Type 254 SMO®
UNS S31254

OUTOKUMPU

Design Features

- High resistance to pitting and crevice corrosion
- Very high resistance to chloride stress corrosion cracking
- 50% stronger than 300-series austenitic stainless steels
- Excellent impact toughness
- Excellent workability and weldability

Product Forms Available

- Plate
- Sheet and KBR Wide Sheet
- Billet and Bar
- Pipe, Tubing, and Fittings
- Castings
- Welding Consumables

Specifications

UNS S31254 (wrought products)
UNS J93254 (cast products)
F 44 (forged piping components)
BMLCuN (bolting)
ACI CK3MCuN

	ASTM	ASME
Plate, Sheet, Strip	A 240, A 480	SA-240, SA-480
Bar, Billet	A 276, A 479	SA-479
Pipe	A 312, A 358, A 409, A 813, A 814	SA-312, SA-358, SA-409
Tubing	A 249, A 269, A 270	SA-249, SA-269
Fittings, Forgings	A 182, A 403, A 473	SA-182, SA-403
Bolting, Nuts	A 193, A 194	
Casting (CK3MCuN)	A 351, A 743, A 744	SA-351

ASME/ANSI B16.34 for A 182, A 240, A 312, A 351, A 358, A 479
ASME/ANSI B16.5 for A 182, A 240, A 351
ASME/ANSI B31.1 for A 182, A 240, A 249, A 312, A 479
ASME Section III Code Cases N-439, N-440, N-441-1
NACE MR0175

Applications

- Seawater Handling Equipment
- Pulp Mill Bleach Systems
- Tall Oil Distillation Columns and Equipment
- Chemical Processing Equipment
- Food Processing Equipment
- Desalination Equipment
- Flue Gas Desulfurization Scrubbers
- Oil and Gas Production Equipment

Composition, wt. pct.

Table 1

Element	Wrought Products	Castings
Carbon	0.020 max	0.025
Chromium	19.5-20.5	19.5-20.5
Nickel	17.5-18.5	17.5-19.5
Molybdenum	6.0-6.5	6.0-7.0
Nitrogen	0.18-0.22	0.180-0.240
Copper	0.50-1.00	0.50-1.00
Sulfur	0.010 max	0.010 max
Phosphorus	0.030 max	0.045 max
Silicon	0.80 max	1.00 max
Manganese	1.00 max	1.20 max
Iron	Balance	Balance

General Characteristics

Outokumpu Stainless 254 SMO® is an austenitic stainless steel designed for maximum resistance to pitting and crevice corrosion. With high levels of chromium, molybdenum, and nitrogen, 254 SMO is especially suited for high-chloride environments such as brackish water, seawater, pulp mill bleach plants, and other high-chloride process streams. 254 SMO offers chloride resistance superior to that of Alloy 904L, Alloy 20, Alloy 825, and Alloy G. 254 SMO is compatible with the common austenitic stainless steels. It is often used as a replacement in critical components of larger constructions where Type 316L or 317L has failed by pitting, crevice attack, or chloride stress corrosion cracking. In new construction, 254 SMO has been found in many cases to be a technically adequate and much less costly substitute for nickel-base alloys and titanium.

254 SMO is substantially stronger than the common austenitic grades, and it is also characterized by high ductility and impact strength. 254 SMO is readily fabricated and welded.

Resistance to Chloride Corrosion

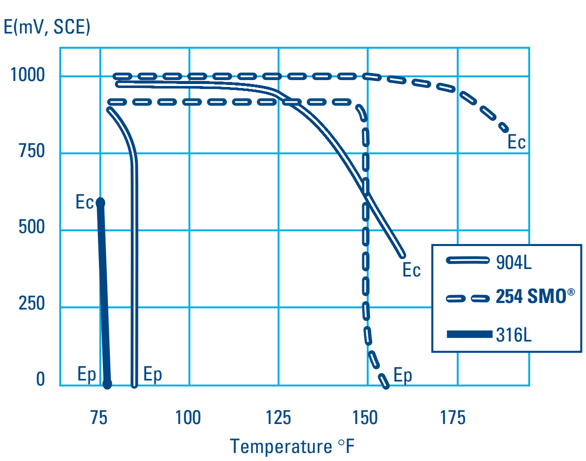
Pitting Corrosion

Pitting is a highly localized form of corrosion. Once started, pitting can lead to perforation in a short time with little total weight loss. Pitting is usually caused by chlorides (or other halides), aggravated by more acidic conditions and higher temperatures. With high levels of chromium, molybdenum, and nitrogen, 254 SMO is extremely resistant to pitting corrosion.

One method of measuring pitting resistance is to determine the electrical potential for a particular chemical environment that is required to initiate pitting, Ec. A related value is the repassivation potential, Ep, which measures the ability of the material to stop pitting once initiated. Higher values of Ec and Ep indicate superior pitting resistance. Figure 1 shows that 254 SMO maintains a high pitting resistance in a chloride solution much stronger than seawater, and can repassivate in this solution at almost 150°F. Alloy 904L is less resistant because of its lower molybdenum and nitrogen contents.

Pitting (Ec) and Repassivation (Ep) Potentials in 3.56% NaCl.20 mV/min. Scan reversal at 5 mA/cm² (ASTM G 61)

Figure 1



Crevice Corrosion

The presence of a crevice on a stainless steel surface, as might be caused by biofouling or a gasket, greatly reduces resistance to chlorides. It is difficult to avoid crevices in construction and operation, although good design and conscientious maintenance help. As with pitting, high chromium, molybdenum, and nitrogen retard crevice corrosion.

There is a critical crevice temperature (CCT) for the initiation of crevice corrosion. The CCT is a function of crevice geometry and environment for each alloy composition. As shown in Figure 2, the CCT for 254 SMO exceeds those of Type 316L, Alloy 904L, Alloy 825, and Alloy G.

Actual seawater exposure confirms the laboratory observations. As shown in Table 2, 254 SMO was

Crevice Corrosion in Seawater

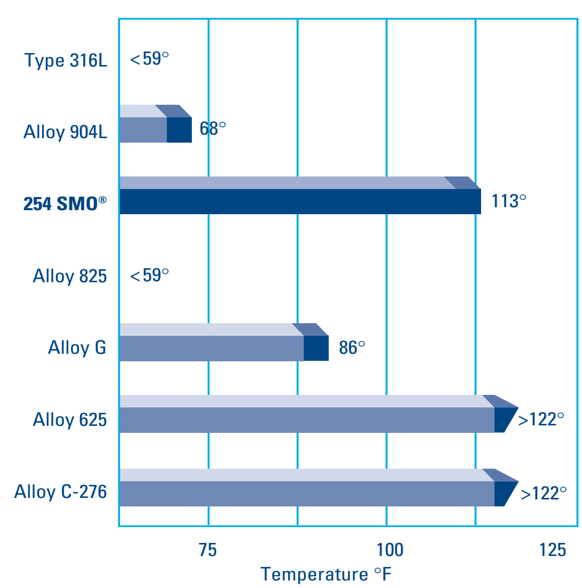
Table 2

Grade	Number of Specimens Attacked	Deepest Attack, Mils
254 SMO®	**0 of 6**	**No Attack**
Type 316L	6 of 6	8
Alloy 904L	6 of 6	6

Low Flow Rate (0.3 ft/sec) Seawater, 140°F, One Year, Plastic Washers

Critical Crevice Corrosion Temperature $FeCl_3$

Figure 2



unattacked after one year in low–flow rate seawater at 140°F, while Type 316L and Alloy 904L were severely attacked.

Chloride Stress Corrosion Cracking

Stress corrosion cracking (SCC) of austenitic stainless steels can occur when the necessary conditions of temperature, tensile stress, and chlorides are present. Those conditions are not easily controlled, often being characteristic of the operating environment. The tensile stress is seldom the operating design stress but rather residual stresses related to fabrication, welding, or thermal cycling. Type 304L and 316L are especially susceptible to SCC, but increasing nickel and molybdenum improves resistance to SCC. This improvement is demonstrated in Table 3. Although 254 SMO can be cracked by boiling 42% magnesium chloride in standard laboratory tests, it does not crack in the wick test or boiling sodium chloride solution, tests that are more representative of practical situations. After twenty-five years of experience in high-chloride environments, no incidents of SCC have been reported for 254 SMO. As a practical engineering remedy to stress corrosion, 254 SMO has successfully replaced 316L components that had failed by SCC.

Resistance to General Corrosion

In discussing the performance of stainless steels in strong acid environments, it is important to recognize that a very small concentration of halides can greatly accelerate general corrosion. As shown in Figure 3, 254 SMO is highly resistant to pure sulfuric acid solutions, but Alloy 904L is somewhat more resistant at higher concentrations. However, as shown in Figure 4, the presence of only 200 ppm chloride makes 254 SMO the more resistant grade for acid concentrations up to 90%.

Chloride Stress Corrosion Cracking Resistance

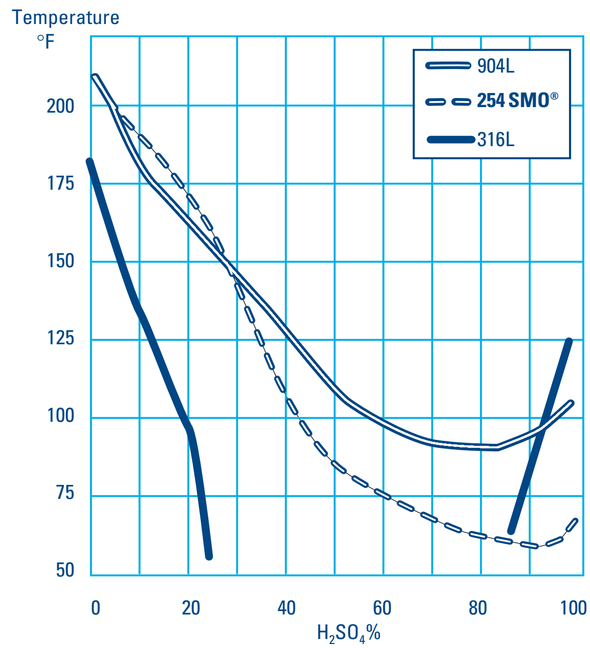
Table 3

Grade	Boiling 42% $MgCl_2$	Wick Test	Boiling 25% NaCl
254 SMO®	**F**	**P**	**P**
Type 316L	F	F	F
Type 317L	F	F	F
Alloy 904L	F	P or F	P or F
Alloy 20	F	P	P
Alloy 625	P	P	P
Alloy C-276	P	P	P

(P = Pass, F = Fail)

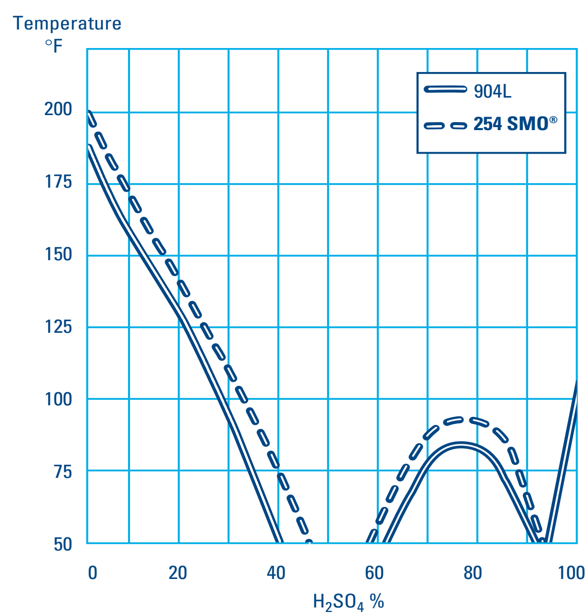
Isocorrosion Curves 0.1 mm/year for given steels in pure sulfuric acid

Figure 3



Isocorrosion Curves 0.1 mm/year for given steels in sulfuric acid containing 200 ppm of chloride

Figure 4

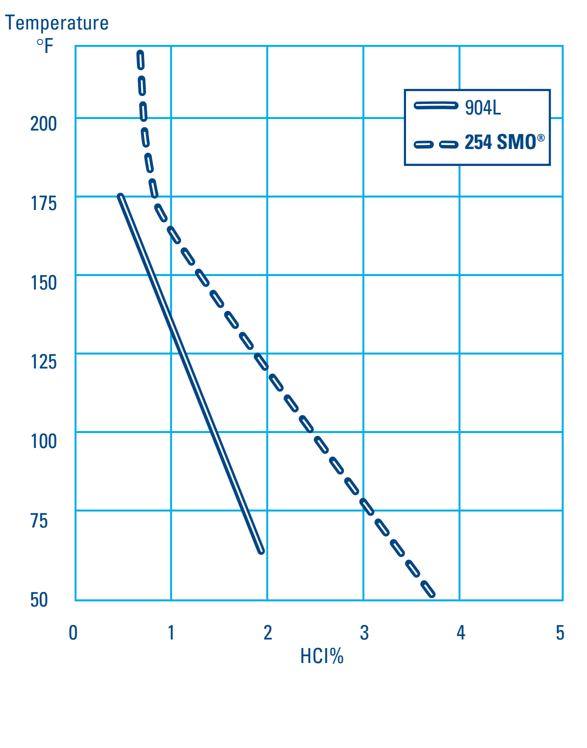


Hydrochloric acid is especially aggressive with respect to stainless steels. Type 316L cannot be used for hydrochloric acid because of the risks of both localized and general corrosion. However, as shown in Figure 5, 254 SMO may be used in dilute hydrochloric acid at moderate temperatures.

Table 4 reports corrosion performance in actual operating environments. Accurate characterization of such environments is not always possible because the material may see substantial variations of the temperature and chemical conditions during the operating and maintenance cycle. Wet process phosphoric acid is a complex mixture of corrosive chemicals including chlorides and fluorides. 254 SMO was found to be substantially more resistant than Type 316L and Alloy 904L. There is a similar result for tall oil distillation, an application in which 254 SMO has successfully replaced Alloy 904L. As is often the case, this replacement has allowed a significant increase in process efficiency because more aggressive operating parameters may be safely used. In a pure, strongly oxidizing acid solution, such as nitric acid, the molybdenum-free Type 304 is found to be superior to the molybdenum-containing grades. However, the presence of halides can reverse this relationship.

Isocorrosion Diagrams, Corrosion rate 0.1 mm/year, in hydrochloric acid

Figure 5



Performance in Selected Process Streams Corrosion Rate, mpy

Table 4

Grade	Tall Oil Distillation 500°F	Wet Process Phosphoric Acid,* 140°F	Pickling Acid 20% HNo_3 4% HF 77°F
254 SMO®	**0.4**	**2**	**12**
316**	35	>200	>200
317LM	11	—	—
904L	2.4	47	20

*Composition, %: 54 P_2O_5, 0.06Cl^-, 4H_2SO_4, 0.27 Fe_2O_3, 0.17 Al_2O_3, 0.10 SiO_2, 0.2 CaO, 0.70 MgO

**2.5 Mo

254 SMO shows superior resistance to a strong pickling acid.

Table 5 compares the performance of 254 SMO with other stainless steels in a variety of common corrosive environments. The table shows the lowest temperature at which the corrosion rate exceeds 5 mpy. All testing was done in accordance with the requirements of the Materials Testing Institute of the Chemical Process Industries (MTI).

Design and Fabrication

Design

254 SMO is a strong, tough stainless steel, as shown in Table 6. The ASME Boiler and Pressure Vessel Code (Table 7) allows use of 254 SMO up

Mechanical Properties at Room Temperature

Table 6

Property/Product Form	Wrought Products	Castings
Tensile Strength, ksi	—	80 min
Sheet and Strip	100 min	NA
Plate	95 min	NA
0.2% Offset Yield Strength, ksi	45 min	38 min
Elongation in 2 in, %	35 min	35 min
Brinell Hardness	210 max	—
Charpy V-Notch Impact Strength, ft-lb	71 min	—

NA = Not Applicable

Lowest Temperature (°F) at Which the Corrosion Rate Exceeds 5 mpy

Table 5

Corrosion Environment	654 SMO®	254 SMO®	904L	Type 316L (2.7 Mo)	Type 304	2507	2205 Code Plus Two®	2304
0.2% Hydrochloric Acid	>Boiling	**>Boiling**	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling
1% Hydrochloric Acid	203	**158**	122	86	86p	>Boiling	185	131
10% Sulfuric Acid	158	**140**	140	122	—	167	140	149
60% Sulfuric Acid	104	**104**	185	<54	—	<57	<59	<<55
96% Sulfuric Acid	86	**68**	95	113	—	86	77	59
85% Phosphoric Acid	194	**230**	248	203	176	203	194	203
10% Nitric Acid	>Boiling	**>Boiling**	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling	>Boiling
65% Nitric Acid	221	**212**	212	212	212	230	221	203
80% Acetic Acid	>Boiling	**>Boiling**	>Boiling	>Boiling	212p	>Boiling	>Boiling	>Boiling
50% Formic Acid	158	**212**	212p	104	≤50	194	194	59
50% Sodium Hydroxide	275	**239**	Boiling	194	185	230	194	203
83% Phosphoric Acid + 2% Hydrofluoric Acid	185	**194**	248	149	113	140	122	95
60% Nitric Acid + 2% Hydrochloric Acid	>140	**140**	>140	>140	>140	>140	>140	>140
50% Acetic Acid + 50% Acetic Anhydride	>Boiling	**>Boiling**	>Boiling	248	>Boiling	230	212	194
1% Hydrochloric Acid + 0.3% Ferric Chloride	>Boiling, p	**203ps**	140ps	77p	68p	203ps	113ps	68p
10% Sulfuric Acid + 2000ppm Cl^- + N_2	149	**104**	131	77	—	122	95	<55
10% Sulfuric Acid + 2000ppm Cl^- + SO_2	167	**140**	122	<<59p	—	104	<59	<<50
WPA1, High Cl^- Content	203	**176**	122	≤50	<<50	203	113	86
WPA2, High F^- Content	176	**140**	95	≤50	<<50	167	140	95

ps = pitting can occur
ps = pitting/crevice corrosion can occur

WPA	P_2O_5	Cl^-	F^-	H_2SO_4	Fe_2O_3	Al_2O_3	SiO_2	CaO	MgO
1	54	0.20	0.50	4.0	0.30	0.20	0.10	0.20	0.70
2	54	0.02	2.0	4.0	0.30	0.20	0.10	0.20	0.70

to 750°F, with excellent strength levels. In many constructions it is possible to use this strength for greater economy by downgauging from the heavier sections that would be required to perform the same function with Type 316L, Alloy 904L, or Alloy G.

Table 8 gives the minimum tensile properties for 254 SMO up to 750°F. 254 SMO should not be used at temperatures above 1100°F because of the danger of precipitation of intermetallic phases and the consequent loss of corrosion resistance and ambient temperature toughness. However, 254 SMO can be used indefinitely at the moderate temperatures typically encountered in chemical processing and heat exchanger service.

Maximum Allowable Stress Values, ASME Boiler and Pressure Vessel Code, Section VIII, Division I, 1999 Addenda, 3.5 Safety Factor

Table 7

Grade	Stress, ksi						
	-20°to 100°F	400°F	500°F	600°F	650°F	700°F	750°F
254 SMO®	**26.9**	**24.3**	**23.5**	**23.0**	**22.8**	**22.7**	**22.6**
2205 (S31803)	25.7	23.9	23.3	23.1	—	—	—
Alloy G	23.3	23.3	23.3	22.7	22.4	22.2	22.0
Type 316L	16.7	15.7	14.8	14.0	13.7	13.5	13.2
Alloy 904L	20.3	13.8	12.7	11.9	11.6	11.4	—

Cold Forming

254 SMO is readily sheared and cold formed on equipment suited to working austenitic stainless steels. 254 SMO does have a high initial yield strength and work hardens rapidly. So greater force is required, as is a greater allowance for springback in comparison with Type 316L. Viewed in another way, the rapid work hardening can provide useful strength while still retaining excellent toughness.

Tensile Properties at Elevated Temperatures

Table 8

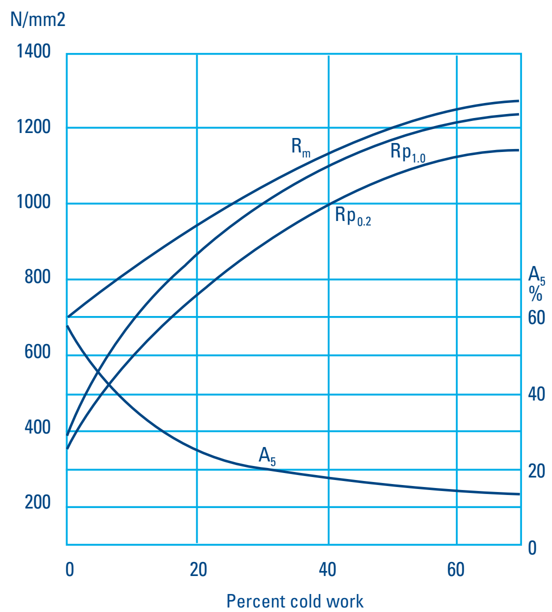
Temperature °F	68	122	212	392	572	752
0.2% Yield Strength, ksi	45	39	34	28	25	23
1.0% Yield Strength, ksi	—	44	39	33	30	28
Tensile Strength, ksi	95	92	89	81	76	74

Machining

Similar to other austenitic stainless steels, 254 SMO is tough and resists machining. However, the special care taken in production of 254 SMO ensures a steel of excellent cleanliness and uniformity. With appropriate selection of tools and machining parameters, satisfactory results have been obtained, as in the drilling of large tubesheets.

Mechanical Properties after Cold Working

Figure 6



Hot Forming, Annealing

Forming at room temperature is recommended whenever possible. When hot working is required, the workpiece should be heated uniformly and worked within the range 1800 to 2100°F. Higher temperatures will reduce workability and cause heavy scaling. After the hot working, the piece should be annealed at 2100°F minimum — long enough to ensure that the whole piece achieves temperature throughout — and then water quenched. The anneal and quench are essential to achieve maximum corrosion resistance.

Welding

254 SMO mill products have been worked and annealed to develop a uniformity of composition throughout the piece. However, remelting of the parent metal, as may occur during welding without filler metal, may cause microscopic segregation of elements such as chromium, nickel, and molybdenum. This phenomenon occurs in all highly alloyed austenitic stainless steels, but becomes increasingly pronounced with the more highly alloyed grades. These variations may reduce the corrosion resistance of the weld. As a principle, 254 SMO should not be welded without filler unless the weld will be subsequently fully annealed.

When the weld is not to be subsequently annealed, an overalloyed filler metal should be used, such as ERNiCrMo-3 (Alloy 625), Outokumpu Stainless P12, or Outokumpu Stainless P16.

Physical Properties

Table 9

Temperature °F		68	212	392	572	752
Modulus of Elasticity	psi x10^6	29	28	27	26	25
Coefficient of Thermal Expansion (68°F to T)	x10^{-6}/°F	–	8.9	8.9	9.2	9.5
Thermal Conductivity	Btu/h ft°F	7.5	8.1	8.7	9.8	10.4
Heat Capacity	Btu/lb°F	0.120	0.124	0.129	0.133	0.136
Electrical Resistivity	Ωin x 10^{-6}	33.5	35.4	37.4	40.6	43.3
Density	lb/in^3	0.287	–	–	–	–
Magnetic Permeability		1.003	–	–	–	–

Characteristic Temperatures

Table 10

	Temperature °F
Solidification Range	2550-2415
Scaling Temperature in Air	1830
Sigma Phase Formation	1300-1800
Carbide Precipitation	840-1470
Hot Forming	1800-2100
Solution Annealing	2100 min, water quench
Stress Relief Annealing	2100 min, water quench

Molybdenum segregation will also occur within these highly alloyed filler metals, but the regions of lowest molybdenum will still be richer in molybdenum than the base metal. So the weld metal will still have corrosion resistance at least equivalent to that of the base metal.

The following procedures have been found to be essential for optimizing the corrosion resistance and mechanical soundness of 254 SMO weldments. More precise descriptions of set-up and welding procedures are provided in the brochure, "How to Weld Type 254 SMO® Stainless Steel."

1. The arc should be struck in the weld joint itself because an arc strike on the face of the base metal can reduce corrosion resistance at that point.
2. Heat input should be minimized, with arc energy input not exceeding 38 kJ/in. Heat input in kJ/in. is calculated as:

$$\frac{\text{Voltage x Amperage x 6}}{\text{Travel Speed (in/min) x 100}}$$

   The weld metal should be deposited as a stringer bead without weaving.
3. In order to minimize the chance for cracking of the high nickel weld in multi-pass welding, the workpiece should be allowed to cool below 212°F between passes.
4. Crater cracks must be removed by grinding. Craters may be avoided by backstepping. The arc should be broken on the weld bead, and not on the base metal.
5. Filler wire should be fed continuously and as evenly as possible, to minimize variations in the composition of the weldment. Dilution from the base metal should be minimized. A minimum root gap of 0.02 to 0.06 inch is required to ensure sufficient filler metal addition. Root shielding is essential in both tacking and joining operations.
6. Preheating, except to the extent necessary to prevent condensation, is not desirable. Heat treatment is not normally required after welding. However, any weld without filler metal should be solution annealed at 2100°F minimum and water quenched for best corrosion resistance.
7. For optimum corrosion resistance, both root and face of the weld should be cleaned, preferably by pickling. Wire brushing should not be relied upon unless the brush is of a material with corrosion resistance equal to that of 254 SMO.

Typical welding currents for Shield Metal Arc Welding (SMAW) of 254 SMO are:

DCRP Welding

Table 11

Electrode size, inch	3/32	1/8	5/32
Amperes	40-70	60-95	90-135

Typical welding parameters for Gas Metal Arc Welding (GMAW) spray-arc welding, with 99.95% argon-shielding gas, 35–55 ft^3/hr., are:

Table 12

Wire Diameter, inch	Amperes	Volts
0.035	170-190	28
0.045	220-280	30
0.062	280-330	31

Cleaning and Passivation

254 SMO mill product forms are delivered with a surface that is cleaned, most frequently by pickling, to remove oxide, embedded iron, or other foreign material. It is essential for maximum corrosion resistance that this cleanliness be maintained or restored after handling and fabrication. A major source of surface contamination is iron transferred from handling equipment, shears, dies, work tables, or other metal equipment. In service this iron can corrode and activate a pit. Other sources of

contamination include slag entrapment in welds, weld spatter, heat tint, forming lubricants, dirt, and paint.

To maximize the corrosion resistance of stainless steel fabrications, including those of 254 SMO, acid passivation should be used to remove surface contaminants. For 254 SMO, the suggested practice is to immerse the piece in a solution of 20 to 40% nitric acid in water for about 30 minutes at 120 to 140°F. Further guidelines for this procedure are given in ASTM A 380.

If the surface of the steel is oxidized, for example, the heat tint associated with welding, it may be necessary to use mechanical cleaning or pickling to restore maximum corrosion resistance. Some guidance is provided in the brochure, "How to Weld Type 254 SMO® Stainless Steel."

Welding Consumables

Our welding unit provides coated electrodes; wires for GTAW, GMAW, FCW, and SAW; welding fluxes; and pickling pastes, all of which have been formulated to produce excellent results when welding 254 SMO. For these products, call our welding unit at 1-800-441-7343.

Casting

254 SMO castings are produced by more than 40 licensed foundries worldwide. A list of licensed North American foundries may be obtained by calling Outokumpu Stainless at 1-800-833-8703.

Technical Support

Outokumpu Stainless, Inc. assists users and fabricators in the selection, qualification, installation, operation, and maintenance of 254 SMO stainless steel. Technical personnel, supported by the research laboratory of Outokumpu Stainless, can draw on years of field experience with 254 SMO to help you make the technically and economically correct materials decision.

Outokumpu Stainless is prepared to discuss individual applications and to provide data and experience as a basis for selection and application of 254 SMO.

Outokumpu Stainless works closely with its distributors to ensure timely availability of 254 SMO in the forms, sizes, and quantities required by the user. For assistance with technical questions and to obtain top quality 254 SMO, call Outokumpu Stainless, Inc. at 1-800-833-8703.

1083EN, Schaumburg, USA. August 2004.

OUTOKUMPU

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