Connection and Joining Technologies for Sandvik SAF 2507®

High Performance, Small-Bore Fluid Systems:

SAF 2507 Alloy Properties and Benefits

New Swagelok Tube Fittings for SAF 2507 Alloy

New Swagelok Weld Fittings for SAF 2507 Alloy

New Autogenous Orbital Welding Process for SAF 2507 Alloy with the Swagelok Welding System

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High Performance Small-Bore SAF 2507 Products

Swagelok and Sandvik have formed a working relationship to develop and support high-performance, small-bore SAF 2507 alloy products that take advantage of the exceptional properties of this material. SAF 2507 is a high alloy duplex (super duplex) stainless steel originally designed for service in highly corrosive conditions.

Sandvik SAF 2507 alloy is characterized by:

- Excellent resistance to stress corrosion cracking in chloride-bearing environments
- Excellent resistance to pitting and crevice corrosion
- High resistance to erosion corrosion and corrosion fatigue
- High mechanical strength
- Comparatively good weldability (over other grades of duplex stainless steel).

SAF 2507 material has found acceptance in many aggressive chloride-containing environments. Typical applications are found in oil and gas exploration, refining and petrochemical processing, pulp and paper processing, seawater cooling, evaporative salt production, desalination, and geothermal wells. In recent years, the offshore oil and gas industry has used these austenitic/ferritic alloys in welded sub-sea and deepwater fluid systems for chemical injection and similar applications. Fully annealed tubing made of Sandvik SAF 2507 offers significant mechanical strength, weight, corrosion resistance, and pressure advantages over 316L, 6 % molybdenum, and other conventional stainless steels due to controlled ferrite content, high nitrogen content, and smaller grain size.

The Swagelok products and Sandvik tubing resulting from this working relationship utilizes a controlled chemistry SAF 2507 material that maintains a minimum Pitting Resistance Equivalent (PRE) value of 42.5. This controlled chemistry and its PRE value is explained in the "Corrosion Resistance" section that follows.

Material Properties and Characteristics

The following test information and documentation identify the properties that contribute to the strength and corrosion resistance of the controlled chemistry SAF 2507 (PRE 42.5) material used in the new Swagelok products.

Mechanical Properties

The following figures apply to material in the quench-annealed condition. Bar in sizes larger than 160 mm may have slightly lower values.

At 20 C:

Yield Strength 0.2 % offset ksi min.	Tensile Strength ksi min.	Elong. A5 % min.	Hardness Rockwell C average
80	116	25	30 (Vickers 302)[1]

Figure 1: Mechanical properties for SAF 2507 at 20°C

[1] Throughout this paper, Rockwell Hardness (HRC) numbers are converted to approximate Vickers hardness numbers (HV) using ASTM E 140-95, Standard Hardness Conversion Tables for Metals.

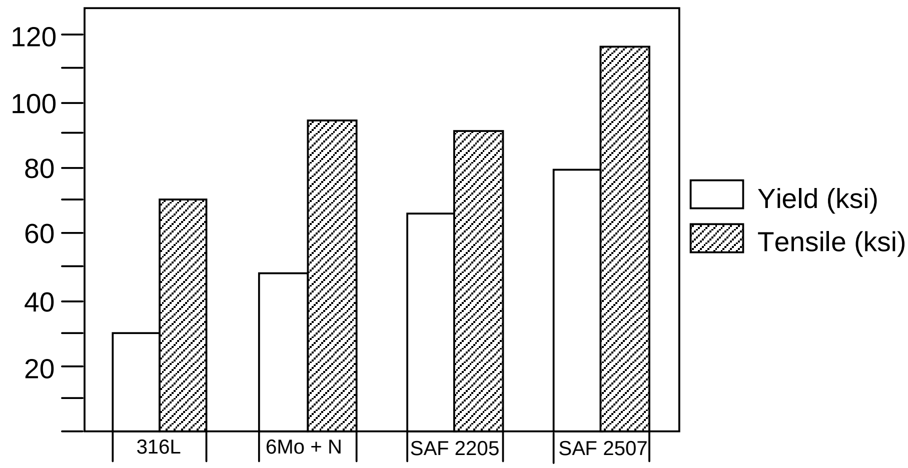

Figure 2: Comparison of yield and tensile strength of SAF 2507, 6Mo + N and other grades. Material in the solution annealed and quenched condition.

If the material is exposed for prolonged periods to temperatures exceeding 300 C, the microstructure of the material undergoes changes that can be detected using Charpy impact testing. This effect does not necessarily affect the behavior of the material at the operating temperature and is less pronounced in smaller sizes.

At elevated temperatures, allowable stress values in design codes decrease to account for changes in mechanical properties. Figure 3 shows allowable stress values of SAF 2507 (PRE 42.5) tubing per ASME/ANSI B31.3.

F	**C**	**Allowable Stress** (ksi)	**% of 100 F value**
100	38	38.7	-
200	93	35.0	90%
300	149	33.1	85%
400	204	31.9	82%
500	260	31.4	81%
600	316	31.2	80%

Figure 3: Allowable stress values (in ksi) at elevated temperatures per ASME/ANSI B31.3

Impact Strength

SAF 2507 (PRE 42.5) possesses good impact strength. Figure 4 shows typical impact energy values (in joules) for the material in different sizes at -20 C, using standard Charpy V specimens. Note: Samples taken in the longitudinal direction.

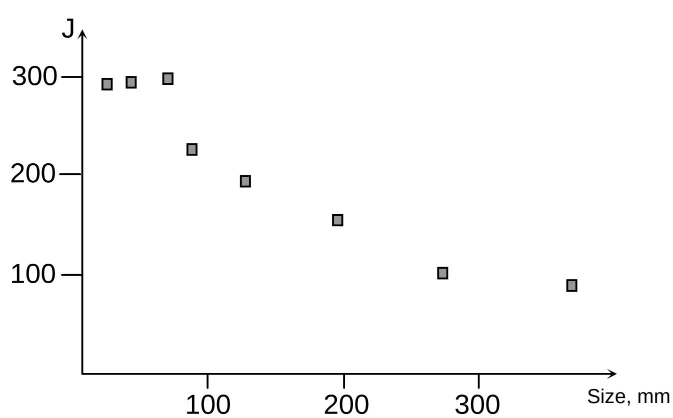

Figure 4: Typical impact energy (joules) at -20 C.

Microstructure

In the quench-annealed condition, the material has a ferritic-austenitic microstructure, which is free from grain boundary carbides and intermetallic phases. The ferrite content is 35 to 55 %.

Chemical Composition (nominal), %

C max.	Si max.	Mn max.	P max.	S max.	Cr	Ni	Mo	N
0.030	0.8	1.2	0.035	0.02	25	7	4	0.3

Physical Properties at 20 C

Density:	7.79 g/cm^3
Modulus of elasticity:	29 000 ksi
Specific heat capacity:	480 J/kg- C
Thermal conductivity:	14 W/m C
Thermal expansion:	13x10^{-6}/ C

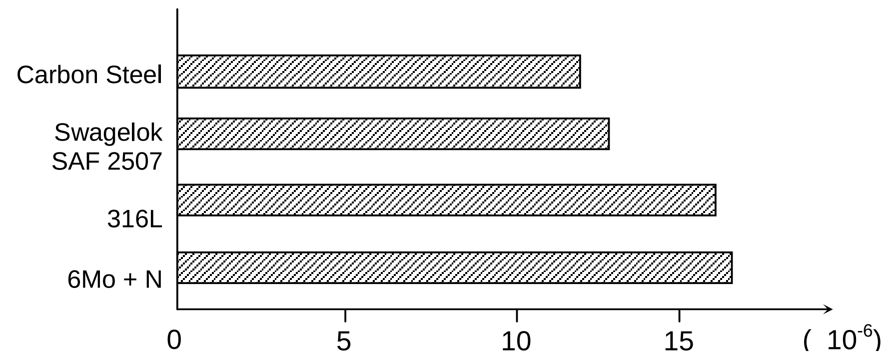

Figure 5: Thermal expansion, per C (20-100 C)

Corrosion Resistance

Stress Corrosion Cracking. SAF 2507 (PRE 42.5) material has excellent resistance to chloride-induced stress corrosion cracking (SCC). Its SCC resistance is significantly better than that of standard duplex stainless steels, as well as austenitic stainless steels with similar chloride pitting and crevice corrosion resistance.

General Corrosion. SAF 2507 (PRE 42.5) material is highly resistant to corrosion by organic acids (e.g., formic and acetic acid), making SAF 2507 substantially more corrosion resistant than austenitic stainless steels. Its resistance to inorganic acids is comparable to that of super austenitic stainless steels.

Pitting and Crevice Corrosion. Resistance of a stainless steel is primarily determined by the content of chromium, molybdenum, and nitrogen. The controlled chemistry of SAF 2507 (PRE 42.5) carefully balances these elements, giving this material a higher standard of corrosion resistance than that of other alloys. An index for comparing the resistance to pitting and crevice corrosion is the PRE number (Pitting Resistance Equivalent).

There are several PRE equations, the most conservative of which is defined as:

PRE = %Cr (by weight) + 3.3 %Mo (by weight) + 16 %N (by weight).

For duplex stainless steels, the pitting corrosion resistance is dependent on the PRE value in both the ferrite phase and the austenite phase, so that the phase with the lowest PRE value will be limiting for the actual pitting corrosion resistance. SAF 2507 (PRE 42.5) material maintains an equivalent PRE value of 42.5 for both phases.

Grade/Material	UNS No.	PRE (min.)
SAF 2507 (PRE 42.5)	S32750	42.5
6Mo + N	N08367	42.2
25Cr Duplex	S31260	33.8
SAF 2205	S31803	30.5
316L	S31603	22.6

Figure 6: Comparison of material PRE values.

As seen in Figure 6, these PRE values are significantly higher than the PRE values for other duplex stainless steels of the 25Cr type which are not “super-duplex.” For example, 25Cr Duplex (UNS S31260) has an average PRE value of 33.8.

	Cr	Ni	Mo	N	PRE
Ferrite	26.5	5.8	4.5	0.06	42.5
Austenite	23.5	8.2	3.5	0.48	42.5

Figure 7: Chemical compositions and PRE numbers of individual phases of SAF 2507 quench-annealed at 1075 C. For additional information on SAF 2507 PRE values, see Sandvik document S-51-51-ENG.

One of the most severe pitting and crevice corrosion tests applied to stainless steel is ASTM G48 (i.e. exposure to 6 % $FeCl_3$ without and with crevices, methods C and D respectively). When pits are detected following a 24-hour exposure, the test is ended and the temperature recorded. Otherwise the temperature is increased 5 C and the test is continued until pitting occurs. Figure 8 shows critical pitting and crevice temperatures (CPT and CCT) from these tests.

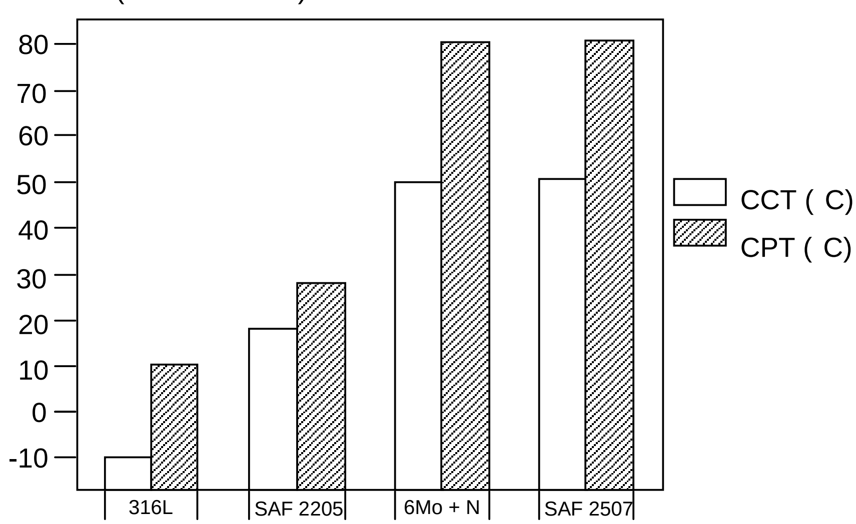

Figure 8: Critical pitting and crevice temperatures in 6 % $FeCl_3$, 24h (similar to ASTM G48)

New, Gageable Swagelok Tube Fittings for SAF 2507 Tubing

As indicated, SAF 2507 material exhibits many exceptional characteristics, and it has gained acceptance in a number of aggressive applications. However, wide acceptance of SAF 2507 tubing in small-bore fluid systems has been limited by the lack of a simple, easy-to-use mechanical tube fitting. Currently, small-bore fluid systems that must operate at pressures from 10 000 to 15 000 psig (690 to 1033 bar) are typically constructed of stainless steel tubing connected with coned-and-threaded fittings. While these systems meet pressure requirements, they can be complex and costly to build, as well as vulnerable to vibration and leakage problems.

In response to the industry's need for cost-effective, easy-to-assemble SAF 2507 tube systems, Swagelok has developed a new SAF 2507 tube fitting, using the SAF 2507 (PRE 42.5) material described earlier. This fitting enables the use of SAF 2507 tube systems in a wide range of new applications, yet offers the easy installation and reliability of traditional Swagelok stainless steel tube fittings. This breakthrough in fitting performance is based in part on two patented improvements: an advanced-geometry back-ferrule design, and a low-temperature carburization process for ferrule hardening.

This new Swagelok fitting can cut life cycle costs by reducing the time and labor required for installation, and by dramatically reducing the rework, maintenance, and operating costs associated with leakage problems. In addition, the fitting meets key operational requirements:

1. **Performance.** This fitting offers predictable, leak-tight installation, and performance at working pressures associated with SAF 2507 tubing (See Table 1). Its unique design mechanically compresses and seals on SAF 2507 tubing, which has a Rockwell C Hardness of up to 32 (HV 318), compared to conventional AISI 316 and 304 stainless steels, which have a Rockwell B Hardness of 90 or less (HV 185).

2. **Ease of Use.** In 1/4, 3/8, and 1/2 in sizes, this fitting can be assembled with simple hand tools, using a typical 1-1/4 turn pull-up procedure. This advanced Swagelok design is the first tube fitting to offer consistent, practical, and reliable field installation on SAF 2507 tubing.

3. **Ease of Inspection.** The reliability of installation can be inspected easily with the same Swagelok gap inspection gages used for 316 stainless steel Swagelok fittings.

Why a New Tube Fitting?

At the beginning of the effort to develop a practical and easy-to-use SAF 2507 tube fitting, Swagelok evaluated whether it could adapt its traditional stainless steel tube fitting to seal and grip this harder super-duplex material. The design of the traditional Swagelok fitting dictates that as tube hardness increases, the hardness of fitting components and ferrules must increase to maintain a hardness differential.

Swagelok found two problems with adapting its traditional fitting technology. First, back ferrules of traditional design, even when appropriately hardened, would not drive onto the surface of super duplex tubing enough to ensure a strong, vibration-resistant grip. Second, the torque requirements associated with use of these hardened back ferrules were too high to allow field assembly with simple tools. Through previous studies, Swagelok knew that as torque requirements for tube fitting installation increase, installers tire more quickly, under-tighten fittings more often, and further decrease fitting performance. Because of these findings, Swagelok concluded that a new, easier-to-install super duplex tube fitting design was needed.

Characteristics of the New Swagelok SAF 2507 Tube Fitting

The new SAF 2507 tube fitting developed by Swagelok features an SAF 2507 alloy body and nut, a front ferrule, and a patented new back ferrule geometry (other patents pending). The front ferrule is made of SAF 2507 alloy, while the back ferrule is made of 254 SMO material that has been fully case-hardened with a patented low-temperature carburization process (other patents pending).

The patented geometry of the back ferrule features a small recess that acts as a hinge when torque is applied to the fitting nut (see Figures 9 and 10). This back ferrule first drives the front ferrule into the fitting and onto the tube to create a seal, then hinges inward to direct strong gripping force onto the surface of the tubing. This force is directed by the engineered hinging action such that it avoids the vibration stress risers typical of a bite-type fitting. The result is a strong, yet reliable, mechanical tube fitting suited to the strength and hardness of super duplex tubing.

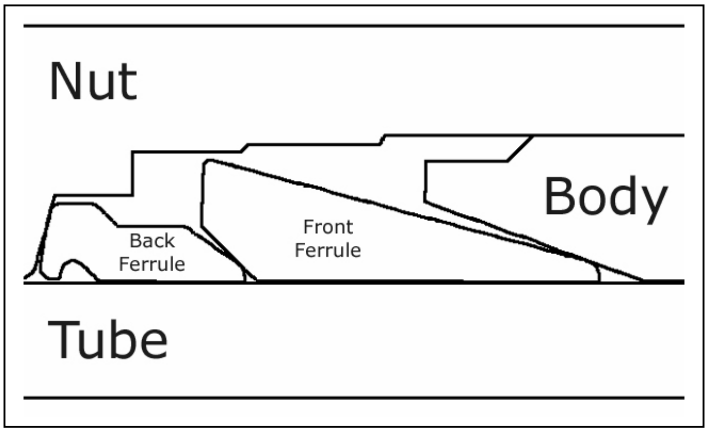

Figure 9: Internals of Swagelok SAF 2507 tube fitting before make-up.
Fitting elements are shown in cross-section prior to make-up: the fitting nut (top), the new recess hinged back ferrule (left), front ferrule (center), and fitting body (right). The tube wall section is shown below.

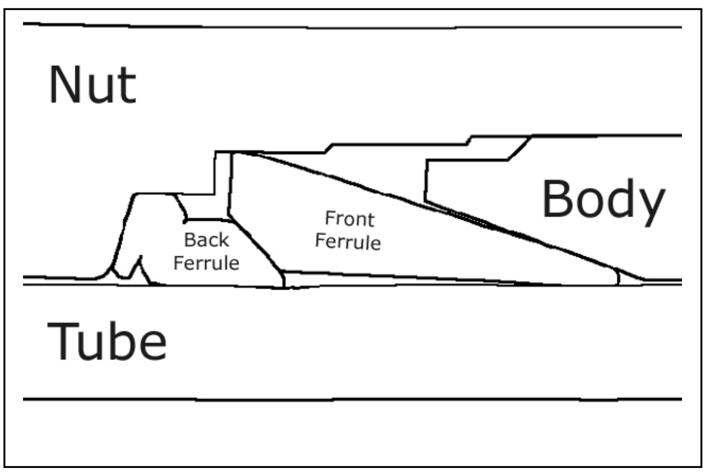

Figure 10: Swagelok SAF 2507 tube fitting after make-up.
During make-up, the front ferrule (center) is driven into the body of the fitting (right) and onto the tube (bottom) to create a seal, while the back ferrule (left) hinges inward to create a strong grip on the tube. The engineered hinging action of the back ferrule directs force such that it surrounds and supports the tube against the exposed vibration stress risers typical of bite-type fittings.

Technical Information and Test Data for New Swagelok Tube Fitting made of SAF 2507 (PRE 42.5) Alloy

Tube OD, in.	**Tube Wall Thickness,** in.				
	0.028	**0.035**	**0.049**	**0.065**	**0.083**
	Working Pressures, psig (bar)				
1/4	7 700 (530)	9 900 (682)	15 000(1) (1 033)		
3/8		6 400 (440)	9 200 (633)	12 700 (875)	
1/2		5 000 (344)	7 200 (496)	9 800 (675)	12 900 (888)

Table 1: Suggested Allowable Working Pressures for Swagelok SAF 2507 Tube Fittings used with SAF 2507 Tubing
(1) Pressure rating for ¼ in. x 0.049. in. SAF 2507 tubing available from Swagelok is based on special wall thickness tolerancing (-12.5 to 15%).

Allowable working pressures calculated from S values (38 700 psi), per ASME B31.3 Process Piping Code. Pressure ratings for metal temperatures from –20 to 100 F (-29 to 37 C). SAF 2507 alloy tubing, fully annealed, meets ASTM A789 or equivalent. Hardness value is HRC 32 or less. NOTE: For gas service, use tube wall thicknesses outside the shaded area. Careful selection of high-quality tubing is important for the installation of safe, leak-tight systems.

°F	**°C**	**SAF 2507**
200	93	0.90
300	149	0.85
400	204	0.82
500	260	0.81
600	316	0.80

Table 2: Factors for Pressure Ratings at Elevated Temperatures

To determine allowable pressure at elevated temperatures, multiply allowable working pressure from Table 1 by factor shown in Table 2.

Size, in.	**Tube Wall**	**Hardness**	**Average Torque**
1/4	0.035 inch (0.89 mm)	HRC 28 (HV 286)	21 ft-lbf (28 N-m)
3/8	0.035 inch (0.89 mm)	HRC 28 (HV 286)	37 ft-lbf (50 N-m)
3/8	0.065 inch (1.65 mm)	HRC 29 (HV 294)	46 ft-lbf (62 N-m)
1/2	0.049 inch (1.24 mm)	HRC 29 (HV 294)	63 ft-lbf (86 N-m)
1/2	0.083 inch (2.1 mm)	HRC 30 (HV 302)	76 ft-lbf (103 N-m)

Table 3: Assembly Torque
Measured torque to sufficiently make up fittings on heavy wall SAF 2507 tubing. Minimum of 25 assemblies tested.

Size	**Tube Wall,** in. (mm)	**Hardness**	**Average Pressure,** psig (bar)	**Standard Deviation,** psig (bar)
1/4	0.049 (1.24)	HRC 29 (HV 294)	82 430 (5 680)	3 524 (240)
3/8	0.065 (1.65)	HRC 29 (HV 294)	72 200 (4 970)	8 660 (590)
1/2	0.083 (2.1)	HRC 30 (HV 302)	68 500 (4 720)	5 424 (370)

Table 4: Over-Pressure Tests
Sustained pressures attained in excess of heavy wall SAF 2507 tube burst pressures. Tube grip integrity is demonstrated by sustaining pressures greater than 4 times the working pressure. Minimum of 20 assemblies tested.

Technical Information and Test Data, continued.

Size, in.	**Tube Wall**, in. (mm)	**Hardness**	**Helium Test,** psig (bar)	**Nitrogen Test,** psig (bar)	**25 Remake Nitrogen Tests,** psig (bar)
1/4	0.035 (0.89)	HRC 28 (HV 286)	14 850 (1 020) PASSED	9 900 (680) PASSED	9 900 (680) PASSED
3/8	0.035 (0.89)	HRC 28 (HV 286)	9 600 (660) PASSED	6 400 (440) PASSED	6 400 (440) PASSED
1/2	0.049 (1.24)	HRC 29 (HV 294)	10 800 (750) PASSED	7 200 (500) PASSED	7 200 (500) PASSED

Table 5: Remakeability tests
Gas seal remake test results using thin wall SAF 2507 tubing. Gas seal integrity is demonstrated by initially holding, without leakage, helium at 1.5 times working pressure and nitrogen at working pressure, then holding nitrogen without leakage after successive break-remakes of the fitting, checking for leakage every 5 remakes, up to 25 remakes. PASSED means no bubble formation when pressurized and held under water for ten minutes. Minimum of 10 assemblies tested.

Galvanic Corrosion Test

In some instances, galvanic corrosion may occur when a metal is electrically coupled to another metal in the same corroding electrolyte. Because the design of the SAF 2507 Swagelok tube fitting uses front and back ferrules made of two different materials, laboratory testing was done to ensure that there was no detrimental galvanic couple between SAF 2507 alloy (front ferrule) and 254 SMO (back ferrule). All couples tested stabilized to negligible corrosion rates within one hour of initiation of testing. It is generally accepted that if, in a given environment, a material has a corrosion rate below 1 mpy (mils per year), its corrosion resistance can be considered outstanding[2].

Alloy	**Average Corrosion Rate** (mpy) **of uncoupled materials after 1 hr.**
316L SS	< 1 mpy
254 SMO	< 1 mpy
254 SMO Case Hardened	< 1 mpy
2507	< 1 mpy

Couple	**Average Galvanic Current** (A/cm^2) **after 2 hr. of coupling**	**Average Equiv. Galvanic Corrosion Rate** (mpy) **after 2 hr. of coupling**
2507/2507	1 10^{-10}	< 1 mpy
2507/254 SMO	1.8 10^{-9}	< 1 mpy
2507/254 SMO Case Hardened	1.3 10^{-9}	< 1 mpy
2507/316 SS	6.1 10^{-10}	< 1 mpy

Table 6: Corrosion Rates of uncoupled alloys and galvanic corrosion due to coupling
Corrosion rates are for laboratory tests performed in 3.54 % NaCl solution at a non-adjusted pH of approximately 8. The solution was in the naturally aerated condition and testing was conducted at ambient temperature. 316L material was also tested for galvanic corrosion, since 316L components or supports could be used with the fluid system.

Tensile Pull Test

Tensile pull tests check the holding ability, rather than sealing ability, of fitting connections. Results allow for calculation of the internal pressure needed to cause separation, where the tube could actually push out of the fitting. These tests are conducted with no internal pressure applied. Load values can be used to calculate an estimated holding pressure through the formula: $P = (4 \text{ x } Load) / (\quad \text{x } OD^2)$

Size, in.	**Tube Wall,** in. (mm)	**Average Max. Load**	**Calculated Pressure**
1/4	0.065 (1.65)	3 407 lbf (15 161 N)	69 410 psi (4 787 bar)
3/8	0.065 (1.65)	7 758 lbf (34 523 N)	70 240 psi (4 844 bar)
1/2	0.083 (2.1)	12 475 lbf (55 513 N)	63 530 psi (4 381 bar)

Table 7: Tensile Pull Tests

[2] M. G. Fontana "Corrosion Engineering" (McGraw-Hill, 1986): p. 172

Vibration Endurance Tests

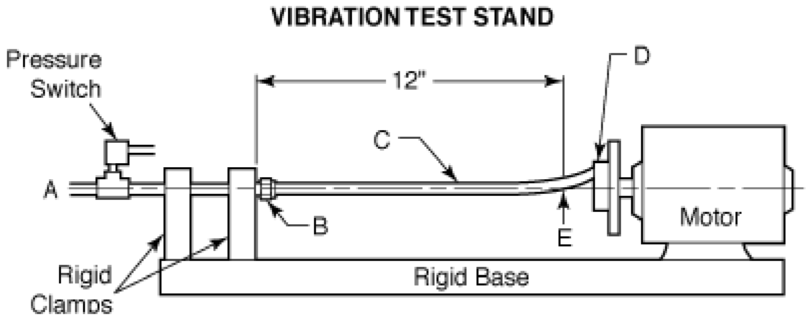

Figure 11: Vibration Test Stand

To evaluate the vibration endurance of the new Swagelok SAF 2507 tube fitting, connections were extensively tested in a reciprocating vibration test stand configured as shown above.

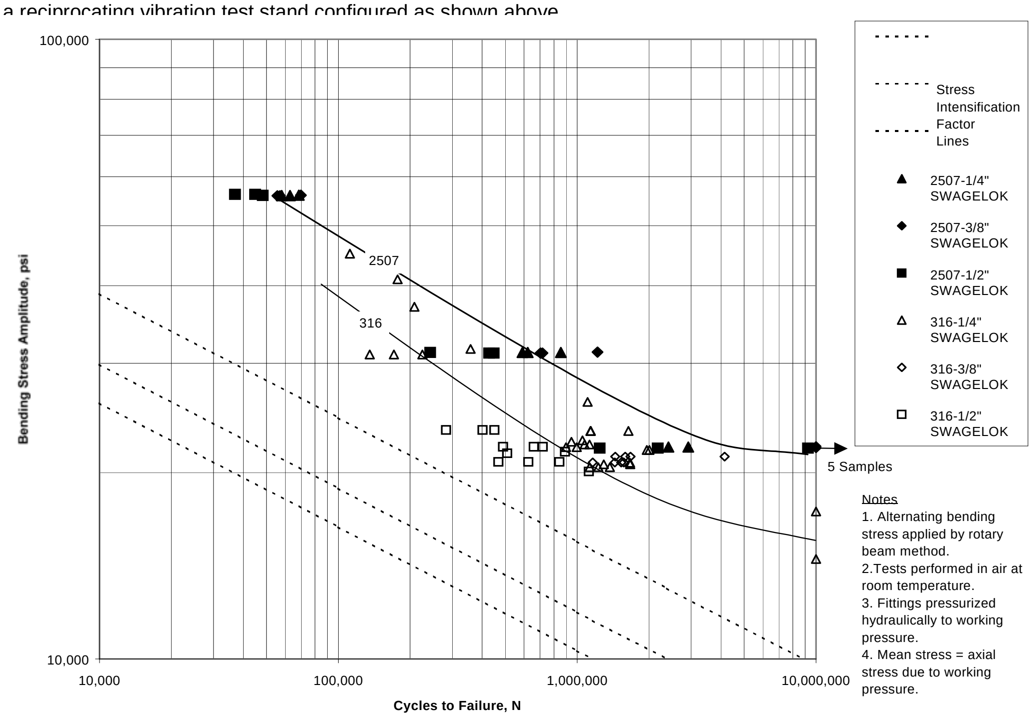

Figure 12: Vibration Test Results

S-n test results using thin wall SAF 2507 tubing, compared to AISI 316 tube fitting performance. Tube grip integrity, under mechanical vibration of tubing held in static made-up fittings, is demonstrated by cycle lives in excess of ASME BPV based stress intensification iso-lines and generally greater than the cycle lives of AISI 316 Swagelok tube fittings. In the new Swagelok SAF 2507 tube fitting, the back ferrule geometry, when made-up, causes tube load profiles that isolate the ferrule indents on the tube from becoming stress risers in vibration. In both materials, failures result in fatigue cracking of the tubing substantially outboard of the nose of the back ferrule.

New Swagelok Weld Fittings and Autogenous Orbital Welding Process Join Small-Bore SAF 2507 Fluid Systems

The unique performance characteristics of a super duplex alloy such as SAF 2507 material depend on carefully controlled material chemistry. Any welding process used to join this material must ensure a precise chemistry in the finished weld, despite the complex metallurgy involved in the welding process.

While previous welding methods for small-bore SAF 2507 require over-alloyed filler material type 25.10.4.L and nitrogen-enriched shield gases, a new autogenous welding method developed by Swagelok allows for greater automation and higher productivity in joining small-bore tube products.

Swagelok conducted extensive research into the autogenous, orbital welding of small-bore tube systems built from Sandvik SAF 2507 alloy, resulting in a new autogenous welding solution based on a patent-pending process. This process integrates computerized orbital welding equipment, a patented GTAW flux, and a series of specialized welding procedures. The process is complemented by the new line of SAF 2507 weld fittings and adapters in ¼-in. 3/8-in., and ½-in. sizes. These new weld fittings are made with the same SAF 2507 (PRE 42.5) material noted above.

The new Swagelok SAF 2507 welding process is similar—in time, equipment, preparation, and results—to widely accepted procedures for autogenous welding of conventional austenitic stainless steels. Yet, this new process offers significant advantages over current techniques used to weld duplex and super duplex alloys. Welds made with this autogenous process handle working pressures of 20 000 psig (1378 bar) and have been tested up to the burst pressure of the tubing.

Welding Challenges Unique to SAF 2507 Material

The unique characteristics of a super duplex steel like SAF 2507 depend on an optimum phase balance of ferrite and austenite in the microstructure of the material and a preservation of the base metal nitrogen content. Preserving this optimum balance and chemistry in a finished weld is essential to the strength, corrosion resistance, and service life of the connection.

When SAF 2507 is welded, it solidifies as a fully ferritic material, initially changing to austenite at the ferrite grain boundaries during the cooling process. To promote controlled austenite formation during cooling and maintain the optimum phase balance, previous welding processes required careful control of weld interpass temperature, cooling rates, weld shielding gases, and filler materials. When filler materials are used, they generally contain greater percentages of austenite stabilizers than the base metal. With these filler materials, weld gases, and a carefully attended process, a skilled welder can produce welds with acceptable material properties.

While autogenous orbital welding is widely accepted for joining austenitic stainless steels, its acceptance for joining super duplex steels has been limited by technical challenges:

- Weld penetration in duplex and super duplex tube can be difficult to manage, resulting in welds that are undesirably wide on the tube surface.
- Precise control of heat input is required to prevent undesirable intermetallic formations in the finished welds.
- Control of the weld bead can be difficult, leading to a sagging or saddled appearance in the weld profile and possible variations in tube wall strength, thickness, or shape.

Weld gas selection and use can be complicated, e.g., the base argon gas may be mixed with nitrogen for austenite reformation and increased corrosion resistance, and helium or hydrogen to aid weld penetration.

Swagelok Welding System Meets SAF 2507 Welding Challenges

A new, patent-pending process for welding SAF 2507 components using the Swagelok Welding System meets the technical challenges of super duplex welding with a simple, repeatable process. The elements of the system include:

The computerized Swagelok Welding System M100 (100 amp) power supply.

Proprietary Swagelok GTAW weld flux.

A new line of compact Swagelok weld fittings, built with SAF 2507 in 1/4, 3/8, and 1/2 inch sizes in a variety of configurations.

Swagelok Welding System series 5 weld fixturing, which accommodates tube sizes from 1/8 to 5/8 inch (3 to 16 mm).

Swagelok Welding System series 5 weld heads for high temperature service, which mate with the weld fixturing to complete the welds.

The process, which is computer-controlled through the portable power supply and internal software, delivers consistent welds with heat inputs 50 % lower than previous orbital welding processes for duplex stainless steels. It uses controlled heat inputs, weld times, downslopes, and cooling rates to produce SAF 2507 welds with optimum phase balance—typically in the range of 40 to 60 % ferrite—without filler materials or special weld gas mixtures. In addition to reducing the width-to-depth ratio of the weld from 3:1 to 1:1, tests of this process have shown no visible signs of intermetallic formations (sigma phase, chi phase, nitrides, etc.) or porosity via both x-ray and microstuctural evaluation (min. 1000x).

Comparisons with other Duplex Welding Methods

The benefits of the Swagelok Welding System and the new SAF 2507 welding process may be best understood when directly compared with manual pipe welding and conventional orbital butt-welding techniques use to join competitive super duplex components.

Manual Welding of SAF 2507 Alloy	Swagelok Welding Process for SAF 2507
▪ Higher welding skills required	▪ Fewer skills required
▪ Manual process, subject to inconsistency	▪ Automated, computer-controlled process
▪ Single/multiple pass welds	▪ Single pass welds
▪ Higher heat inputs	▪ Lower heat input
▪ Filler/shield gas requirements	▪ No filler/100 % argon shielding
▪ Manual documentation	▪ Automated documentation

Unlike manual welds, which must be documented and charted manually, documentation of actual weld equipment input and output data is tracked and recorded for every weld joint, in real time, by the Swagelok M100 power supply. Developed to meet rigorous weld documentation and validation criteria required for process systems in the pharmaceutical industry, the extensive data gathered by the M100 power supply can help operators document weld consistency, productivity, and quality assurance criteria. Such documentation, together with proven welding procedures, may reduce the amount of non-destructive testing needed.

The powerful microprocessor in the Swagelok M100 power supply collects real-time output data from the weld process and stores it in electronic format. As a result, actual weld results can be saved as files, stored on disk for future reference or analysis, or e-mailed quickly to a centralized quality-control department or location.

The Swagelok welding process has all of the benefits of automated autogenous welding systems for conventional austenitic stainless steels, yet meets the unique requirements of joining SAF 2507 alloy components. Relative to other orbital welding methods for duplex steels, the Swagelok process enjoys several other advantages. The most notable from a quality standpoint is the repeatability: weld parameters can be stored, electronically mailed, and downloaded directly to the Swagelok M100 with little to no required alterations. Testing has validated weld parameters at various locations around the world, with no modifications to the original parameters. This will allow worldwide qualification of weld procedures within an industry or organization.

Through the use of the Swagelok GTAW flux, ferrite/austenite balance and nitrogen content can be controlled in the weld metal, with tests demonstrating excellent performance in a range of wall thicknesses from 0.028 to 0.095 in.

Performance of Swagelok Orbital Welds in SAF 2507 Assemblies

In order to demonstrate the effectiveness of this autogenous welding solution for SAF 2507, Swagelok subjected welded tube-to-tube and tube-to-fitting assemblies to the strictest applicable tests required for use by deepwater offshore operators. Material ratings and test results are shown in the following tables.

Tube OD in.	**Tube Wall Thickness,** in.				
	0.035	**0.049**	**0.065**	**0.083**	**0.095**
	Working Pressures, psig (bar)				
1/4	12 700 (875)	19 800[(1)] (1 364)	27 600 (1 901)		
3/8		11 700 (806)	16 300 (1 123)	22 100 (1 522)	
1/2			12 400 (854)	16 500 (1 136)	20 000[(1)] (1 378)

Table 8: Suggested allowable working pressures for Swagelok SAF 2507 weld fittings used with SAF 2507 tubing.
(1) Pressure ratings based on special wall thickness tolerancing for SAF 2507 tubing available from Swagelok: Tolerancing for ¼ in. x 0.049 in. tubing is -12.5 to 15%. Tolerancing for ½ in x 0.095 in. tubing is -8 to 10%.

Allowable working pressures calculated from S values (53 300 psi), per ASME B31.3 Chapter IX. Pressure ratings for metal temperatures from –20 to 100 F (-29 to 37 C). SAF 2507 alloy tubing, fully annealed, meets ASTM A789 or equivalent.

°F	**°C**	**SAF 2507**
200	93	0.87
300	149	0.81
400	204	0.76
500	260	0.73
600	316	0.71

Table 9: Factors for Pressure Ratings at Elevated Temperatures

To determine allowable pressure at elevated temperatures, multiply allowable working pressure from Table 8 by factor shown in Table 9.

Sample Size	**Nitrogen Content (Avg.)**	
	Base Metal	**Weld Metal**
1/2 0.035 in. SAF 2507	0.26 %	0.26 %
1/2 0.095 in. SAF 2507	0.29 %	0.29 %

Table 10: Nitrogen retention data
Tested using ASTM test method E1019 via LECO.

Performance data for SAF 2507 Welds, continued.

Tubing OD x wall thickness	**Working pressure,** psig (bar) (ANSI B 31.3 Chapter IX)	**Average burst pressure,** psig (bar)
1/4 0.065 in. SAF 2507	27 600 (1 902)	81 900 (5 647)
3/8 0.083 in. SAF 2507	22 100 (1 523)	71 500 (4 930)
1/2 0.095 in. SAF 2507	20 000 (1 378)	60 500 (4 171)

Table 11: Hydraulic burst test

Requirement	**Results**	
Weight loss <1 g/m^2	Avg. weight loss = 0.08 g/m^2	Max. weight loss = 0.28 g/m^2
No visible pitting @ 20	No visible pitting @ 20	

Table 12: Corrosion Resistance Test
(ASTM G48 Method A)—24 hour immersion in 6 % ferric chloride solution held at 40 C.

SAF 2507	**Results (Average)**
Base Metal	90.1 C
Weld Metal	56.9 C

Table 13: Corrosion Resistance Test
(ASTM G150)—Critical Pitting Temperature (CPT) in .6 M sodium chloride solution.

Requirement	**Sample Size**	**Results (Avg.)**
Tensile Testing UTS >116 000 psi	1/4 0.065 inch SAF 2507	122 000 psig (841 MPa)
	3/8 0.083 inch SAF 2507	129 000 psig (889 MPa)
	1/2 0.095 inch SAF 2507	132 600 psig (896 MPa)
Guided bend tests No Visible Defects Face and Root Bends	1/4 0.065 inch SAF 2507	Passed
	3/8 0.083 inch SAF 2507	Passed
	1/2 0.095 inch SAF 2507	Passed
Radiograph 2 % Sensitivity	All Sizes	Passed @ <2 % Sensitivity

Table 14: Mechanical and X-ray Tests
All mechanical and radiography testing in accordance with ASME B&PV Code Section IX.

Requirement	**Results**
% Ferrite (by volume) (35 to 65 % required)	40 to 60 %
No detrimental phases @ 400 (sigma, carbides, nitrides, etc.)	None visible @ 1000

Table 15: Microstructural Evaluation
Requirements determined through an oil and gas industry assessment of all super duplex weld requirements.

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