numbers (PREN). Alloys are grouped into the following types: martensitic, precipitation hardening, duplex, austenitic and super austenitic. Only the principal alloys in use are shown. Less widely used alloys of each type can be found in the applicable ASTM Specification. The side bar provides further details on the structure of the various alloys.

Cast stainless steels, like their wrought counterparts, have much improved quality when made using the argon-oxygen-decarbonization (AOD) process. Many, but not all, stainless steel foundries now use this process. Cast alloys have higher silicon content, which improves fluidity in pouring, and 5% to 10% ferrite, which reduces hot tears and micro fissuring. Their wrought counterparts by comparison have lower silicon and an austenitic structure with little or no ferrite. Despite these inherent differences, the corrosion resistance of AODproduced stainless steel castings is quite comparable to the corrosion resistance of their wrought counterparts.

CORROSION RESISTANCE IN PULP MILL AND PAPER MACHINE ENVIRONMENTS. Mill engineers are generally familiar with the corrosion behavior of austenitic stainless steels and the increasing resistance to corrosion that is provided by inclusion of molybdenum.Table 2 reports the resistance to crevice corrosion in fresh and brackish waters (at neutral pH and room temperature) of several of the alloys that have been extensively studied. The chloride content should always be considered in selecting alloys for pulp mill and paper machine environments.

In recent years a semi-quantitative method of estimating relative corrosion resistance in acid chloride environments based on composition has been developed. It's derived from the alloys' critical pitting temperature in ferric chloride. Data on the various alloys that are provided in Table 1 include the PREN or pitting resistance equivalent number for each.

Mill engineers can use PREN to estimate the corrosion behavior of a material relative to CF-3/CF-8 and CF-3M/CF8M. Type CF-3/CF-8 without Mo has a PREN of 19.The martensitic and precipitation hardening alloys have a significantly lower PREN and have proven to be somewhat less resistant in service than CF-3/CF-8. CF-3M/CF-8M alloys, with 2% Mo, have a PREN of 25 which clearly identifies the much improved resistance of these products to pitting compared to Mo free CF-3/CF-8 grades. The CG-3M/CG-8M grades, with 3% Mo, have a PREN of 29 and somewhat better resistance than CF-3M/CF-8M. The duplex alloys have PRENs of 30-35 and thus may be used wherever the 3-4% Mo grades are applied. In many cases the duplex alloys are an upgrade. The super austenitic grades CK-3MCuN and CN-3MN with 6% Mo have PREN of 38 and 41 and have become the principal alloys used for bleach plant pumps in the C and D bleaching stage.

The PREN is particularly useful for evaluation of a proprietary cast alloy offered by a vendor in lieu of one of the alloys shown in Table 1. Mill engineers can calculate PREN for the offered alloy based on its composition using the PREN formula:

PREN = %Cr + 3.3x %Mo + 16x %N

The calculated PREN will allow the mill engineer to make a good first approximation of the corrosion behavior, comparing it to alloys he is familiar with.

ABRASION RESISTANCE IN THE PULP MILL. Many mill process streams contain materials that are abrasive. The ability of a surface to "work harden" seems to be very important in determining erosion/ abrasion resistance of various materials. Austenitic alloys have good work hardening characteristics that seem to increase with alloy content. Erosion/abrasion resistance increases with hardness. Work hardening, hardness and tensile strength are roughly proportional for the austenitic and duplex alloys in Table 1. In other words, the alloy with the higher tensile strength will normally have the higher hardness and the better work hardening characteristics.

Table 3 is a rough guide for the relative erosion/abrasion resistance of various alloys. The alloys have been divided into six groups of roughly equivalent abrasion resistance. Materials in group I are used in the most severe service. The

TABLE 1: *Typical Composition and Mechanical Properties of Cast Stainless Steels used in Pumps and Valves and PREN.*

	Cast Grade	Cmax	Cr	Ni	Mo	N	Yield Strength MPa (ksi)	Tensile Strength MPa (ksi)	PREN[5]
White Cast Irons									
	28% Cr	2.0-3.3	23-30	-	3.0 max	-	-	Hardened to 699 Bhn, 59RC	
Martensitic									
	CA-15	0.15	12.8	1.0	0.5	-	450 (65)	620 (90)	13
	CA-6NM	0.06	12.8	4.0	0.7	-	515 (80)	760 (110)	14
	CB-6 16Cr5Ni1Mo DIN 1.4405[1]	0.03	16	5	1	-	540 (78)	900 (130)	18
Precipitation Hardening									
	CB-7Cu-1	0.07	16.6	4.1	-	0.05	670 (97)[2] 1000 (145)	860 (125)[2] 1170 (170)	17
	CB-7Cu-2	0.07	15.3	5.0	-	0.05	670 (97)[2] 1000 (145)	860 (125)[2] 1170 (170)	16
Duplex									
	CD-61VIN (3A)	0.06	25.5	5	2.1	0.2	450 (65)	655 (95)	35
	CD-4MCuN (1B)	0.04	25.5	5.4	2	0.2	485 (70)	690 (100)	30
	J92205	0.03	22.5	5.5	3.0	0.2	415 (60)	620 (90)	34
Austenitic									
	CF-3	0.03	19	10		-	205 (30)	485 (70)	19
	CF-8	0.08	19.5	9.5	-	-	205 (30)	485 (70)	19
	CF-3M	0.03	19	11	2.5	-	205 (30)	485 (70)	25
	CF-8M	0.08	19.5	10.5	2.5	-	205 (30)	485 (70)	25
	CG-3M	0.03	19.5	11	3.5	-	240 (35)	515 (75)	29
	CG-8M	0.08	19.5	11	3.5	-	240 (35)	520 (75)	29
	CN-7M	0.07	20.5	29	2.5	-	170 (25)	425 (62)	27
	CU-5MCUC[3]	0.05	21	41	3	-	240 (35)	520 (75)	30
Superaustenitic									
	CK-3MCuN	0.025	20	18.5	6.5	0.2	260 (38)	550 (80)	38
	CN-3MN	0.03	21	24.5	6.5	0.2	260 (38)	550 (80)	41
	(654SM0)[4]	0.01	24.5	22	7.5	0.5	440 (64)	725 (106)	57

(1) German alloy designation.
(2) Minimum; can be increased by variations in heat treatment
(3) Contains 1.0 Nb
(4) Designation not yet assigned
(5) The PREN rankings, while useful in bleach plant acidic chloride environments, may not be directly applicable to all pulp and paper machine environments.

28% Cr white iron has enough Cr to have better corrosion resistance than carbon steel, but it and the martensitic grades lack the good corrosion resistance of the austenitic steels. The 28% Cr alloy is used where maximum abrasion resistance is the principal consideration. Stellite 6, and other hard facing alloys, are a good second choice where abrasion is severe and abrasion resistance the principal consideration. The hard facing alloys are usually applied as a weld overlay on worn CF-3 and CF-3M pump cases.

Martensitic and precipitation hardening alloys (group II) are generally the first choice for the more severe abrasive services until experience shows that abrasion is extremely severe. In these cases only 28% Cr white iron or a Stellite 6 weld overlay will suffice.

The duplex alloys, group III, have been the materials of choice for pumps where sand and dirt carried through from the wood yard have eroded the softer, more common austenitic grades. This type of sand erosion/abrasion has become very prevalent, especially in pumps, throughout the front end of the mill. Therefore, the 3A and CD-4MCuN alloys rank second to CF-3 and CF-3M in pumps and may; in time, displace these grades.

Group IV materials seem to have slightly better resistance to mildly erosive/abrasive services, as compared to the less highly alloyed, more common materials in group V Group V materials, although widely used, are easily eroded by sand, grit, chips, fibers and similar materials found in process streams.

Unlike corrosion, it is not possible to generalize an alloy's erosion/abrasion resistance with one test, as abrasion can vary widely under different test conditions such as load, speed, heat treatment, etc. Therefore, while simple selection factors like hardness or tensile strength can by used for ballpark rankings, specific site experience is the best and most reliable guide as to when an upgrade in abrasion resistance is required.

SUGGESTED MILL APPLICATIONS FOR VARIOUS ALLOYS. Table 4 identifies some of the principal applications for the alloys listed in Table (.The CF-3 and CF-8 alloys are preferred for digester blow valves, compared to CF-3M and CF-8M.The Mo in the CF-3M and CF-8M grades adds lit tle, if anything, to corrosion resistance in digester liquor service.

In the bleach plant, the two 6% Mo alloys have replaced CG-3M and CG-8M for the chlorine and chlorine dioxide stages. However, these 6% Mo alloys offer no advantage over the lower Mo content grades in oxygen, H202 or ozone bleaching service. CN-7M is not as widely used in the pulp and paper as in the chemical industry. It is included pri marily because some manufacturers offer CN-7M valves as an alternative to CF-3M/8M at virtually the same price in order to better manage their inventories.

PROCUREMENT GUIDELINES. Although mill engineers have full control of alloy selection, they have only an indirect influence, through the pump or valve manufacturer, on casting quality. The pump or valve manufacturer has more influence over casting quality through procurement practices, but it is the foundry that has direct control. However, there are several things mill engineers can do that will improve the quality of the cast pumps and valves they purchase. These steps add very little, if any, additional cost to the manufactured items.The following are the key procurement guidelines:

1. Insist on documentation.
2. Select and specify the low carbon grades of the common alloys.
3. Specify procurement to ASTM A744 when it is necessary to solution anneal after all weld repairs have been made.

DOCUMENTATION DETAILS. Mill engineers should always ask for the following:

- Certification of chemical composition and mechanical properties
- Hydrostatic test certification
- Furnace temperature charts for solution annealing
- Foundry welder and welding procedure qualification reports

Chemical composition and mechanical properties are routinely supplied. Not all ASTM specifications require hydro testing, but nearly all manufacturers do.

Furnace temperature charts are not normally furnished unless specifically requested. It is highly desirable to have documentation on the solution annealing temperature for the molybdenum grades because many foundries do not have furnaces that will reach temperatures above 1900-1950E Others have furnaces that will reach temperatures of 2000F, high enough to homogenize the molybdenum that gives the Mo grades their improved resistance to pitting. Knowing the annealing temperature the foundry used is essential, should unexpected corrosion occur in service.

Foundry and welder and welding procedure qualification reports are normally on file, but are not usually furnished unless specifically requested.

Documentation is a matter of good housekeeping and maintaining good records at very little, if any extra cost, if routinely requested during original procurement.

TABLE *2: Resistance to Crevice Corrosion in Fresh and Brackish Waters of pH 7-8.*

Alloys	Max. chloride ion content(1)
CF-3 and CF-8	200 mg/l
CF-3M and CF-8M	1000 mg/l
J92205	3000 mg/l
CK - 3MCuN and CN-3MN	18,000 mg/l (sea water)

(1) Under crevice corrosion may occur at lower chloride concentrations in the bulk water when deposits either:
(a) function to increase chloride ion concentration in the deposit or
(b) function to promote microbiologically influenced corrosion (MICI.
When SOq ≤ Cl-, crevice corrosion may occur at substantially lower chloride ion concentrations.

TABLE 3*: Relative Erosion/Abrasion Resistance.*

Group	Alloys	Hardness	Erosion/ Abrasion
I	28% Cr White Iron	600 Bhn 59RC	Excellent
	Stellite 6 Co-base Hard Facing Alloy	45-50 RC	
		Tensile Strength MPa	
II	Precipitation Hardening Alloys	860	
	Martensitic Stainless Steels	620-900	
III	Duplex Stainless Steels	620-690	
IV	CU-5M CuC	520	
	Superaustenitic	550	
	CG-3M/CG-8M	515-520	
V	CF-3/CF-8 and CF-3M/CF-8M	485	Poor

SELECT AND SPECIFY LOW CARBON GRADES. It is standard practice for foundries to grind out and weld repair visible defects in large castings such as those for pulp and paper pumps and valves. For this reason, mill engineers should specify the low carbon grades such as CF-3, CF-3M and CG-3M. The higher carbon grades, 0.08% C max, will be sensitized to inter-granular corrosion by these weld repairs, normally without advising customers their castings have been weld repaired.Their low carbon content does not eliminate the need to solution anneal as some suppliers have contended.

SPECIFY ASTM A744 WHEN NEEDED. In certain environments, it is necessary to insure that the castings have been solution annealed after all weld repairs have been made. When mill engineers have been advised or have learned that this is necessary for a particular service, the pump or valve manufacturer can be required to procure castings to ASTM A744. This requires solution annealing after all weld repairs, rather than ASTM A743, which permits weld repairs after solution annealing, and is normally used. An extra cost will be incurred for pro curement to A744 so procurement to A744 should be specified only when experience or corrosion specialist's advice indicates the extra cost is justi fied for the intended service.

USEFUL INFORMATION FOR PUMP AND VALVE USERS. The following will assist mill engineers concerned with pumps and valves. In most instances, the ser vices of a materials specialist may be required to review and advise how best to employ the information in this sec tion. Reference (1) contains some useful information on procurement of quality stainless steel castings.

1. *Ferrite Content of Cast Austenitic Grades*. A little ferrite is good. Too much is bad. The cast austenitic grades are designed to have 5-15% ferrite which improves casting and welding. Nadezhdin[2] et al. have drawn attention to weeping, corrosion and cracking failures of CF-3M pumps with 25% ferrite and high porosity. Forty-four cast stain less steel pump casings and other cast components from three different suppliers were analyzed for ferrite content. Ferrite ranged from 10.4% to 24%. The

TABLE 4: *Common Usage of Cast Stainless Steels.*

	NO.	CAST GRADE	ASTM SPECIFICATION	WROUGHT EQUIVALENT	USAGE
White Cast Irons					
	1	28% Cr	A523 IIIA	none	Refiner discs and pumps
Martensitic					
	2	CA-15	A487	S41000	Boiler feedwater pumps, mechanical pulping equipment, feeders for continuous digesters
	3	CA-6NM	A487	S41500	Upgrade from 2, preferred.
	4	CB-6	A743	SS2387(2)	Mechanical pulping equipment
		16Cr5Ni1Mo	SS2387(2)	DIN 1.4418(1)	
		DIN 1.4405(1)	DIN 1.4418(1)		
Precipitation Hardening					
	5	CB-7Cu-1	A747	17-4PH	Liners for rotary valves and pressure feeders
	6	CB-7Cu-2	A747	15-5PH	Refiner discs; other mechanical pulping equipment
Duplex					
	7	CD-6MN (3A)	A890	329 (SS2324)(2)	Same as 8
	8	CD-4MCuN (1B)	A890	-	Alternative to 10-17 below, preferred when sand or other abrasives are present
	9	J92205	A890	2205	Same as 8
Austenitic					
	10	CF-3	A743/A744	304L	Digester blow valves, stock pumps in
	11	CF-8	A743/A744	304	clean water, kraft liquor and mill effluent
	12	CF-3M	A743/A744	316L	White water, chemical recovery, milder bleach
	13	CF-8M	A743/A744	316	plant services, & kraft liquor & mill effluent
	14	CG-3M	A743/A744	317L	Bleach plant services except most aggressive
	15	CG-8M	A743/A744	317	chlorine and chlorine dioxide services
	16	CN-7M	A743/A744	N08020	Alternative to CF-8M for valves
	17	CU-5MCUC(3)	A494	N08825	Chip injectors for continuous digesters
Superaustenitic					
	18	CK-3MCuN	A743/A744	S31254	Aggressive chlorine and chlorine dioxide bleach plant services
	19	CN-3MN	A743/A744	N08637	Aggressive chlorine and chlorine dioxide bleach plant services
	20	(654SM0)(4)	-	S32654	Aggressive chlorine dioxide bleach plant services

(1) German alloy designation (2) Swedish alloy designation (3) Contains1.0 Nb (4) Designation not yet assigned.

most serious failures were associated with the higher ferrite contents.

Ferrite content is not controlled by the ASTM specifications and is only rarely controlled in procurement. Most foundries hold ferrite content below 18°/ but some do not. Methods for measuring ferrite content are set forth in ASTMA800.When unexpected corrosion or cracking problems arise, it is good practice to check the ferrite content.

2. Duplex Grades. ASTM A890 3A, CD-6MN, cast duplex stainless steel has been used for many years for pumps in the pulp and paper industry. It is probably second in terms of tonnage of cast alloys used for pumps to CF-3M. Two grades of CD-4MCU are covered in A890; Grade lA without nitrogen, and Grade 1B with nitrogen. Grade 113 should always be specified because the nitrogen addition is critical to best performance of this grade. The three most widely used duplex grades, 3A, CD-4MCuN, and J92205, have substantially higher PRENs than CG-3M/CG-8M and may be used in place of, or as an upgrade, in services where CG-3M/CG-8M has been employed.

3. *SuperAustenitic 6% Molybdenum Grades.* The CK-3MCuN and CN3MN grades are two of the newer 6% Mo cast "super austenitic" stainless steels. They are the cast counterparts of 531254 and N08637 respectively, which have become standard for washers, vats and piping in the more aggressive bleach plant environments.

Super austenitic stainless steels in cast form have been used as chlorine and chlorine dioxide bleaching stage pumps and valves with good success over the past six years.

Full documentation, especially the furnace charts, are important for these grades. Mills can specify either 6% Mo grade under ASTM A743 or A744. Although more expensive, procurement to A744 is recommended, which requires solution annealing after all foundry weld repairs.A caution to mill engineers is warranted here. Mill engineers should definitely reject/ban foundry requests to solution anneal at temperatures below 2100E for longer times, as some foundries (with furnaces not designed for the high temperatures required) frequently offer to do. Heating for a longer time at a lower temperature destroys much of the excellent corrosion resistance of these highly alloyed materials and should never be considered acceptable.

ALLOY 654SMO: This is an even newer and more corrosion resistant high Mo, high N, wrought composition that has been cast successfully for three large valves for D stage service.There is no cast designation as yet and no ASTM specification. It is included as a matter of interest.

4. *Major/minor welded repairs.* ASTM Specification A703, "Standard

specification for steel castings, general requirements, for pressure containing parts", defines major repairs. Major repairs are those that either result in: 1) leakage on hydrostatic test; 2) are > 20% of wall thickness; 3) are > 1" (25mm) in depth; or 4) exceed 10 sq in. (65 sq cm). All other weld repairs are considered minor. Most specifications permit repair of minor defects without notification to the customer.

ASTM A890, to which the duplex grades are normally procured, does not require post-weld repair heat treatment unless so stipulated by the purchaser.

ASTM A747 controls the conditions for weld repair and reheat treatment of the precipitation hardening grades.

5. Other inspection and casting quality specifications and standards. Visual Examination: ASTM A802 and Manufacturers Standardization Society of the Valve and Fitting Industry, (MSS) SP-55, provide criteria for visual inspection of castings. A802 bases inspection on Steel Casting Research and Trade Association (SCRATA) graded reference comparisons. MSS SP-55 uses photographic standards but includes a table that correlates these to those ofA802.

MSS SP-93 Liquid Penetrant (LP), MSS SP-94 Ultrasonic (UT) and MSS SP-54 Radiographic Examination standards provide useful criteria for each NDT method. LP will disclose hairline cracks and other surface defects, but not subsurface defects. UT will detect subsurface defects on machined flat surfaces, and with less accuracy, on smooth curved as cast surfaces. Radiographic examination is the most powerful and most expensive method of insuring integrity and high quality in castings. Radiographic examination can usually be limited to the obviously critical sections of pump and valve castings which normally mean that no more than 10% of the total area needs to be examined.

ALLOY APPLICATIONS FOR NON-CHLORINE BLEACH PLANTS. Oxygen, ozone and hydrogen peroxide are not as aggressive as chlorine and chlorine dioxide. Therefore these chemical environments do not require the most corrosion resis tant alloys. CG-3M/CG-8M is expected to predominate for these services, except when sand loadings are a factor. When sand is a factor, the duplex compositions are preferred.

CONCLUSIONS. 1. Mill engineers control selection of the alloy to be used. Specifying low carbon grade austenitic alloys and nitrogen-containing duplex alloy grades can avoid many problems.

2. Mills do not have direct control over the quality of the cast stainless steels used in pumps and valves. Suggestions mill engineers should consider for inclusion in all procurement for pumps and valves include documentation, specifying the low carbon grades and, when appropriate, specifying pro curement to ASTMA744 instead ofA743.

3. Mill engineers can use the PREN number of a known or newer alloy as a guide to its corrosion resistance in most pulp and paper mill applications.

4. Alloy selection for wear and abrasion resistance is usually site and application specific because there are so many influencing variables. Some general guidelines are given.

5. The newer cast 6% Mo austenitic stainless steels are performing well in aggressive bleach plant services.

6. Introduction of oxygen, ozone and hydroxide bleaching processes pose no significant problem for the CG-3M/CG 8M and duplex alloys now being used for pumps, valves, and other cast com ponents. The more highly alloyed super austenitic alloys are unlikely to be required for these services.

Structure and Description of Major Types of Alloys

Ferrite and Austenite. Ferrite is the designation for the body-centered cubic atomic structure of carbon steel and the Cr-Fe alloys. Austenite is the designation for the face-centered cubic atomic structure which carbon steel assumes after heating to forging temperatures. Austenite is also the structure of the Fe-Cr-Ni alloys, or series 300 stainless steels, at ambient and higher temperatures made possible by the addition of nickel. Ferrite is magnetic. Austenite is non-magnetic. There is a common misconception that ferrite is equivalent to carbon steel. Although the ferrite structure is present in carbon steel, as well as in the Fe-Cr alloys and the duplex alloys, ferrite describes only the structure, not the composition. The 10% or so ferrite in cast austenitic stainless steels is beneficial, almost necessary, as it reduces micro and macro cracking and improves weldability. The percentage of ferrite in a cast stainless steel can be estimated from the magnetic response, from the composition or from metallography. ASTM A800 describes these methods of estimating ferrite content.

Martensite. Martensitic stainless steels have 10-12% chromium and small austenite stabilizing addition of carbon, nickel, manganese and nitrogen that permit heat treatment similar to the heat treatment of tool steels. Heat treatment develops high strength, hardness and abrasion resistance. The tempering temperature is about 1100E (595C1. Martensitic stainless steels are strongly magnetic, have higher strength than austenitic and duplex alloys, and have excellent abrasion and wear resistance.

Precipitation Hardening Stainless Steels. The precipitation hardening stainless steels are austenitic, semi-austenitic or martensitic. After solution annealing, they are age hardened at temperatures ranging from 900-1200E (480-650C) by precipitation of very fine second-phase particles that give these alloys their high strength. In the absence of other information, the 1150F-X621 C) heat treatment is preferred for the best combination of strength, ductility, wear and abrasion resistance.

Duplex. Duplex alloys are half ferrite and half austenitic, maintaining most of the best characteristics of each structure. The duplex alloys are quite magnetic. The cast duplex grades have higher strength, better corrosion resistance and much better resistance to sand abrasion than the older CF-3M/CF-8M austenitic grades that they continue to displace. The pulp and paper industry has long been a major user of duplex stainless steels in cast form for pumps, although only recently a major user of duplex alloys in wrought form.

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