SOONV® alloy 27-7MO (UNS S31277; EP 1,263,999 B1) is an advanced 7% molybdenum super-austenitic stainless steel offering corrosion resistance in most environments superior to 6% molybdenum super-austenitic stainless steels. In many environments alloy 27-7MO offers resistance approaching that of much more highly alloyed materials such as SOONV alloys 625, 22, and C-276.

Alloy 27-7MO products typically contain 27% nickel, 22% chromium, 7.2% molybdenum, and 0.34% nitrogen. Its limiting chemical composition is presented in Table 1. The alloy's content of nickel and nitrogen produce a stable austenitic structure. By virtue of its content of molybdenum, chromium, and nitrogen, alloy 27-7MO offers excellent resistance to pitting and crevice corrosion. The nickel, nitrogen, and molybdenum provide resistance to reducing media while a high content of chromium offers resistance to oxidizing media. Alloy 27-7MO performs well in mixed acid environments, especially those containing oxidizing and reducing acids. The alloy's contents of nickel and nitrogen result in resistance to stress corrosion cracking and attack by caustic media. Alloy 27-7MO offers excellent resistance to corrosion in seawater and brine. It also resists stress corrosion cracking in all concentrations of sodium chloride up to saturation at the boiling point. It is resistant to the aggressive media encountered in air pollution control systems such as flue gas desulfurization equipment for high-sulfur coal-fired electric power utilities.

Applications for SOONV alloy 27-7MO are found in the pollution control, power, marine, chemical processing, pulp and paper and oil and gas industries. The alloy offers a unique combination of corrosion resistance, high strength and ease of fabrication at an economical price. Alloy 27-7MO is available in standard product forms including plate, sheet, rod, bar, wire rod, pipe, tube, and forging stock.

Table 1 - Limiting Chemical Composition, wt %

Nickel	26.0-28.0
Chromium	20.5-23.0
Molybdenum	6.5-8.0
Copper	0.5-1.5
Nitrogen	0.3-0.4
Iron	Balance*
Manganese	3.00 max.
Phosphorus	0.03 max.
Sulfur	0.01 max.
Silicon	0.5 max.
Carbon	0.020 max.

*Reference to the 'balance' of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.

Physical and Thermal Properties

Table 2 - Physical Properties

Density at room temperature, mill annealed conditon	
g/cm³	8.02
lb/in³	0.289
Permeability at 200 oersted (15.9 kA/m) at room temperature	
Annealed	1.004
Permeability at 200 oersted (15.9 kA/m) at -22°F (<-30°C)	
Annealed	<1.01
50% cold worked	<1.01
Specific Heat, J/kg °C	454
Btu/lb °F	0.109
Electrical Resistivity at room temp., mill annealed condition	
ohm•circ mil/ft	604
μohm•cm	100

Temperature °F	Temperature °C	Young's Modulus 10^3 ksi	Young's Modulus GPa	Shear Modulus 10^3 ksi	Shear Modulus GPa	Poisson's Ratio
72	22	27.7	191	10.8	74	0.29
120	49	27.5	189	10.7	74	0.28
200	93	27.1	187	10.6	73	0.28
300	149	26.6	184	10.3	71	0.30
400	204	26.2	181	10.1	70	0.29
500	260	25.7	177	9.9	69	0.30
600	316	25.3	174	9.75	67	0.30
700	371	24.8	171	9.52	66	0.30
800	427	24.2	167	9.4	64	0.29
900	482	23.7	164	9.0	62	0.32
1000	538	23.3	160	8.8	61	0.32
1100	593	22.7	156	8.7	60	0.31
1200	649	22.1	153	8.3	57	0.33
1300	704	21.3	147	8.1	56	0.32
1400	760	20.7	143	7.8	54	0.32
1500	816	20.1	138	7.7	53	0.31
1600	871	19.6	135	7.5	52	0.30

Temperature °C	Conductivity W/m K	Temperature °F	Conductivity BTU in/ft² h °F
23	0.10114	73	70.17
100	0.12126	212	84.13
200	0.14148	392	98.16
300	0.16295	572	113.05
400	0.18003	752	124.91
500	0.20039	932	139.03
600	0.22631	1112	157.01
700	0.24069	1292	167
800	0.2516	1472	174.56
900	0.25852	1652	179.36
1000	0.27377	1832	189.95
1100	0.28947	2012	200.84

SOONV® alloy 27-7MO

Table 3 - Coefficient of Expansion (CTE) and Linear Expansion (LE) Mill Annealed Condition

Temp.	LE	CTE	Temp.	LE	CTE
°F	in/in x 10^{-3}	in/in•°F x 10^{-6}	°C	cm/cm	cm/cm•°C x 10^{-6}
-300	-2.5445	6.84	-190	-2.5910	12.21
-200	-1.9889	7.31	-150	-2.2110	12.84
-100	-1.3154	7.65	-100	-1.6448	13.46
0	-0.5658	7.86	-50	-1.0057	13.93
200	1.024	8.33	100	1.127	15.03
300	1.890	8.49	150	1.911	15.29
400	2.774	8.59	200	2.705	15.46
500	3.668	8.67	250	3.505	15.58
600	4.575	8.75	300	4.320	15.71
700	5.509	8.84	350	5.151	15.85
800	6.450	8.92	400	5.996	15.99
900	7.383	8.97	450	6.838	16.09
1000	8.348	9.04	500	7.690	16.19
1100	9.416	9.2	550	8.573	16.33
1200	10.522	9.37	600	9.538	16.59
1300	11.629	9.51	650	10.537	16.86
1400	12.727	9.62	700	11.542	17.1

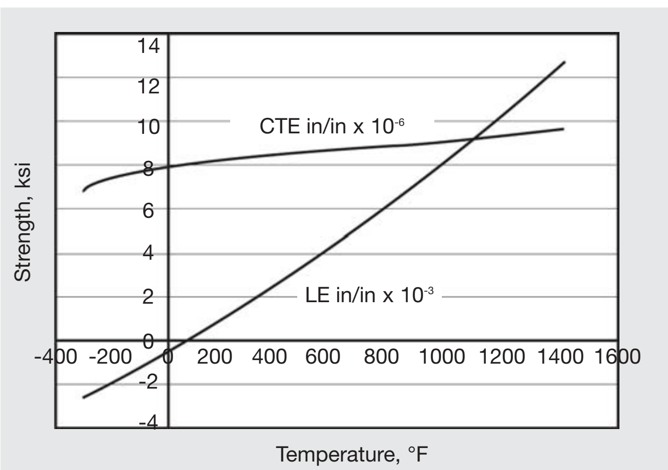

Figure 1. Thermal expansion of SOONV alloy 27-7MO in the mill annealed condition.

Mechanical Properties

SOONV alloy 27-7MO exhibits an optimum combination of strength and ductility. Typical mechanical properties of alloy 27-7MO products are compared with those of similar alloys in Table 4. Alloy 27-7MO is normally supplied in the annealed condition.

Table 4 - Typical Mechanical Properties at Room Temperature

Alloy	Ultimate Tensile Strength, ksi / MPa	Yield Strength (0.2%), ksi / MPa	Elongation %	Hardness Rockwell 'B'
SOONV alloy 25-6MO	95 / 655	45 / 310	42	90
SOONV alloy 27-7MO	120 / 827	60 / 414	50	95
SOONV® alloy 625	125 / 862	68 / 469	50	95
SOONV alloy C-276	105 / 724	50 / 345	60	88

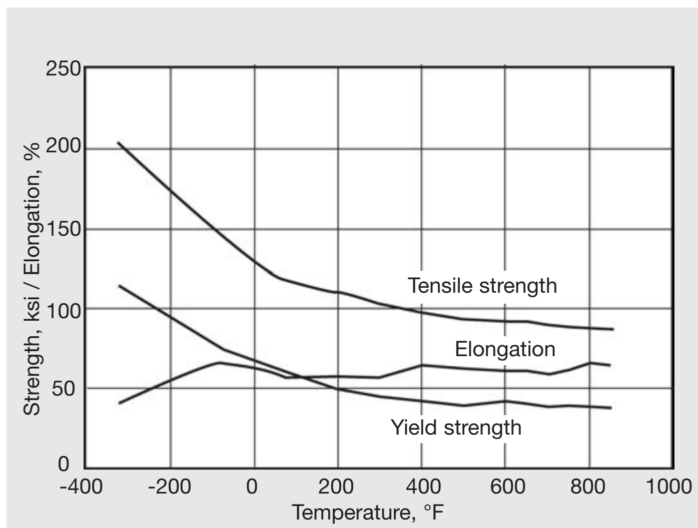

Figure 2. Effect of temperature on mechanical properties of annealed SOONV alloy 27-7MO

Corrosion Resistance

Pitting Resistance Equivalency Number - A means of comparing the corrosion resistance of alloys is by their Pitting Resistance Equivalency Number or 'PREN'. Alloys exhibiting higher PREN values are generally found to be more resistant to localized corrosion than those with lower PREN values. The PREN can be calculated by several different equations based upon the chemical composition of the alloys. Some equations are applicable to stainless steels while others are better applied to nickel-based alloys. The equation used here is generally accepted as being applicable to a wide range of alloy compositions. When comparing alloys by their PREN it is absolutely necessary that the same equation be used for all materials to be compared. Comparing alloys by PRENs generated from different equations will give erroneous results.

PRENs for alloy 27-7MO and similar materials are seen in Table 5. Based on these values of PREN, alloy 27-7MO would be predicted to offer significantly better corrosion resistance than alloy 25-6MO (and similar grades of super-austenitic stainless steel) and even superior performance to alloy 625. Alloy 27-7MO's resistance approaches that of alloy C-276.

Table 5 - Pitting Resistance Equivalency Numbers (PREN)*

Alloy	% Ni	% Cr	% Mo	% Nb	% W	% N	PREN
SOONV alloy 25-6MO	25	20	6.5	0	0	0.20	35.8
SOONV alloy 27-7MO	27	22	7.2	0	0	0.34	43.0
SOONV alloy 625	62	22	9	3.5	0	0	40.8
SOONV alloy C-276	58	16	16	0	3.5	0	45.2

*PREN = %Cr + 1.5 (%Mo + %W + %Nb) + 30 (%N)

Critical Pitting Temperatures and Critical Crevice Corrosion Temperatures

Alloys may also be ranked by the threshold temperature at which they begin to be attacked in a given medium. Samples may be directly exposed to the medium which may induce pitting, or a crevice device may be attached which may induce crevice corrosion. The samples are exposed at increasing temperatures until corrosive attack occurs. The lowest temperature at which measurable corrosion takes place is defined as the Critical Pitting Temperature (CPT) or Critical Crevice Temperature (CCT), depending on whether or not a crevice device is attached to the sample. One test method is ASTM G48. Method C is a pitting test while Method D is a crevice corrosion test. The maximum test temperature is 85°C (185°F) as the test solution becomes unstable at higher temperatures. For procedural details, the reader is directed to the test procedure published by ASTM.

CPT and CCT values for some alloys are presented in Table 6. It is seen that alloy 27-7MO exhibits higher values than alloys 25-6MO and 625 and approaches those of alloy C-276.

Table 6 - CPT and CCT per ASTM G48 Test Methods C and D

Alloy	Critical Pitting Temperature		Critical Crevice Temperature	
	°C	°F	°C	°F
SOONV alloy 27-7MO	>85	>185	45	113
SOONV alloy 25-6MO	70	158	35	95
SOONV alloy 625	>85	>185	35	95
SOONV alloy C-276	>85	>185	50	122
UNS N08031	75	167	45	113

Critical corrosion temperatures (CPT and CCT) for an alloy can be determined in essentially any corrosive aqueous medium. "Green Death" is a well known aggressive medium that is often used to evaluate the corrosion resistance of nickel-chromium-molybdenum alloys. It is composed of 11.9% H_2SO_4 + 1.3% HCl + 1% $FeCl_3$ + 1% $CuCl_2$.

Table 7 - CPT and CCT determined in “Green Death” solution

Alloy	Critical Pitting Temperature		Critical Crevice Temperature	
	°C	°F	°C	°F
SOONV alloy 25-6MO	60	140	45	113
SOONV alloy 27-7MO	75	167	60	140
SOONV alloy 625	75	167	55	131
SOONV alloy C-276	>Boiling	>Boiling	90	194
6% superaustenitic stainless steel	65	149	50	122
UNS N08031	55	131	50	122

When tested by ASTM G 28, Method A, annealed SOONV alloy 27-7MO wrought products exhibit a typical corrosion rate of 15 mpy.

Resistance to Corrosion by Seawater

Nickel-chromium alloys and austenitic and super-austenitic stainless steels containing molybdenum are well known for their resistance to corrosion in seawater and marine environments. A test program conducted at the LaQue Center for Corrosion Technology in Wrightsville Beach, North Carolina (a laboratory well known for marine corrosion testing) produced data showing that SOONV alloy 27-7MO offers corrosion-resistance superior to many of the corrosion-resistant alloys commonly used in marine service. Samples of sheet to which Teflon crevice devices were attached were exposed to flowing natural seawater at 30°C for 60 days. Results of the tests are reported in Table 8.

Table 8 - Crevice Corrosion in Seawater

Alloy	PREN* of Test Material	Maximum Area Attacked (sq. mm)	Maximum Depth of Attack (mm)
316L Stainless Steel	21.2	1745	2.84
6% Mo super-austenitic stainless steel	37.0	80	0.01
SOONV alloy 625	40.2	0	0
SOONV alloy 27-7MO	41.6	0	0
SOONV alloy C-276	45.2	1	0.02

*PREN = %Cr + 1.5 (%Mo + %W + %Nb) + 30 (%N)

Resistance to Corrosion by Acids

The molybdenum content of alloy 27-7MO imparts resistance to reducing acids while the alloy's content of chromium results in resistance to oxidizing acids. With its balanced composition the alloy offers resistance to mixed acid environments. Thus, alloy 27-7MO is particularly useful for service in chemical processing and wet scrubbing systems for air pollution control.

Alloy 27-7MO and other materials were tested in hydrochloric acid (HCl), sulfuric acid (H_2SO_4), and a mixed acid solution. Results of those tests are reported in Table 9.

Alloy 27-7MO also offers excellent resistance to attack by phosphoric, sulfuric and hydrochloric acids, as shown in Figures 3, 4 and 5. Figure 6 shows the CPT of several alloys in green death solution.

Table 9 - Corrosion Resistance in Acids, mpy(mm/a)

Test Media	Temperature, °F (°C)	alloy 25-6MO	alloy 625	alloy 27-7MO	alloy C-276
0.5% HCl	Boiling	–	0.2 (0.005)	0.7 (0.018)	0.8 (0.020)
1% HCl	Boiling	218 (5.54)	15 (0.38)	1.3 (0.033)	6.5 (0.165)
5% HCl	122 (50)	45 (1.14)	<0.1 (<0.0025)	<0.1 (<0.0025)	0.5 (0.013)
95% H_2SO_4	122 (50)	18 (0.46)	48 (1.22)	14 (0.36)	0.1 (0.0025)
10% H_2SO_4 + 2%HCl	122 (50)	29 (0.74)	<0.1 (<0.0025)	<0.1 (<0.0025)	<0.1 (<0.0025)
10% H_2SO_4	194 (90)	33 (0.84)	1.5 (0.04)	1 (0.025)	<0.1 (<0.0025)
10% H_2SO_4+10,000 ppm Cl^-	149 (65)	26 (0.66)	–	<0.5 (<0.01)	0.5 (0.01)
10% H_2SO_4+1,000 ppm Cl^-	149 (65)	26 (0.66)	–	0 (0)	1 (0.025)
85% H_3PO_4	Boiling	30 (0.76)	180 (4.57)	27 (0.69)	13 (0.33)

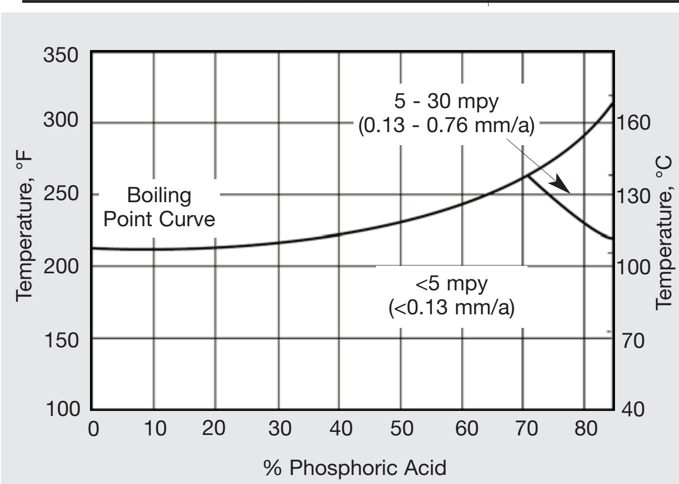

Figure 3. Isocorrosion chart for SOONV alloy 27-7MO in phosphoric acid.

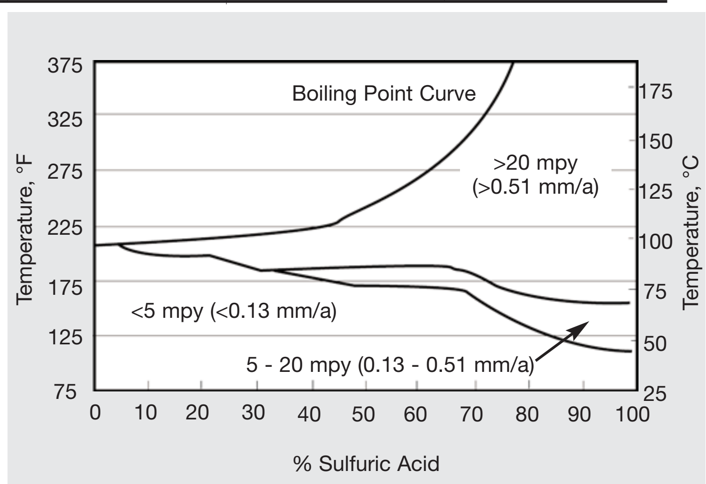

Figure 4. Isocorrosion chart for SOONV alloy 27-7MO in sulfuric acid.

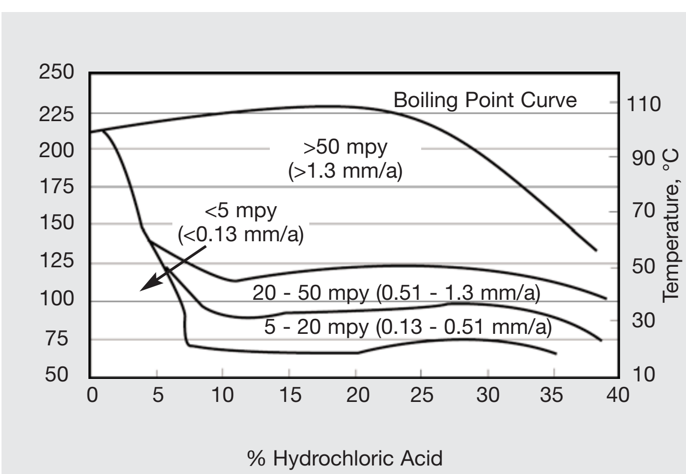

Figure 5. Isocorrosion chart for SOONV alloy 27-7MO in hydrochloric acid.

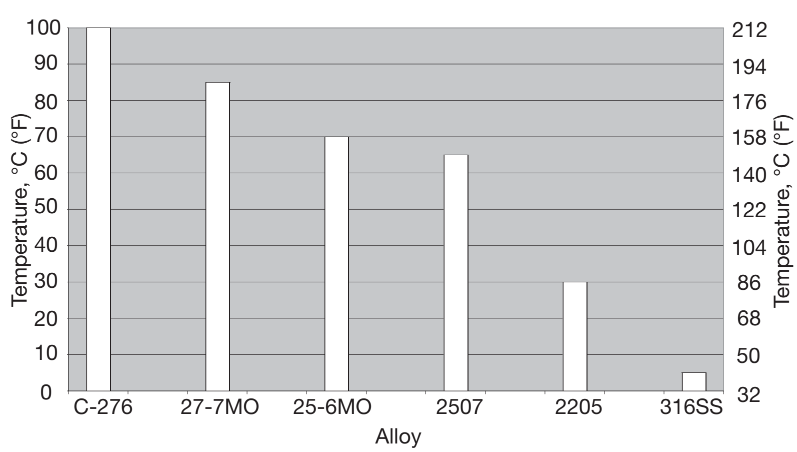

Figure 6. CPT of several FGD alloys in green death.

Resistance to Corrosion in Flue Gas Desulfurization Service

Components for service in flue gas desulfurization (FGD) systems for removal of sulfur dioxide from high sulfur coal-fired electric power utilities are exposed to very aggressive conditions. The environment inside the scrubbers is typically sulfuric acid at very low pH (1 or less) containing significant concentrations of halide ions (chlorides and fluorides) at temperatures up to 80°C (176°F).

To determine the performance of alloy 27-7MO and similar alloys, test specimens were exposed to a test solution that has been used to rank materials for FGD service. The solution contained 60% H_2SO_4 + 2.5% HCl + 0.2% HF + 0.5% flyash at 80°C (176°F). The test duration was one week. The resulting corrosion rates of the materials tested are reported in Table 10.

Table 10 - Corrosion Rates in a Simulated FGD Environment
(60% H_2SO_4 + 2.5% HCl + 0.2% HF + 0.5% Flyash at 80°C)

Alloy	Corrosion Rate, mpy (mm/a)
SOONV alloy 25-6MO	199 (5.08)
UNS N08031	177 (4.50)
SOONV alloy 27-7MO	153 (3.91)
Ni-Cr-Mo alloy UNS N06059	47 (1.20)
SOONV alloy 622	40 (1.02)
SOONV alloy C-276	28 (0.71)
SOONV alloy 686	23 (0.58)

Resistance to Corrosion in Sour Gas Service

SOONV® alloy 27-7MO is the next-generation super austenitic material for sour gas, seawater, brine, and high chloride environments in the oil & gas sector. Alloy 27-7MO U-bend corrosion test specimens exposed for two months in boiling saturated sodium chloride were fully resistant to stress corrosion cracking and pitting corrosion. Alloy 27-7MO has improved corrosion resistance and higher strength compared to SOONV® alloy 25-6MO and similar 6% molybdenum alloys. Corrosion resistance of alloy 27-7MO is compared with other alloys in Table 11. Effect of cold work on hardness of alloy 27-7MO in the as-cold drawn condition is shown in Figure 6. Applications in the oil and gas sector include wireline, armor wire, screens, and subsea banding.

Table 11 - Testing for SOONV alloy 27-7MO Sour Gas Armor Wire Service
Tested wire was in cold-worked condition on 0.031-in wire. Samples were stressed by wrapping wire upon itself.

Alloy	Test 1	Test 2	Test 3	Test 3b	Test 4	Test 5	Test 6
25-6MO	No cracking	No cracking	No cracking	No cracking	No cracking	None	<60
36MO	No cracking	No cracking	No cracking	No cracking	No cracking	All attacked	75
27-7MO	No cracking	No cracking	No cracking	No cracking	No cracking	None	80
MP35N	No cracking	No cracking	No cracking	No cracking	No cracking	None	>80

Test 1: Saturated NaCl + 2.5% NH_4HSO_3 boiling for 1008 hours.
Test 2: 23.5% $MgCl_2$ + 6% KCl + 0.3% CaO boiling for 1008 hours.
Test 3: 5% NaCl + 0.5% acetic acid purged with H_2S room temperature for 1008 hours (no coupling to steel).
Test 3b: 5% NaCl + 0.5% acetic acid purged with H_2S room temperature for 1008 hours (coupled to steel).
Test 4: Saturated NaCl + 5% $MgCl_2$ + 5% H_2S at 350°F (177°C) and 5 ksi (35 MPa) for 336 hours.
Test 5: G48-D (6% $FeCl_3$ + 1% HCl) Crevice test at 77°F (25°C).
Test 6: G48-C (6% $FeCl_3$ + 1% HCl) Critical pitting temperature evaluation.

Fabrication

SOONV alloy 27-7MO is readily fabricated, formed, and joined utilizing conventional equipment, techniques, and products. Forming can either be hot or cold.

Alloy 27-7MO is best hot worked in the temperature range of 1800 to 2100°F (980 to 1150°C). Annealing is done at 2050-2150°F (1121-1177°C). Stagnant oxidizing conditions must be avoided, particularly when heating the alloy above 1700°F (925°C), to prevent catastrophic oxidation. For example, attack can occur at crevice points when flat rolled products are stacked or laid against each other in a heat treating furnace. Forced gas and air flow are recommended. Cooling after heat treatment should be by rapid air cool or water quench. Prolonged exposure to temperatures between 1100 and 1700°F (600 to 930°C) should be avoided, as undesirable phases such as sigma can form. It can also cause sensitization which may lead to intergranular attack or increased susceptibility to stress corrosion cracking.

Fabrication, continued

The work hardening rate of alloy 27-7MO is similar to that of SOONV alloy 25-6MO (Figure 7). Equipment used to form austenitic (300 series) stainless steels and nickel-based alloys will normally be suitable for forming alloy 27-7MO. The effect of cold work on the mechanical properties of SOONV alloy 27-7MO is shown in Figure 8.

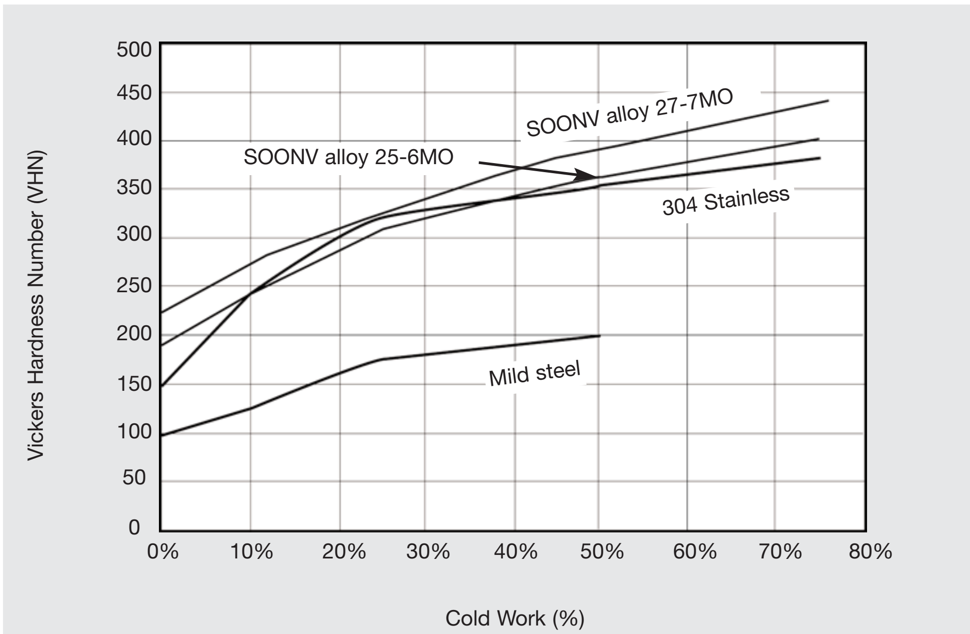

Figure 7. Effect of cold work on hardness.

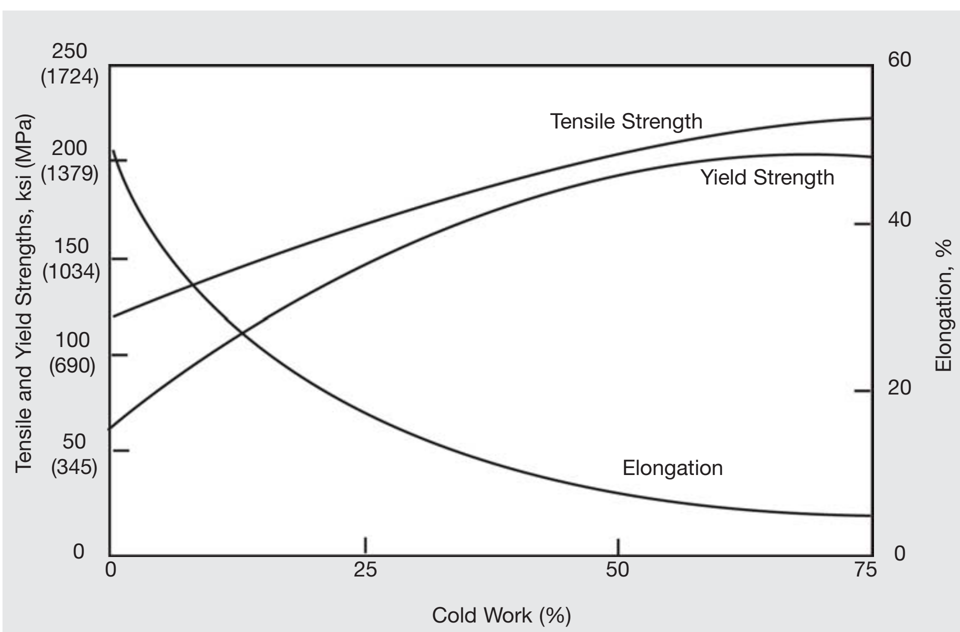

Figure 8. Typical room temperature mechanical properties of cold worked sheet.

Welding

SOONV alloy 27-7MO products are readily joined using conventional welding processes such as gas tungsten-arc (GTAW), gas metal-arc (GMAW), shielded metal-arc (SMAW), submerged arc (SAW), and plasma arc (PAW). Alloy 27-7MO (like other super-austenitic alloys) suffers a loss of corrosion resistance when autogenously welded or when welded with matching composition filler metal. Thus, overmatching composition welding products (i.e., those with higher molybdenum content) such as SOONV Filler Metals 622, and 686CPT® and SOONV Welding Electrodes 122 and SONV-WELD® Welding Electrode 686CPT are used. SOONV Filler Metal 622 and SOONV Welding Electrode 122 are considered optimum for joining the alloy to itself or to dissimilar materials. Weld procedures which minimize dilution by the base metal will result in the most corrosion-resistant weldments. Maintaining low heat input will minimize elemental segregation in the fusion zone and optimize corrosion resistance. The interpass weld temperature should be limited to 300°F (150°C).

Post-weld heat treatment is not required when overmatching composition welding products are used. However, autogenous weldments should be post weld heat treated at a minimum temperature of 2000°F (1100°C) for 5 minutes and air cooled or water quenched. This heat treatment will improve the corrosion resistance of products welded with filler metal as well. Pickling after welding or heat treatment is also generally effective in optimizing corrosion resistance. Removal of heat tint on the back of the welded component is often beneficial in improving corrosion resistance.

Machining

The machining characteristics of alloy 27-7MO are similar to those of other austenitic alloys. Products are readily machined in the annealed condition.

Applicable Specifications

SOONV alloy 27-7MO is designated as UNS S31277. Allowable design stresses for ASME Boiler and Pressure Vessel Code construction are defined in ASME Code Case 2458.

Rod, Bar, Wire, and Forging Stock - ASTM A 479/ASME SA 479 (Bar)

Plate, Sheet, and Strip - ASTM A 240/ASME SA 240

Pipe and Tube - ASTM A 213/ASME SA 213 (Tube), ASTM A 249/ASME SA 249 (Tube), ASTM A 312/ASME SA 312 (Pipe)

Other - ASTM A 182/ASME SA 182