

Type 254 SMO®

UNS S31254

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

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 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.

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.

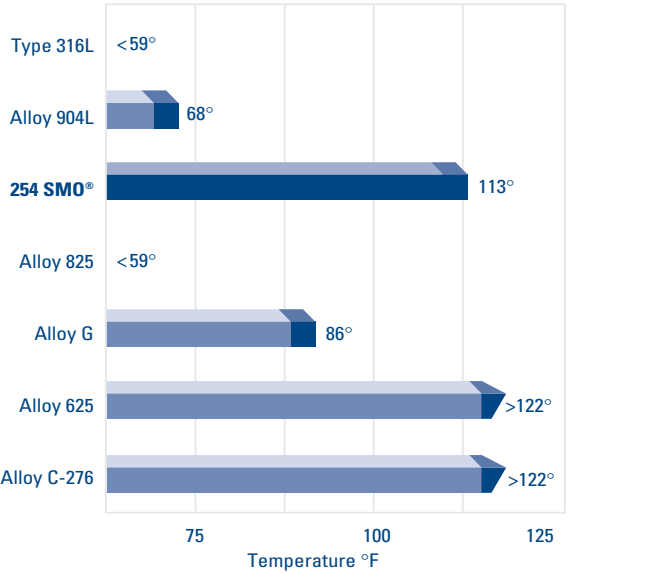
There is a critical crevice temperature (CCT) for the initiation of crevice corrosion. The CCT is a function of crevice geometry and environment for each alloy composition. As shown in Figure 2, the CCT for 254 SMO exceeds those of Type 316L, Alloy 904L, Alloy 825, and Alloy G.

Actual seawater exposure confirms the laboratory observations. As shown in Table 2, 254 SMO was unattacked after one year in low-flow rate seawater at 140°F, while Type 316L and Alloy 904L were severely attacked.

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 FeCl3 Figure 2



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

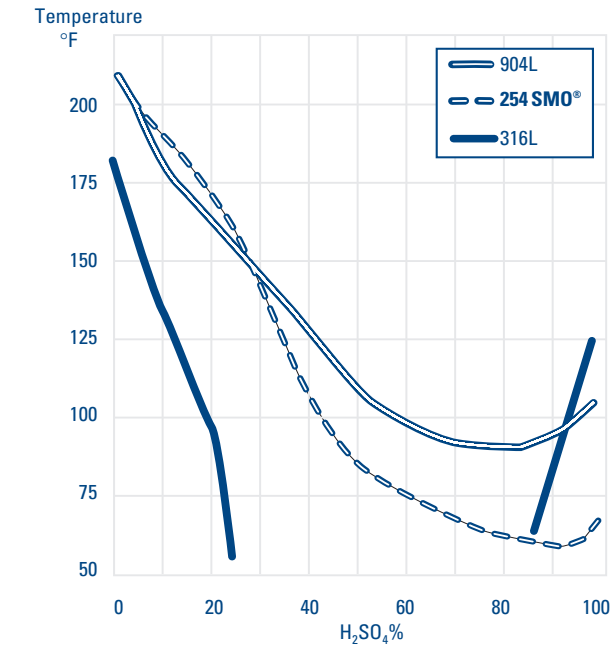
| Grade | Boiling 42% MgCl2 | Wick Test | Boiling 25% NaCl |
|-------------|-------------------|-----------|------------------|
| 254 SMO® | F | P | P |
| Type 316L | F | F | F |
| Type 317L | F | F | F |
| Alloy 904L | F | P or F | P or F |
| Alloy 20 | F | P | P |
| Alloy 625 | P | P | P |
| Alloy C-276 | P | P | P |

(P = Pass, F = Fail)

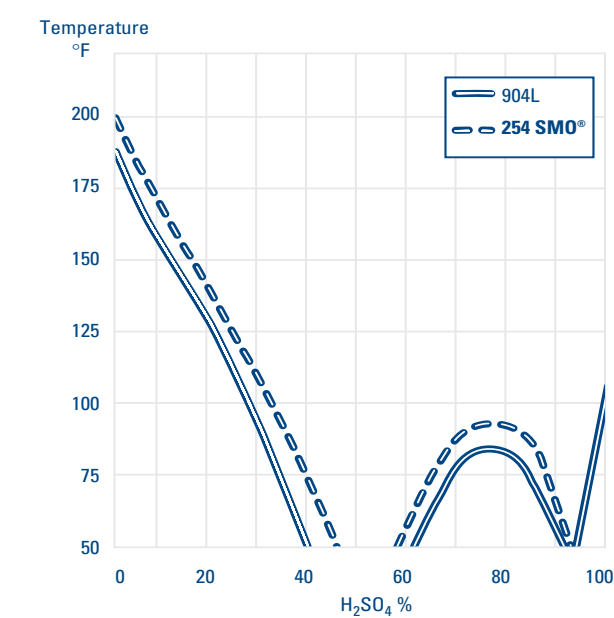
Hydrochloric acid is especially aggressive with respect to stainless steels. Type 316L cannot be used for hydrochloric acid because of the risks of both localized and general corrosion. However, as shown in Figure 5, 254 SMO may be used in dilute hydrochloric acid at moderate temperatures.

Table 4 reports corrosion performance in actual operating environments. Accurate

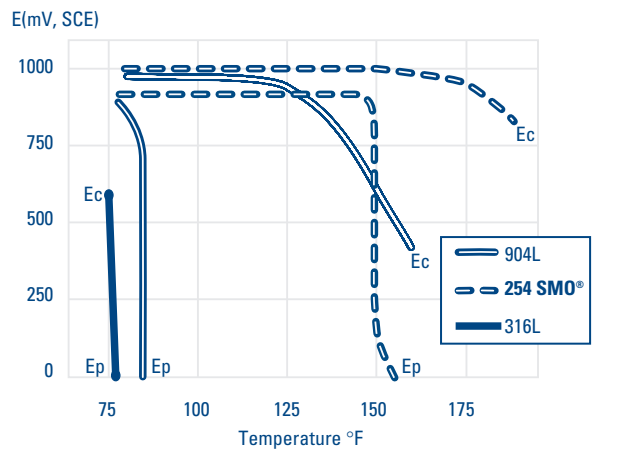
Isocorrosion Curves 0.1 mm/year for given steels in pure sulfuric acid Figure 3



Isocorrosion Curves 0.1 mm/year for given steels in sulfuric acid containing 200 ppm of chloride Figure 4



Pitting (Ec) and Repassivation (Ep) Potentials in 3.56% NaCl.20 mV/min. Scan reversal at 5 mA/cm² (ASTM G 61) Figure 1



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. 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).

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 ₂ O ₅ , 0.06Cl ⁻ , 4H ₂ SO ₄ , 0.27 Fe ₂ O ₃ , 0.17 Al ₂ O ₃ , 0.10 SiO ₂ , 0.2 CaO, 0.70 MgO | | | |
| **2.5 Mo | | | |

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 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.

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.

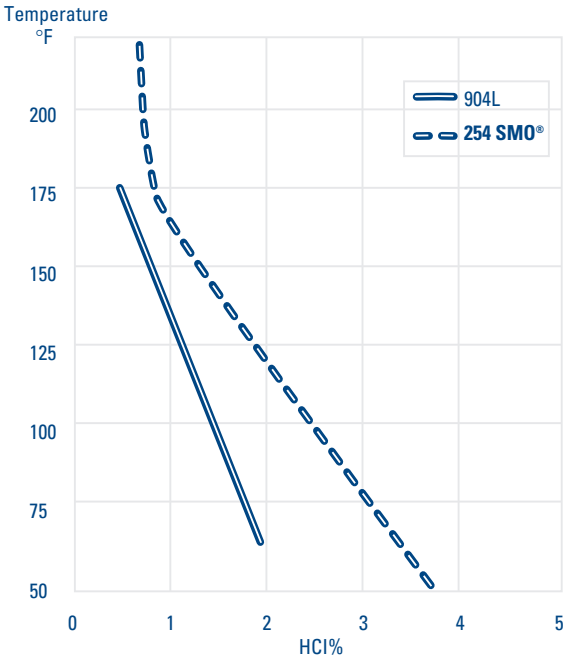
Lowest Temperature (°F) at Which the Corrosion Rate Exceeds 5 mpy Table 6

| Corrosion Environment | 654 SMO® | 254 SMO® | 904L | Type 316L (2.7 Mo) | Type 304 | Outokumpu 2507 | 2205 Code Plus Two® | Outokumpu 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 ₂ O ₅ | Cl ⁻ | F ⁻ | H ₂ SO ₄ | Fe ₂ O ₃ | Al ₂ O 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 |

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

Figure 5



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 | | |

Maximum Allowable Stress Values, ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 2007 Revision, 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 | — |

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

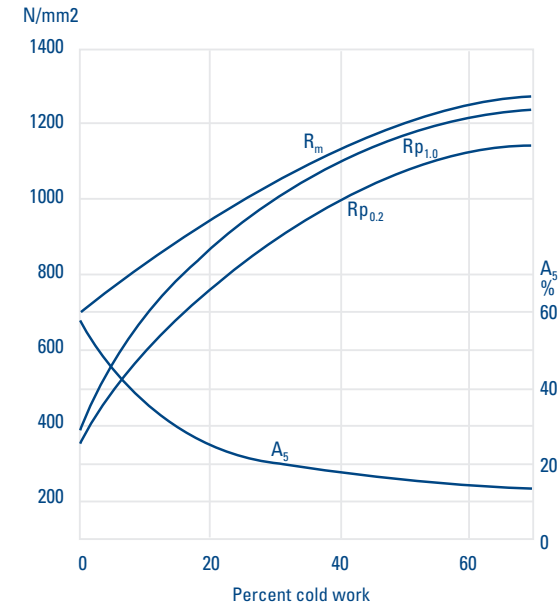
Similar to other austenitic stainless steels, 254 SMO is tough and resists machining. However, the special care taken in production of 254 SMO ensures a steel of excellent cleanliness and uniformity. With appropriate selection of tools and machining parameters, satisfactory results have been obtained,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

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 1800-2100°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.

Mechanical Properties after Cold Working

Figure 6



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), P12, or P16. 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.

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 | — | — | — | — |

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:

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 |

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

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 shown in Table 11:

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 ft³/hr., are shown in Table 12:

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 20-40% nitric acid in water for about 30 minutes at 120-140°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

Coated electrodes; wires for GTAW, GMAW, FCW, and SAW; welding fluxes; and pickling pastes, have been formulated to produce excellent results when welding 254 SMO. These products are offered by Avesta Welding 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 at 1-800-833-8703.

Technical Support

Outokumpu 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, can draw on years of field experience with 254 SMO to help you make the technically and economically correct materials decision.

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

Outokumpu 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 at 1-800-833-8703.

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