6Mo & 316 Engineered Combinations

BP Tangguh Expansion Project

Swagelok

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BP Tangguh Expansion Project Support
Swagelok Capital Projects Company &
Swagelok Indonesia

Project Support and Value Added Services

Swagelok Capital Projects Company (SCPC) supports BP and the offshore / onshore components of the Tangguh Expansion project. Working closely with the local official Swagelok Sales & Service Center – Swagelok Indonesia - we are here to help the consortia deliver a successful project to BP.

This two page document provides your key contact details as well as a range of other service and product commitments from both Swagelok Indonesia and SCPC that will contribute to the success of your project.

Key Swagelok Project Contact Support

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BP Tangguh Expansion Project Support
Swagelok Capital Projects Company &
Swagelok Indonesia

Engineered Combinations

316 Stainless Steel tube fittings used in conjunction with 6 Moly tubing helps realize significant material cost savings whilst offering a robust corrosion resistant solution. This fully validated and proven combination supports suitability for the operating conditions. This range of products is available worldwide through dedicated Swagelok sales and service locations and information is included within this document.

Local Operations Support

Swagelok Indonesia have been engaged with BP Berau for many years and are an existing approved supplier to BP. Swagelok have previously collaborated heavily with the EPCs and pre-FEED contractors on the project.

Design Support

Product details and part numbering defined and embedded within design documents and loaded into hook-up drawings to drive standardization and continuity, and realize time savings. This will support stakeholder alignment with project requirements for tubing, tube fittings and valves.

Package Vendor Support

SCPC will coordinate engagement through our dedicated, exclusive Swagelok Distributor locations, to support Subcontractors, Package Suppliers and equipment suppliers across project.

AIMS Pre-Commissioning Survey

Swagelok Indonesia will provide an Asset Integrity Management Service (AIMS). Having completed this for many clients across Indonesia – and with BP previously in Berau in 2012 - the AIMS survey proactively supports a project's performance, commissioning and operational objectives.

Project Management

A dedicated Swagelok regional construction manager (SCPC) oversees the BP Tangguh Expansion project coordinating activity with Swagelok distributors, package vendors and others at all locations as required. SCPC will provide support at all stages through design, procurement, construction and commissioning.

Swagelok Installation and Competency Training

Certified installation training for personnel at all locations ensuring right first time product install in line with Swagelok's instructions and procedures.

BP Tangguh Web Based Resource Center

A customer portal has been created within the Swagelok Indonesia website housing our data warehouse capabilities enabling access to reference materials such as key contacts, BP user part numbers, catalogues, drawings, MSDS and CAD images 24/7 in multiple languages.

Global Support - Local Service (Additional Services)

Fluid system assemblies, training, kitting and pre-engineered subsystems are a few of the services available locally from Swagelok Indonesia to service your project needs and reduce cost and wastage.

Swagelok Lifetime Warranty

ALL Swagelok products carry a unique, limited lifetime warranty guaranteeing that they will be free of defects in materials and workmanship throughout their life in service.

Tube Fitting Performance
Product Test Reports
6Mo, 316 and Engineered Combinations

Introduction

Tube fitting performance can be evaluated using three specific types of test criteria. These tests allow a tube fitting to be evaluated under varying dynamic conditions. Furthermore, extreme corrosion can affect the integrity of your fluid systems.

Tube Grip

The main function of a tube fitting is to grip the tubing sufficiently to contain system fluid. The tubing and fitting must remain connected without leakage at maximum working pressure. When overpressure occurs, such as in proof testing or when pressure spikes occur outside normal operating conditions, the fitting must also maintain both grip and seal on the tubing. Heavy-wall tubing presents greater challenges for ferrule gripping action because it can be taken to higher pressure and is more resistant to the ferrule swaging or indentation.

Gas Seal

Evaluating small molecule gas applications is important when determining if a tube fitting is reliable. Performance of a fitting in high-pressure gas applications must be evaluated under the conditions of initial assembly and repeated reassembly of the components. Another challenge in gas seal applications pertains to thin-wall tubing, since it offers the least swaging resistance to provide for the coining action of the ferrules.

Vibration Resistance

Any system may experience vibration during operation. Rotary equipment, such as pumps or compressors, can impart alternating stress vibration on the tubing runs. Because tube fittings grip the surface of the tubing, creating potential stress risers on the tube surface, the tubing can be exposed to amplified alternating stress and fatigue fracture.

Product Test Reports for Engineered Combinations

The following Tube Grip, Gas Seal and Vibration Resistance Product Test Reports (PTRs) are for 316 stainless steel Swagelok® tube fittings with 6-Moly stainless steel tubing. Also included are two further PTRs which shows the performance of Swagelok tube fittings (Engineered Combinations and 316 only) in an sea-water type environment.

Test Report	Description	Tubing Sizes	
		Thin Wall	Heavy Wall
PTR-2852	Hydrostatic Pressure Test		¼ to 1 in
PTR-2834	Tensile Pull Test		¼ to 1 in
PTR-2849	Hydraulic Impulse Test and Hydrostatic Proof Test	¼ to 1 in	¼ to 1 in
PTR-2853	Nitrogen Gas Seal Test with Repeated Reassembly	¼ to 1 in	¼ to 1 in
PTR-2835	High-Temperature Thermal Cycling and Hydrostatic Proof Test	¼ to 1 in	¼ to 1 in
PTR-2836	Low-Temperature Thermal Cycling and Hydrostatic Proof Test	¼ to 1 in	¼ to 1 in
PTR-2841	Rotary Flex Test	¼ to 1 in	
PTR-4183	Chloride Stress Corrosion Cracking – Engineered Combinations	3/8 to ½ in	
PTR-4184	Chloride Stress Corrosion Cracking – 316 Only	3/8 to 1 ¼ in	

Tubing Data—Engineered Combinations

Scope

This data sheet contains suggested allowable working pressures for assemblies of Swagelok® tube fittings with tubing of diverse materials.

Although matching tubing and fitting materials is common practice for optimal system operation, the performance advantages of Swagelok 316 stainless steel tube fittings enable successful mixed-material combinations, even in severe environments. These advantages include:

- Higher chromium and nickel concentrations than standard 316 stainless steel for enhanced corrosion resistance.
- Superior tube grip achieved with Swagelok's patented hinging-colleting™ back ferrule design that translates axial motion into radial swaging action on the tube, yet operates with a low assembly torque requirement.

Consequently, for example, the combination of Swagelok 316 tube fittings and alloy 254 tubing can provide an economical, corrosion-resistant solution for installations that might be exposed to sea water. As with any mixed-material assembly, pressure ratings for tubing and fittings from different alloys will be governed by the lower material rating.

See the Swagelok *Gaugeable Tube Fittings and Adapter Fittings* catalog (MS-01-140) for more information about Swagelok tube fitting features and performance.

Contents

Tubing Selection

Proper selection, handling, and installation of tubing, when combined with proper selection of Swagelok® tube fittings, are essential to reliable tubing systems.

The following variables should be considered when ordering tubing for use with Swagelok tube fittings:

- Surface finish
- Material
- Hardness
- Wall thickness.

Tubing Surface Finish

Many ASTM specifications cover the above requirements, but they often are not very detailed on surface finish. For example, ASTM A450, a general tubing specification, reads:

> 11. Straightness and Finish
>
> 11.1 Finished tubes shall be reasonably straight and have smooth ends free of burrs. They shall have a workmanlike finish. Surface imperfections (Note) may be removed by grinding, provided that a smooth curved surface is maintained, and the wall thickness is not decreased to less than that permitted by this or the product specification. The outside diameter at the point of grinding may be reduced by the amount so removed.
>
> **Note:** An imperfection is any discontinuity or irregularity found in the tube.

Tubing Material

Our suggested ordering instructions for each type of tubing are shown under the respective tables.

Tubing Outside Diameter Hardness

The key to selecting proper tubing for use with metal Swagelok tube fittings is that the tubing must be softer than the fitting material. Swagelok tube fittings are designed to work properly with the tubing that is suggested in the ordering instructions.

Swagelok

Tubing Wall Thickness

The accompanying tables show working pressure ratings of tubing in a wide range of wall thicknesses. Allowable pressure ratings are calculated from *S* values for the lower-strength material as specified by ASME B31.3, ASME BPV Section II, Part D, or based on repeated pressure testing of the Swagelok tube fitting with a 4:1 design factor based on hydraulic fluid leakage.

Swagelok tube fittings have been repeatedly tested in both the minimum and maximum wall thicknesses shown.

Swagelok tube fittings are not recommended for tube wall thicknesses outside the ranges shown in the accompanying tables for each size.

Tubing Handling

Good handling practices can greatly reduce scratches on tubing and protect the good surface finish that reliable tube manufacturers supply.

- Tubing should never be dragged out of a tubing rack or across a rough surface.
- Tube cutters or hacksaws should be sharp. Do not take deep cuts with each turn of the cutter or stroke of the saw.
- Tube ends should be deburred. This helps to ensure that the tubing will go all the way through the ferrules without damaging the ferrule sealing edge.

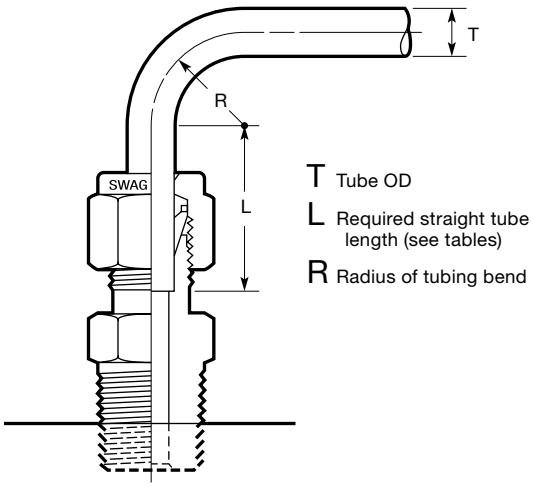
Gas Service

Gases (air, hydrogen, helium, nitrogen, etc.) have very small molecules that can escape through even the most minute leak path. Some surface defects on the tubing can provide such a leak path. As tube outside diameter (OD) increases, so does the likelihood of a scratch or other surface defect interfering with proper sealing.

The most successful connection for gas service will occur if all installation instructions are carefully followed and the heavier wall thicknesses of tubing on the accompanying tables are selected.

A heavy-wall tube resists ferrule action more than a thin-wall tube, allowing the ferrules to coin out minor surface imperfections. A thin-wall tube offers less resistance to ferrule action during installation, reducing the chance of coining out surface defects, such as scratches. Within the applicable suggested allowable working pressure table, select a tube wall thickness whose working pressure is *outside* of the shaded areas.

Tubing Installation



Tubing properly selected and handled, combined with properly installed Swagelok tube fittings, will give you a leak-tight system and provide reliable service in a wide variety of applications.

For maximum assurance of reliable performance, use:

- properly selected and handled high-quality tubing—such as provided by Swagelok
- Swagelok tube fittings assembled in accordance with catalog instructions
- an appropriate tube support system to limit the movement of tubing and fluid system components.

When installing fittings near tube bends, there must be a sufficient straight length of tubing to allow the tube to be bottomed in the Swagelok fitting (see tables).

Fractional, in.	
T Tube OD	**L**①
1/16	1/2
1/8	23/32
3/16	3/4
1/4	13/16
5/16	7/8
3/8	15/16
1/2	1 3/16
5/8	1 1/4
3/4	
7/8	1 5/16
1	1 1/2

① Required straight tube length.

Metric, mm	
T Tube OD	**L**①
3	19
6	21
8	23
10	25
12	31
14	32
15	
16	
18	
20	34
22	
25	40

Suggested Allowable Working Pressure Tables

Figure and tables are for reference only. No implication is made that these values can be used for design work. Applicable codes and practices in industry should be considered. ASME Codes are the successor to and replacement of ASA Piping Codes.

- All pressures are calculated from equations in ASME B31.3, Process Piping. See factors for calculating working pressures in accordance with ASME B31.1, Power Piping.
- Calculations are based on maximum OD and minimum wall thickness, except as noted in individual tables.

  Example: 1/2 in. OD × 0.035 in. wall alloy 254 tubing purchased to ASTM A269:

  OD Tolerance ± 0.005 in. / Wall Thickness ± 10 %

  Calculations are based on 0.505 in. OD × 0.0315 in. wall tubing.
- No allowance is made for corrosion or erosion.

Pressure Ratings at Elevated Temperatures

Elevated temperature factors were derived from allowable stress in accordance with ASME B31.3 or ASME BPV Section II, Part D.

Table 1—Elevated Temperature Factors

Temperature		Tubing Materials		
°F	°C	Alloy 254	UNS C69100 Temper TF00	Type 904L
200	93	0.88	1.00	0.82
300	149	0.79	1.00	0.74
400	204	0.73	0.96	0.68
500	260	0.69		0.63
600	315	0.66		0.58
700	371	0.64		0.56

To determine allowable working pressure at elevated temperatures, multiply allowable working pressures from Tables 2 through 7 by a factor shown in Table 1.

Example: Alloy 254 1/2 in. OD × 0.065 in. wall at 600°F

1. The allowable working pressure at –20 to 100°F (–28 to 37°C) is 5100 psig (Table 2, page 4).
2. The elevated temperature factor for 600°F (315°C) is 0.66 (Table 1, above):

   5100 psig × 0.66 = 3366 psig

The allowable working pressure for alloy 254 1/2 in. OD × 0.065 in. wall at 600°F is 3366 psig.

316 Stainless Steel Tube Fittings with Alloy 254 Tubing

Swagelok 316 stainless steel tube fittings in 1/4 to 1 in. and 6 to 25 mm sizes may be used with high quality, fully annealed (seamless or welded and drawn) alloy 254 hydraulic tubing.

For welded and drawn tubing, a derating factor must be applied for weld integrity: for double-welded tubing, multiply working pressure by 0.85; for single-welded tubing, multiply working pressure by 0.80.

Table 2—Fractional Sizes

Allowable working pressures are based on repeated pressure testing of the Swagelok tube fitting with a 4:1 design factor based on hydraulic fluid leakage

Tube OD in.	Tube Wall Thickness, in.								Fitting Series	Installation Method	
	0.028	0.035	0.049	0.065	0.083	0.095	0.109	0.120		1 1/4 Turns	Pre-swage
	Working Pressure, psig **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service,** page 2.)										
1/4	4000	5100	7500	10 200					400	Yes	Yes
3/8		3300	4800	6 500					600	Yes	Yes
1/2		2600	3700	5 100	6700				800	Yes	Yes
5/8①			4000	5 400	6000	6000			1010	No	Yes
3/4①			3300	4 400	4900	4900	4900		1210	No	Yes
7/8①			2800	3 700	4800	4800	4800		1410	No	Yes
1①				3 300	3600	3600	3600	3600	1610	No	Yes

① Requires a preswage tool or the Swagelok multihead hydraulic swaging unit (MHSU) for installation. See the Swagelok *Gaugeable Tube Fittings and Adapter Fittings* catalog (MS-01-140) for more information.

Table 3—Metric Sizes

Allowable working pressures are based on repeated pressure testing of the Swagelok tube fitting with a 4:1 design factor based on hydraulic fluid leakage

Tube OD mm	Tube Wall Thickness, mm										Fitting Series	Installation Method	
	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.5	2.8	3.0		1 1/4 Turns	Pre-swage
	Working Pressure, bar **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service,** page 2.)												
6	310	420	540	710							6M0	Yes	Yes
8		310	390	520							8M0	Yes	Yes
10		240	300	400							10M0	Yes	Yes
12		200	250	330	410	470					12M0	Yes	Yes
18①			210	280	320	320	320				18M0	No	Yes
20①			190	250	290	290	290				20M0	No	Yes
22①			170	220	260	260	260				22M0	No	Yes
25①					240	240	240	240	240	240	25M0	No	Yes

① Requires a preswage tool or the Swagelok multihead hydraulic swaging unit (MHSU) for installation. See the Swagelok *Gaugeable Tube Fittings and Adapter Fittings* catalog (MS-01-140) for more information.

Suggested Ordering Information

High-quality, fully annealed seamless or welded and drawn alloy 254 hydraulic tubing, ASTM A269 or ASTM A213, or equivalent. Hardness not to exceed 96 HRB. Tubing to be free of scratches, suitable for bending and flaring.

316 Stainless Steel Tube Fittings with Type 904L Stainless Steel Tubing

Swagelok 316 stainless steel tube fittings in 1/4 to 1 in. and 6 to 25 mm sizes may be used with high quality, seamless Type 904L stainless steel hydraulic tubing.

Table 4—Fractional Sizes

Allowable working pressures are based on equations from ASME B31.3 and B31.1 for a maximum *S* value of 20 000 psi (137.8 MPa).

Tube OD in.	Tube Wall Thickness, in.								Fitting Series
	0.028	0.035	0.049	0.065	0.083	0.095	0.109	0.120	
	Working Pressure, psig **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service,** page 2.)								
1/4	4000	5100	7500	10 200					400
5/16		4000	5800	8 000					500
3/8		3300	4800	6 500	7500				600
1/2		2600	3700	5 100	6700				800
5/8			2900	4 000	5200	6000			1010
3/4			2400	3 300	4200	4900	5800		1210
7/8			2000	2 800	3600	4200	4800		1410
1				2 400	3100	3600	4200	4700	1610

Table 5—Metric Sizes

Allowable working pressures are based on equations from ASME B31.3 and B31.1 for a maximum *S* value of 137.8 MPa (20 000 psi).

Tube OD mm	Tube Wall Thickness, mm										Fitting Series
	0.8	1.0	1.2	1.5	1.8	2.0	2.2	2.5	2.8	3.0	
	Working Pressure, bar **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service,** page 2.)										
6	310	420	540	710							6M0
8		310	390	520							8M0
10		240	300	400	510	580					10M0
12		200	250	330	410	470					12M0
14		160	200	270	340	380	430				14M0
15		150	190	250	310	360	400				15M0
16			170	230	290	330	370	400			16M0
18			150	200	260	290	320	370			18M0
20			140	180	230	260	290	330	380		20M0
22			140	160	200	230	260	300	340		22M0
25					180	200	230	260	290	320	25M0

Suggested Ordering Information

High quality, fully annealed, Type 904L, seamless hydraulic tubing, ASTM 269 and ASTM B677 or equivalent. Hardness not to exceed 90 HRB or 200 HV. Tubing to be free of scratches, suitable for bending and flaring.

316 Stainless Steel Tube Fittings with UNS C69100 Copper Alloy (Tungum) Tubing

Swagelok 316 stainless steel tube fittings in 1/4 to 1 in. and 6 to 25 mm sizes may be used with high-quality, precipitation-hardened, temper TF00, seamless UNS C69100, ASTM B706 copper alloy hydraulic tubing.

Table 6—Fractional Sizes

Allowable working pressures are calculated from an *S* value of 20 000 psi (137.8 MPa) for precipitation hardened, temper TF00, seamless UNS C69100, ASTM B706 copper alloy (Tungum or equivalent) tubing at –20 to 100°F (–28 to 37°C) as listed in ASME B31.3.

Tube OD in.	**Tube Wall Thickness,** in.							Fitting Series
	0.028	**0.035**	**0.049**	**0.065**	**0.083**	**0.109**	**0.120**	
	Working Pressure, psig **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service,** page 2.)							
1/4	4000	5100	7500	10 200				400
5/16		4000	5800	8 000				600
3/8		3300	4800	6 500				800
1/2		2600	3700	5 100	6700			1010
5/8			2900	4 000	5200			1210
3/4			2400	3 300	4200	5800		1410
1				2 400	3100	4200	4700	1610

Table 7—Metric Sizes

Allowable working pressures are calculated from an *S* value of 137.8 MPa (20 000 psi) for precipitation hardened, temper TF00, seamless UNS C69100, ASTM B706 copper alloy (Tungum or equivalent) tubing at –28 to 37°C (–20 to 100°F) as listed in ASME B31.3.

Tube OD mm	**Tube Wall Thickness,** mm								Fitting Series
	0.8	**1.0**	**1.2**	**1.5**	**2.0**	**2.2**	**2.5**	**3.0**	
	Working Pressure, bar **Note:** For gas service, select a tube wall thickness outside of the shaded area. (See **Gas Service,** page 2.)								
6	310	420	540						6M0
8		310	390	520					8M0
10		240	300	400	580				10M0
12		200	250	330	470				12M0
14		160	200	270	380	430			14M0
16			170	230	330	370	400		16M0
20				180	260	290	330		20M0
25					200	230	260	320	25M0

Suggested Ordering Information

High-quality, precipitation-hardened, temper TF00, seamless copper alloy tubing, UNS C69100, ASTM B706 or equivalent. Hardness not to exceed 90 HRB. Tubing to be free of scratches, suitable for bending and flaring.

Safe Product Selection
When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

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Product Test Report

Swagelok Company
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PTR-2852
Rev. C
September 2013

TITLE

Hydrostatic Pressure Test of Super Austenitic 254 SMO® (6-moly) Stainless Steel Tubing With Stainless Steel Swagelok® Tube Fittings

PRODUCT TESTED

Samples Tested	254 SMO SS Tubing Size OD × Wall in.	Tubing Hardness HRB	Part Description Ordering Number	Form
28	1/4 × 0.065	94	Male Connector SS-400-1-4	Bar stock
			Union Elbow SS-400-9	Forging
			Plug SS-400-P	Bar stock
28	1/2 × 0.083	86	Male Connector SS-810-1-4	Bar stock
			Union Elbow SS-810-9	Forging
			Plug SS-810-P	Bar stock
24	3/4 × 0.095	90	Male Connector SS-1210-1-8	Bar stock
			Union Elbow SS-1210-9	Forging
			Plug SS-1210-P	Bar stock
24	1 × 0.120	86	Male Connector SS-1610-1-8	Bar stock
			Union Elbow SS-1610-9	Forging
			Plug SS-1610-P	Bar stock

PURPOSE

These assemblies were tested under laboratory conditions to observe the tube grip performance of stainless steel Swagelok tube fittings when installed on heavy-wall, 254 SMO stainless steel tubing with hydrostatic pressure.

TEST CONDITIONS

- Each sample tested consisted of one tube length and two test fittings. The fittings were assembled according to Swagelok tube fitting installation instructions.
- Testing was conducted at room temperature in a laboratory environment.

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TEST METHOD

Hardness Measurements of Tubing:

1. Performed five measurements equally spaced apart on each tube O.D. with the United Hardness Tester using the 15-T scale with the 1/16-inch diameter ball penetrator.
2. Reported the average of the five measurements.
3. Added the tubing cylindrical values taken from the Wilson Chart #53 Cylindrical Conversion Table.
4. Used the ASTM E140 Table 6—Austenitic Stainless Steel hardness conversion chart to convert the 15-T readings to the HRB values.

Hydrostatic Pressure Test:

1. Each sample was attached to a hydraulic test stand.
2. The tubing was restricted from burst by clamping blocks, thereby forcing a failure at the fitting-to-tubing engagement.
3. Pressure was gradually increased and the pressure was recorded when loss of tube grip, material rupture or leakage that prevented applying higher pressure occurred, whichever came first.
4. Results were compared to the tubing working pressure.

TEST RESULTS

Samples Tested	**254 SMO SS Tubing Size OD × Wall** in.	**Working Pressure** psig (bar)	**4 × Working Pressure** psig (bar)	**Samples Attaining 4 × W.P.**
28	1/4 × 0.065	10 200 (702)	40 800 (2 811)	28 / 28
28	1/2 × 0.083	6 700 (461)	26 800 (1 846)	28 / 28
24	3/4 × 0.095	4 900 (337)	19 600 (1 350)	24 / 24
24	1 × 0.120	3 600 (248)	14 400 (992)	24 / 24

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The test results contained in this Product Test Report are made available for informational purposes only. The tests were conducted beyond the product's recommended operating parameters and do not modify the published product ratings. See the product catalog for technical data.

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SAFE PRODUCT SELECTION

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

REFERENCES

Wilson Cylindrical Correction Chart # 53, Wilson Instrument Division, 929 Connecticut Avenue, Bridgeport, CT 06602

ASTM E140*, Table 6—Approximate Hardness Conversion Numbers for Austenitic SS*, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2858

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254 SMO—TM Outokumpu Oyj Limited Liability Company

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Product Test Report

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TITLE

Tensile Pull Test of Super Austenitic 254 SMO® (6-moly) Stainless Steel Tubing With Stainless Steel Swagelok® Tube Fittings

PRODUCT TESTED

Samples Tested	254 SMO SS Tubing Size OD × Wall in.	Tubing Hardness HRB	Part Description Ordering Number
6	1/4 × 0.065	95	Male Connector SS-400-1-4
6	1/2 × 0.083	87	Male Connector SS-810-1-4
6	3/4 × 0.095	90	Male Connector SS-1210-1-4
6	1 × 0.120	86	Male Connector SS-1610-1-4

PURPOSE

These assemblies were tested under laboratory conditions to observe the tube grip performance of stainless steel Swagelok tube fittings when installed on 254 SMO stainless steel heavy-wall tubing under tensile load.

TEST CONDITIONS

Laboratory environment

TEST METHOD

Hardness Measurements of Tubing:

1. Performed five measurements equally spaced apart on each tube OD with the United Hardness Tester using the 15-T scale with the 1/16-inch diameter ball penetrator.
2. Reported the average of the five measurements.
3. Added the tubing cylindrical values taken from the Wilson Chart #53 Cylindrical Conversion Table.
4. Used the ASTM E140 Table 6—Austenitic Stainless Steel hardness conversion chart to convert the 15-T readings to the HRB values.

Tensile Pull Test:

1. For each sample, assembled one tube length and two male connectors according to Swagelok assembly procedures.
2. Attached non-pressurized samples to a tensile test machine.
3. Tensile pulled samples at a rate of 0.125 in. (3.2 mm) per minute until either the tube pulled out of the fitting or the tube fractured.

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4. The acceptance criterion was:

   Minimum Load = Area based on Tubing Outside Diameter × *Tubing Working Pressure* × *Performance Factor*

5. The test result should exceed the calculated minimum load.

TEST RESULTS

Tensile Pull Test

254 SMO Tubing Size OD × Wall in.	Performance Factor η①	Acceptance Criterion (Minimum Load) lbf (N)	Minimum Load Attained lbf (N)	Results
1/4 × 0.065	4.0	2 000 (8 896)	2 957 (13 152)	Pass
1/2 × 0.083	4.0	5 260 (23 396)	8 896 (39 569)	Pass
3/4 × 0.095	4.0	8 860 (39 409)	10 289 (45 765)	Pass
1 × 0.120	3.5	9 800 (43 590)	9 865 (43 879)	Pass

① Target performance factors listed in the table are based on the use of the maximum working pressure tubing wall thickness, according to Swagelok Tubing Data (MS-01-107), and annealed body material (e.g. forged shapes).

The test results contained in this Product Test Report are made available for informational purposes only. The tests were conducted beyond the product's recommended operating parameters and do not modify the published product ratings. See the product catalog for technical data.

SAFE PRODUCT SELECTION

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

REFERENCES

Wilson Cylindrical Correction Chart # 53, Wilson Instrument Division, 929 Connecticut Avenue, Bridgeport, CT 06602

ASTM E140*, Table 6—Approximate Hardness Conversion Numbers for Austenitic SS*, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2858

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254 SMO—TM Outokumpu Oyj Limited Liability Company

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Swagelok Company
29500 Solon Road
Solon, Ohio 44139 U.S.A.

TITLE

Hydraulic Impulse Test and Hydrostatic Proof Test of Super Austenitic 254 SMO® (6-moly) Stainless Steel Tubing With Stainless Steel Swagelok® Tube Fittings

PRODUCT TESTED

Samples Tested	254 SMO SS Tubing Size OD × Wall in.	Tubing Hardness HRB	Working Pressure psig (bar)	Part Description Ordering Number	Part Description Ordering Number
6	1/4 × 0.028	84	4 000 (275)	Union Straight SS-400-6	Union Elbow SS-400-9
6	1/4 × 0.065	96	10 200 (702)	Union Straight SS-400-6	Union Elbow SS-400-9
6	1/2 × 0.035	87	2 600 (179)	Union Straight SS-810-6	Union Elbow SS-810-9
6	1/2 × 0.083	86	6 700 (461)	Union Straight SS-810-6	Union Elbow SS-810-9
6	3/4 × 0.049	86	3 300 (227)	Union Straight SS-1210-6	Union Elbow SS-1210-9
6	3/4 × 0.095	90	4 900 (337)	Union Straight SS-1210-6	Union Elbow SS-1210-9
6	1 × 0.065	83	3 300 (227)	Union Straight SS-1610-6	Union Elbow SS-1610-9
6	1 × 0.120	86	3 600 (248)	Union Straight SS-1610-6	Union Elbow SS-1610-9

PURPOSE

These assemblies were tested under laboratory test conditions to observe the hydraulic performance (during and after impulse testing) of stainless steel Swagelok tube fittings when installed on 254 SMO stainless steel tubing.

TEST CONDITIONS

Laboratory environment

TEST METHOD

Hardness Measurements of Tubing:

1. Performed five measurements equally spaced apart on each tube O.D. with the United Hardness Tester using the 15-T scale with the 1/16-inch diameter ball penetrator.
2. Reported the average of the five measurements.
3. Added the tubing cylindrical values taken from the Wilson Chart #53 Cylindrical Conversion Table.
4. Used the ASTM E140 Table 6—Austenitic Stainless Steel hardness conversion chart to convert the 15-T readings to the HRB values.

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Impulse Test with Repeat Assembly (Reference ASTM F1387):

1. Assembled one tube length with one union straight and one union elbow according to Swagelok assembly procedures.
2. Prior to impulse testing, some of the samples were identified for repeat assembly according to ASTM F1837 Annex A9. These samples were disassembled and reassembled once according to Swagelok procedures. In order to reseat the ferrules at a different location, the disassembled samples were rotated approximately 90° between each disassembly / reassembly cycle.
3. Impulse testing was then performed according to ASTM F1387 Annex A5. The samples were attached to an impulse stand, pressurized with hydraulic oil to 133 +/- 5 % of the working pressure, and then depressurized to 20 +/- 5 % of the working pressure. This constituted one impulse cycle.
4. Impulse cycles were modeled with a square waveform, and cycling continued for 1 000 000 cycles at a rate of one Hz (one cycle per second) with the rate not exceeding 75 cycles per minute.
5. At the conclusion of 250 000 impulse cycles, the samples identified for repeat assembly were disassembled and reassembled twice as described in step 2.
6. This cycling and reassembly process was repeated with two remakes of the identified samples at the conclusion of 500 000, 750 000, and 1 000 000 of the impulse cycles. There were 9 total reassemblies for the repeat assembly samples.
7. Monitored the samples for leakage during the test; the pass criterion was no visible leakage.

Hydrostatic Proof Test Procedure (Reference ASTM F1387 Annex A4):

1. Upon completion of the Impulse Test with Repeat Assembly, the samples were subjected to a hydrostatic proof test at ambient laboratory temperature.
2. Samples were pressurized to 100 psig (6.8 bar) and held for a period of five minutes.
3. After 5 minutes at 100 psig (6.8 bar), the samples were pressurized to 150 % (+/- 5%) of the working pressure and held for an additional period of 5 minutes.
4. Monitored the samples for leakage throughout the test; the pass criterion was no visible leakage.

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TEST RESULTS

Impulse Test with Repeat Assembly

254 SMO SS Tubing Size OD × Wall in.	Impulse Test Pressure Cycle psig (bar)	Samples Tested	Number of Reassemblies at % of 1 000 000 Total Cycles					Results
			0 % (Prior to Impulse)	25 %	50 %	75 %	100 %	
1/4 × 0.028	800 to 5 320 (55.1 to 366)	2	Not required					Pass
		4	1	2	2	2	2	Pass
1/4 × 0.065	2 040 to 13 566 (140 to 934)	2	Not required					Pass
		4	1	Pass	2	2	2	Pass
1/2 × 0.035	520 to 3 458 (35.8 to 238)	2	Not required					Pass
		4	1	Pass	2	2	2	Pass
1/2 × 0.083	1340 to 8 911 (92.3 to 613)	2	Not required					Pass
		4	1	Pass	2	2	2	Pass
3/4 × 0.049	660 to 4 400 (45.4 to 303)	2	Not required					Pass
		4	1	2	2	2	2	Pass
3/4 × 0.095	980 to 6 500 (67.5 to 447)	2	Not required					Pass
		4	1	Pass	2	2	2	Pass
1 × 0.065	660 to 4 400 (45.4 to 303)	2	Not required					Pass
		4	1	Pass	2	2	2	Pass
1 × 0.120	720 to 4 800 (49.6 to 330)	2	Not required					Pass
		4	1	Pass	2	2	2	Pass

Hydrostatic Proof Test

254 SMO SS Tubing Size OD × Wall in.	Samples Tested	Proof Test Pressure psig (bar)	Test Results
1/4 × 0.028	6	6 000 (413)	Pass
1/4 × 0.065	6	15 300 (1054)	Pass
1/2 × 0.035	6	3 900 (268)	Pass
1/2 × 0.083	6	10 050 (692)	Pass
3/4 × 0.049	6	4 950 (341)	Pass
3/4 × 0.095	6	7 350 (506)	Pass
1 × 0.065	6	4 950 (341)	Pass
1 × 0.120	6	5 400 (372)	Pass

The test results contained in this Product Test Report are made available for informational purposes only. The tests were conducted beyond the product's recommended operating parameters and do not modify the published product ratings. See the product catalog for technical data.

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SAFE PRODUCT SELECTION

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

REFERENCES

Wilson Cylindrical Correction Chart # 53, Wilson Instrument Division, 929 Connecticut Avenue, Bridgeport, CT 06602

ASTM E140*, Table 6—Approximate Hardness Conversion Numbers for Austenitic SS*, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2858

ASTM F1387-99, *Standard Specification for Performance of Piping and Tubing Mechanically Attached Fittings*, American Society of Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428

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254 SMO—TM Outokumpu Oyj Limited Liability Company

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TITLE

Nitrogen Gas Seal Test with Repeated Reassembly of Super Austenitic 254 SMO® Stainless Steel (6-moly) Tubing With Stainless Steel Swagelok® Tube Fittings

PRODUCT TESTED

Samples Tested	254 SMO SS Tubing Size OD × Wall in.	Tubing Hardness HRB	Working Pressure psig (bar)	Part Description Ordering Number	Part Description Ordering Number
12	1/4 × 0.028	85	4 000 (275)	Union Straight SS-400-6	Union Elbow SS-400-9
12	1/4 × 0.065	95	10 200 (702)	Union Straight SS-400-6	Union Elbow SS-400-9
12	1/2 × 0.035	87	2 600 (179)	Union Straight SS-810-6	Union Elbow SS-810-9
12	1/2 × 0.083	87	6 700 (461)	Union Straight SS-810-6	Union Elbow SS-810-9
12	3/4 × 0.095	90	4 900 (337)	Union Straight SS-1210-6	Union Elbow SS-1210-9
12	1 × 0.083	85	3 600 (248)	Union Straight SS-1610-6	Union Elbow SS-1610-9
12	1 × 0.120	86	3 600 (248)	Union Straight SS-1610-6	Union Elbow SS-1610-9

PURPOSE

These assemblies were tested under laboratory test conditions to observe the gas seal reassembly performance of stainless steel Swagelok tube fittings when installed on 254 SMO stainless steel tubing.

TEST CONDITIONS

- Each sample tested consisted of one tube length and two test fittings. The fittings were assembled according to the Swagelok tube fitting installation instructions.
- Testing was completed in a room temperature laboratory environment.

TEST METHOD

Hardness Measurements of Tubing:

1. Performed five measurements equally spaced apart on each tube O.D. with the United Hardness Tester using the 15-T scale with the 1/16-inch diameter ball penetrator.
2. Reported the average of the five measurements.
3. Added the tubing cylindrical values taken from the Wilson Chart #53 Cylindrical Conversion Table.
4. Used the ASTM E140 Table 6—Austenitic Stainless Steel hardness conversion chart to convert the 15-T readings to the HRB values.

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Gas Seal Testing

1. The samples were attached to a positive pressure gas test stand, submerged in water, and pressurized to working pressure with nitrogen gas for at least 10 minutes.
2. If leakage was observed, the pressure was dropped and samples showing leaks were tightened with a 1/8 turn-of-the-nut tightening. Step 1 was then repeated.
3. If leakage was not observed, the pressure was increased to 1.25 times working pressure for at least 10 minutes.

Gas Seal Reassembly Testing

4. The pressure was dropped, and the samples were disassembled and reassembled according to Swagelok reassembly instructions.
5. The samples were tested for at least 10 minutes at 1 times working pressure and 1.25 times working pressure.
6. Steps 4 and 5 were repeated at the reassembly points described in the test results tables. The acceptance criterion was less than 1 bubble per minute at the applied pressure.

TEST RESULTS

Tubing Size OD × Wall in.	**1.25 × WP** psig (bar)	**End Connections Tested**	**Number of Acceptable Samples**		
			After Standard Assembly and Initial Test	**After Additional 1/8 Turn and Retest**	**After 1, 5, 10, 15, 20 and 25 Reassemblies**
1/4 × 0.028	5 000 (344)	24	24 / 24	Not applicable	24 / 24
1/4 × 0.065	12 750 (878)	24	24 / 24	Not applicable	24 / 24
1/2 × 0.035	3 250 (223)	24	24 / 24	Not applicable	24 / 24
1/2 × 0.083	8 375 (577)	24	21 / 24	3/3①	23 / 24②

① For tubing using gas at high-pressure, use of the Swagelok installation instructions for High-Pressure Applications and High Safety-Factor Systems is appropriate. Samples demonstrating leakage were tightened an additional 1/8 turn as defined in the test method simulating the High-Pressure Applications and High Safety-Factor Systems instructions. Nitrogen gas testing resulted in no detectable leakage of the re-tested samples.

② One fitting end leaked at reassemblies 1 and 5, but sealed upon subsequent reassemblies.

Tubing Size OD × Wall in.	**1.25 × WP** psig (bar)	**End Connections Tested**	**Number of Acceptable Samples**		
			After Standard Assembly and Initial Test	**After Additional 1/8 Turn and Retest**	**After 1, 5, and 10, Reassemblies**
3/4 × 0.095	6 125 (422)	24	24 / 24	Not applicable	24 / 24
1 × 0.083	4 500 (310)	24	24 / 24	Not applicable	24 / 24
1 × 0.120	4 500 (310)	24	24 / 24	Not applicable	24 / 24

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SAFE PRODUCT SELECTION

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REFERENCES

Wilson Cylindrical Correction Chart # 53, Wilson Instrument Division, 929 Connecticut Avenue, Bridgeport, CT 06602

ASTM E140*, Table 6—Approximate Hardness Conversion Numbers for Austenitic SS*, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2858

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254 SMO—TM Outokumpu Oyj Limited Liability Company

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29500 Solon Road
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TITLE

High-Temperature Thermal Cycling and Hydrostatic Proof Test of Super Austenitic 254 SMO® (6-moly) Stainless Steel Tubing With Stainless Steel Swagelok® Tube Fittings

PRODUCT TESTED

Samples Tested	254 SMO SS Tubing Size OD × Wall in.	Tubing Hardness HRB	Part Description Ordering Number	Part Description Ordering Number
4	1/4 × 0.028	84	Union Straight SS-400-6	Union Elbow SS-400-9
4	1/4 × 0.065	95	Union Straight SS-400-6	Union Elbow SS-400-9
4	1/2 × 0.035	83	Union Straight SS-810-6	Union Elbow SS-810-9
4	1/2 × 0.083	87	Union Straight SS-810-6	Union Elbow SS-810-9
12	3/4 × 0.065	87	Union Straight SS-1210-6	Union Elbow SS-1210-9
12	3/4 × 0.095	90	Union Straight SS-1210-6	Union Elbow SS-1210-9
12	1 × 0.083	85	Union Straight SS-1610-6	Union Elbow SS-1610-9
12	1 × 0.120	86	Union Straight SS-1610-6	Union Elbow SS-1610-9

PURPOSE

These assemblies were tested under laboratory test conditions to observe the leakage performance (during and after thermal cycling) of stainless steel Swagelok tube fittings when installed on 254 SMO stainless steel tubing.

TEST CONDITIONS

Laboratory environment

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TEST METHOD

Hardness Measurements of Tubing:

1. Performed five measurements equally spaced apart on each tube O.D. with the United Hardness Tester using the 15-T scale with the 1/16-inch diameter ball penetrator.
2. Reported the average of the five measurements.
3. Added the tubing cylindrical values taken from the Wilson Chart #53 Cylindrical Conversion Table.
4. Used the ASTM E140 Table 6—Austenitic Stainless Steel hardness conversion chart to convert the 15-T readings to the HRB values.

High-Temperature Thermal Cycling Procedure:

1. Assembled one tube length with one union straight and one union elbow according to Swagelok assembly procedures.
2. Attached the test samples to a high-temperature furnace and pressurized to test pressure.
3. Increased the samples to test temperature of 750°F (398°C) within a period of one hour. The samples were allowed to stabilize at temperature for a minimum of 2 hours while being monitored for pressure decay.
4. The temperature was then lowered to laboratory room temperature (within one hour) while the test pressure was maintained. Samples were then stabilized at room temperature for a minimum of two hours while being monitored for pressure decay.
5. Repeated the above cycle two additional times.
6. Monitored the samples for leakage during the test; the pass criterion was no pressure decay.

Hydrostatic Proof Test Procedure:

1. Upon completion of the high-temperature thermal cycling procedure, the samples were subjected to a hydraulic proof test at ambient laboratory temperature.
2. Samples were pressurized to 100 psig (6.8 bar) and held for a period of five minutes.
3. After 5 minutes at 100 psig (6.8 bar), the samples were pressurized to test pressure (1.5 times ambient working pressure) and held for an additional period of 5 minutes.
4. Monitored the samples for leakage throughout the test; the pass criterion was no visible leakage.

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TEST RESULTS

High-Temperature Thermal Cycle Test

254 SMO SS Tubing Size OD × Wall in.	Ambient Working Pressure① psig (bar)	Test Pressure at Elevated Temperature① psig (bar)	Test Results
1/4 × 0.028	4 000 (275)	2360 (162)	Pass
1/4 × 0.065	10 200 (702)	6018 (414)	Pass
1/2 × 0.035	2 600 (179)	1534 (105)	Pass
1/2 × 0.083	6 700 (461)	3953 (272)	Pass
3/4 × 0.065	3 700 (254)	3136 (216)	Pass
3/4 × 0.095	4 900 (337)	2816 (194)	Pass
1 × 0.083	3 600 (248)	2124 (146)	Pass
1 × 0.120	3 600 (248)	2124 (146)	Pass

① A de-rating factor of 0.59 was applied to the ambient working pressures to determine the test pressures.

Hydrostatic Proof Test

254 SMO SS Tubing Size OD × Wall in.	Proof Test Pressure psig (bar)	Test Results
1/4 × 0.028	6 000 (413)	Pass
1/4 × 0.065	15 300 (1 054)	Pass
1/2 × 0.035	3 900 (268)	Pass
1/2 × 0.083	10 050 (692)	Pass
3/4 × 0.065	5 500 (378)	Pass
3/4 × 0.095	7 350 (506)	Pass
1 × 0.083	5 400 (372)	Pass
1 × 0.120	5 400 (372)	Pass

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SAFE PRODUCT SELECTION

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REFERENCES

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29500 Solon Road
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TITLE

Low-Temperature Thermal Cycling and Hydrostatic Proof Test of Super Austenitic 254 SMO® (6-moly) Stainless Steel Tubing With Stainless Steel Swagelok® Tube Fittings

PRODUCT TESTED

Samples Tested	254 SMO SS Tubing Size OD × Wall in.	Tubing Hardness HRB	Part Description Ordering Number	Part Description Ordering Number
4	1/4 × 0.028	84	Union Straight SS-400-6	Union Elbow SS-400-9
4	1/4 × 0.065	95	Union Straight SS-400-6	Union Elbow SS-400-9
4	1/2 × 0.035	87	Union Straight SS-810-6	Union Elbow SS-810-9
4	1/2 × 0.083	86	Union Straight SS-810-6	Union Elbow SS-810-9
12	3/4 × 0.065	87	Union Straight SS-1210-6	Union Elbow SS-1210-9
12	3/4 × 0.095	90	Union Straight SS-1210-6	Union Elbow SS-1210-9
12	1 × 0.083	85	Union Straight SS-1610-6	Union Elbow SS-1610-9
12	1 × 0.120	86	Union Straight SS-1610-6	Union Elbow SS-1610-9

PURPOSE

These assemblies were tested under laboratory test conditions to observe the leakage performance (during and after thermal cycling) of stainless steel Swagelok tube fittings when installed on 254 SMO stainless steel tubing.

TEST CONDITIONS

Laboratory environment

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TEST METHOD

Hardness Measurements of Tubing:

1. Performed five measurements equally spaced apart on each tube O.D. with the United Hardness Tester using the 15-T scale with the 1/16-inch diameter ball penetrator.
2. Reported the average of the five measurements.
3. Added the tubing cylindrical values taken from the Wilson Chart #53 Cylindrical Conversion Table.
4. Used the ASTM E140 Table 6—Austenitic Stainless Steel hardness conversion chart to convert the 15-T readings to the HRB values.

Low Temperature Thermal Cycling Procedure:

1. Assembled one tube length with one union straight and one union elbow according to Swagelok assembly procedures.
2. Placed test samples in an environmental chamber and pressurized to test pressure with nitrogen.
3. Decreased the samples to test temperature of –58°F (–50°C) within a period of one hour. The samples were allowed to stabilize at temperature for a minimum of 2 hours while being monitored for pressure decay.
4. The temperature was then increased to laboratory room temperature (within one hour) while the test pressure was maintained. Samples were then stabilized at room temperature for a minimum of two hours while being monitored for pressure decay.
5. Repeated the above cycle two additional times.
6. Recorded any pressure decay; the pass criterion was no pressure decay.

Hydrostatic Proof Test Procedure:

1. Upon completion of the low-temperature thermal cycling procedure, the samples were subjected to a hydraulic proof test at ambient laboratory temperature.
2. Samples were pressurized to 100 psig (6.8 bar) and held for a period of five minutes.
3. After 5 minutes at 100 psig (6.8 bar), the samples were pressurized to test pressure (1.5 times ambient working pressure) and held for an additional period of 5 minutes.
4. Monitored the samples for leakage throughout the test; the pass criterion was no visible leakage.

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TEST RESULTS

Low-Temperature Thermal Cycle Test

254 SMO SS Tubing Size OD × Wall in.	Ambient Working Pressure psig (bar)	Test Pressure at Reduced Temperature psig (bar)	Test Results
1/4 × 0.028	4 000 (275)	4 000 (275)	Pass
1/4 × 0.065	10 200 (702)	10 200 (702)	Pass
1/2 × 0.035	2 600 (179)	2 600 (179)	Pass
1/2 × 0.083	6 700 (461)	6 700 (461)	Pass
3/4 × 0.065	3 700 (254)	3 700 (254)	Pass
3/4 × 0.095	4 900 (337)	4 900 (337)	Pass
1 × 0.083	3 600 (248)	3 600 (248)	Pass
1 × 0.120	3 600 (248)	3 600 (248)	Pass

Hydrostatic Proof Test

254 SMO SS Tubing Size OD × Wall in.	Test Pressure psig (bar)	Test Results
1/4 × 0.028	6 000 (413)	Pass
1/4 × 0.065	15 300 (1 054)	Pass
1/2 × 0.035	3 900 (268)	Pass
1/2 × 0.083	10 050 (692)	Pass
3/4 × 0.065	5 500 (378)	Pass
3/4 × 0.095	7 350 (506)	Pass
1 × 0.083	5 400 (372)	Pass
1 × 0.120	5 400 (372)	Pass

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SAFE PRODUCT SELECTION

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REFERENCES

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ASTM E140*, Table 6—Approximate Hardness Conversion Numbers for Austenitic SS*, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2858

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Product Test Report

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TITLE

Rotary Flexure Test of Super Austenitic 254 SMO® (6-moly) Stainless Steel Tubing With Stainless Steel Swagelok® Tube Fittings

PRODUCT TESTED

Samples Tested	254 SMO SS Tubing Size OD × Wall in.	Tubing Hardness HRB	Part Description Ordering Number	Working Pressure① psig (bar)
16	1/4 × 0.028	85	Male Connector SS-400-1-4	4 000 (275)
16	1/2 × 0.035	87	Male Connector SS-810-1-4	2 600 (179)

① Working pressures were calculated from an S value of 20 000 psig (137.8 MPa) for ASTM A269 tubing at –20 to 100°F (–28 to 37°C), as listed in ASME B31.3 and ASME B31.1.

PURPOSE

The assemblies were tested under laboratory conditions to observe the fatigue endurance of stainless steel Swagelok tube fittings when installed on 254 SMO stainless steel tubing at various levels of applied alternating bending stress of the tube.

TEST CONDITIONS

- Each sample tested consisted of one tube length and one test fitting. The fitting was assembled according to the Swagelok assembly procedures.
- Testing was conducted at room temperature.

TEST METHOD

Hardness Measurements of Tubing:

1. Performed five measurements equally spaced apart on each tube O.D. with the United Hardness Tester using the 15-T scale with the 1/16-inch diameter ball penetrator.
2. Reported the average of the five measurements.
3. Added the tubing cylindrical values taken from the Wilson Chart #53 Cylindrical Conversion Table.
4. Used the ASTM E140 Table 6—Austenitic Stainless Steel hardness conversion chart to convert the 15-T readings to the HRB values.

Rotary Flexure Testing:

Rotary flexure testing procedures have been derived from SAE-ARP-1185. This method applies a completely reversed bending stress on the fitting connection while pressurized with hydraulic oil at the tubing working pressure. The test samples were flexed until either the fitting leaked, the tube fractured, or at least 10 million cycles were achieved, whichever occurred first.

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ASME Pressure Vessel and Piping, volume 62 (ASME PVP-62) reports that vibration at or above an alternating stress of 200 µin./in. peak-to-peak strain level results in frequent piping system failures. The 200 µin./in. strain level calculates to an alternating stress of 2 900 lb/in.2 (19.9 MPa) for 254 SMO stainless steel tubing. ASME PVP-62 also reports that measured field data for piping systems suggest that if the system lasts beyond 10 million cycles, it will have infinite life.

The ASME BPV Code, Section III NC-3673, lists stress intensification factors for various types of fittings. For example, for certain butt-welds i = 1.0, socket welds i = 1.3 to 1.9, brazed joints i = 2.1 and pipe joints i = 2.3. The stress intensity lines, i = 1.0, 1.3, and 2.3, that are shown on the graph are based on fatigue bend testing of 254 SMO stainless steel tubing. The lines allow visual comparison to other fitting types and are defined by Equation 3 and Equation 5a from the ASME B31J Code, Standard Test Method for Determining Stress Intensification Factors (*i*-Factors) for Metallic Piping Components:

Equation 3: $i = C/S(N)^b$

where

b = material exponent, 0.2 for metals
C = material constant, 245 000 psi for a carbon steel test specimen
i = stress intensification factor
N = number of cycles to failure
S = nominal stress amplitude at the leak point (lb/in.^{2})

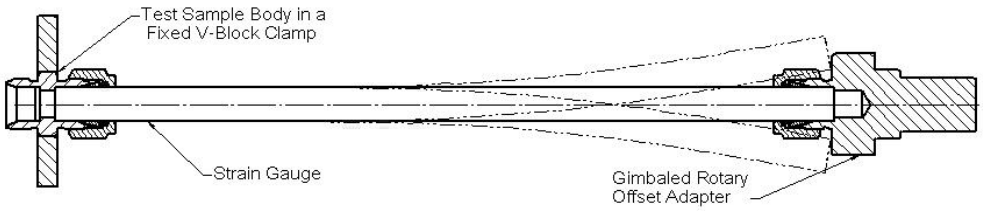
Equation 5a: C (other material) = 245 000 × E (other material)/27 800 000 psi

where

C = Material constant, for use in Equation 3 (psi)
E = Modulus of Elasticity (psi) for 254 SMO

Test Procedure

1. Each test sample was attached to a rotary flex test stand. Refer to the figure below.



2. A bending stress was applied to each sample by a gimbaled rotary offset. The bending stresses were selected to generate the stress versus number of cycles (S/N) graph. The stress levels support a highly accelerated life test protocol and are not indicative of any specific application.

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3. The alternating bending stress was computed from the actual measured flexure strain in the tubing (1/2 of alternating peak-to-peak flexure range).

Nominal Alternating Bending Stress① lb/in.^{2} (MPa)	Samples Tested
25 000 (172.2)	8
20 000 (137.8)	8
15 000 (103.3)	8
10 000 (68.9)	8
TOTAL	**32**

① Zero-to-peak stress

4. Test samples were pressurized to working pressure with hydraulic oil and rotated at a speed greater than 1750 rpm.
5. The test samples were flexed until either the fitting leaked, the tube fractured, or 10 million cycles were achieved, whichever occurred first. An in-line pressure transducer stopped the test if fitting leakage or tube fatigue fracture occurred.
6. A bending stress versus number of cycles graph (S/N) was made from the data and the results were compared to the ASME based data describe earlier.
7. Test samples pass the rotary flex test if all samples remain leak-tight over the duration of the test and demonstrate for a given bending stress the number of cycles that meets or exceeds the predicted number of cycles for fittings having a stress intensification factor of i = 1.3.

TEST RESULTS

- No fitting leakage was detected throughout the testing criteria. The test was stopped when the tube fractured or the test sample exceeded 10 million cycles.
- The shaded area of the following S/N graph envelopes the test results of the rotary test data. The shaded area is truncated at 10 million cycles to indicate testing was suspended without leakage at 10 million cycles in accordance with the test method.
- Point AMSE PVP-62 on the graph is the intersection of 2900 lb/in.^{2} (19.9 MPa) and 10 million cycles.
- The 316 stainless steel Swagelok tube fittings remained leak tight while protecting the 254 SMO stainless steel tubing from premature fracture at alternating stresses greatly exceeding the ASME PVP-62 recommended upper limit. The fitting's performance also resulted in a calculated endurance stress at ten million cycles which exceeds a stress intensification factor of i = 1.3 as defined in ASME BPV Code Section III, NC-3673, therefore passing the rotary flex test.

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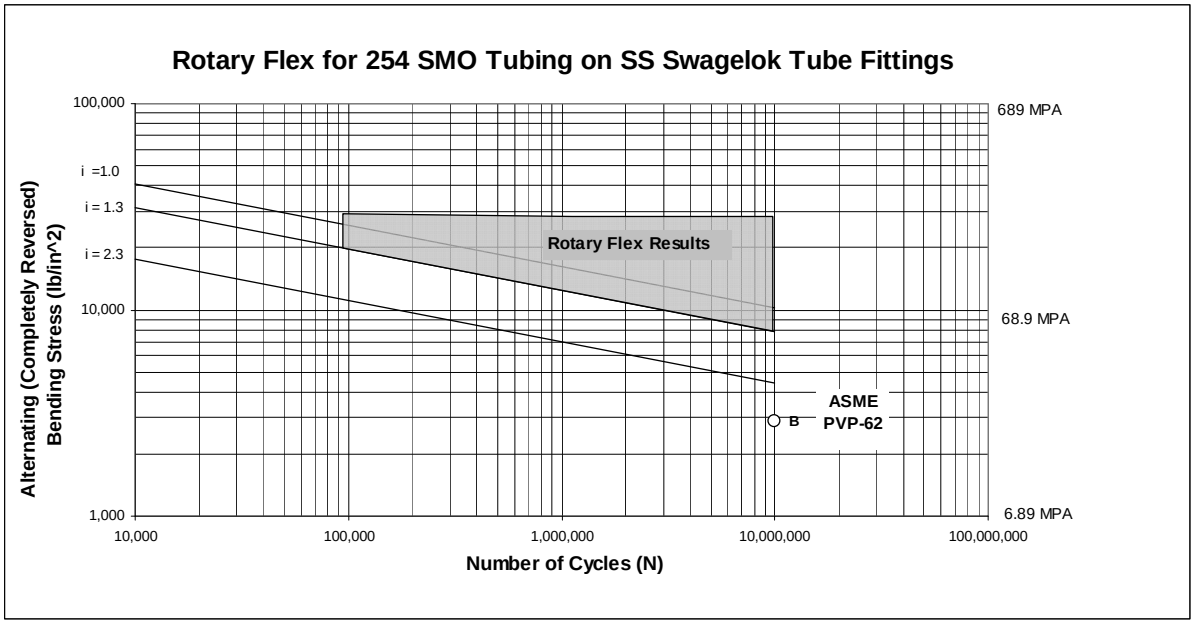

The tests were conducted beyond the product's recommended operating parameters and do not modify the published product ratings.

These tests do not simulate any specific application. These tests were performed to support use of this product under a specific set of published product pressure and temperature ratings and should not be considered valid outside those ratings. Laboratory tests cannot duplicate the variety of actual operating conditions. Material compatibility was not examined as part of these tests.

SAFE PRODUCT SELECTION

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

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REFERENCES

Wilson Cylindrical Correction Chart # 53, Wilson Instrument Division, 929 Connecticut Avenue, Bridgeport, CT 06602

ASTM E140*, Table 6—Approximate Hardness Conversion Numbers for Austenitic SS*, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2858

ASME B31.1, *Power Piping*, The American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5590.

ASME B31.3, *Process Piping*, The American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5590.

ASTM A269, *Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service*, 100 Barr Harbor Drive, West Conshohocken, PA 19428

ASME Pressure Vessel and Piping (PVP), Vol. 62, 1982, and *ASME Boiler and Pressure Vessel (BPV) Code, Section III*, 2007, ASME International, Three Park Avenue, New York, NY 10016-5990, www.asme.org

ASME B31J-2008, *Standard Test Method for Determining Stress Intensification Factors (i-Factors) for Metallic Piping Components*, The American Society of Mechanical Engineers, New York, NY 10016-5990

SAE-ARP-1185, *Flexure Testing of Hydraulic Tubing Joints and Fittings,* SAE International, 400 Commonwealth Drive, Warrendale, PA 15096

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TITLE

Chloride Stress Corrosion Cracking (CSCC) Test of 316 Stainless Steel Swagelok® Tube Fitting Engineered Combinations Using 65°C Cyclic Salt Spray with Substitute Ocean Water

PRODUCT TESTED

Ordering Number	Tubing Material	Number of Fittings Tested	Test Pressure psig (MPa)	Tubing Size and Wall in.	Tubing Hardness HRB
SS-600-6	Alloy 254	4	7500 (51.6)	3/8 × 0.065	87
SS-600-9		4			
SS-600-6	Alloy 825	4	7500 (51.6)	3/8 × 0.065	87
SS-600-9		4			
SS-600-6	Tungum	4	7500 (51.6)	3/8 × 0.065	40
SS-600-9		4			
SS-600-6	Alloy 316	4	7500 (51.6)	3/8 × 0.083	88
SS-600-9		4			
SS-810-6	Alloy 254	4	6700 (46.6)	1/2 × 0.083	80
SS-810-9		4			
SS-810-6	Alloy 825	4	6700 (46.6)	1/2 × 0.065	76
SS-810-9		4			
SS-810-6	Tungum	4	6700 (46.6)	1/2 × 0.065	42
SS-810-9		4			
SS-810-6	Alloy 316	4	6700 (46.6)	1/2 × 0.083	82
SS-810-9		4			

PURPOSE

Assemblies of 316 stainless steel Swagelok tube fittings with stainless steel tubing and with various tubing materials described in Swagelok's Engineered Combinations catalog MS-06-117 were tested under laboratory conditions to observe the effects of an environment that promotes CSCC of 316 stainless steel.

The assemblies were exposed at 65ºC (149ºF) for 720h to alternate cycles of (a) salt spray (substitute ocean water per ASTM D1141) and (b) controlled humidity (60 to 70 %) to encourage concentrating chlorides in surface pits and crevices to particularly accelerate CSCC of 316 SS. Assemblies of one and seven-eighths turns past finger tight (TPFT) were included to increase tensile stress in the tube fitting components to further increase the risk of CSCC.

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TEST METHOD

1. Eight samples were prepared for each size. Each tubing assembly was comprised of two fittings, one barstock, and one forging, assembled to a 64 mm (2 1/2 in.) length of tubing.
2. Additional sample fitting components and tubing of each size were set aside to comprise a control group for comparing surface structures before and after the CSCC test.
3. Four each of 3/8 inch and 1/2 inch size sample fittings were assembled according to Swagelok tube fitting installation instructions: one and one-quarter turns past finger-tight (TPFT). The other four of each size were assembled one and seven-eighths TPFT.
4. Each sample was pressurized with nitrogen to the test pressure and monitored for leakage for 10 minutes prior to the CSCC test.
5. Samples were placed into a salt spray chamber that utilized substitute ocean water per ASTM D1141.
6. Samples were pressurized with water to the test pressure and held at that pressure throughout the CSCC test.
7. The chamber temperature was elevated to 65°C (149°F) and the following salt spray schedule, derived from SAE J2334 and ASTM B117, was initiated:
    a. continuous salt spray maintained at 65°C for 24 hours
    b. salt spray turned off, 60 % to 70 % relative humidity maintained at 65°C for 48 hours
    c. repeat step a for 48 hours
    d. repeat step b for 96 hours
    e. repeat step a for 168 hours
    f. repeat step b for 336 hours, for a schedule total of 720 hours (see **Figure 1**)
8. Upon completion of the 720 hours, the samples were removed and rinsed in de-ionized water.
9. Each sample was again pressurized with nitrogen to its test pressure and monitored for leakage for 10 minutes.
10. Samples were then disassembled. The components (nut, body, and ferrules) swaged on the tubing were then liquid penetrant examined per ASTM E165 to reveal any cracks.
11. Sample components were then sectioned and metallurgically examined by 100× optical microscope for signs of CSCC.

TEST RESULTS

- All samples (64 ends total) successfully passed 720 hours in the salt spray chamber without loss of pressure.
- All samples successfully passed the pre- and post-salt spray nitrogen gas pressure tests without leakage.
- Liquid penetrant evaluation of the sample components found no evidence of crack formation.
- No evidence of CSCC crack initiation and propagation beyond surface structures of the sample components was observed.

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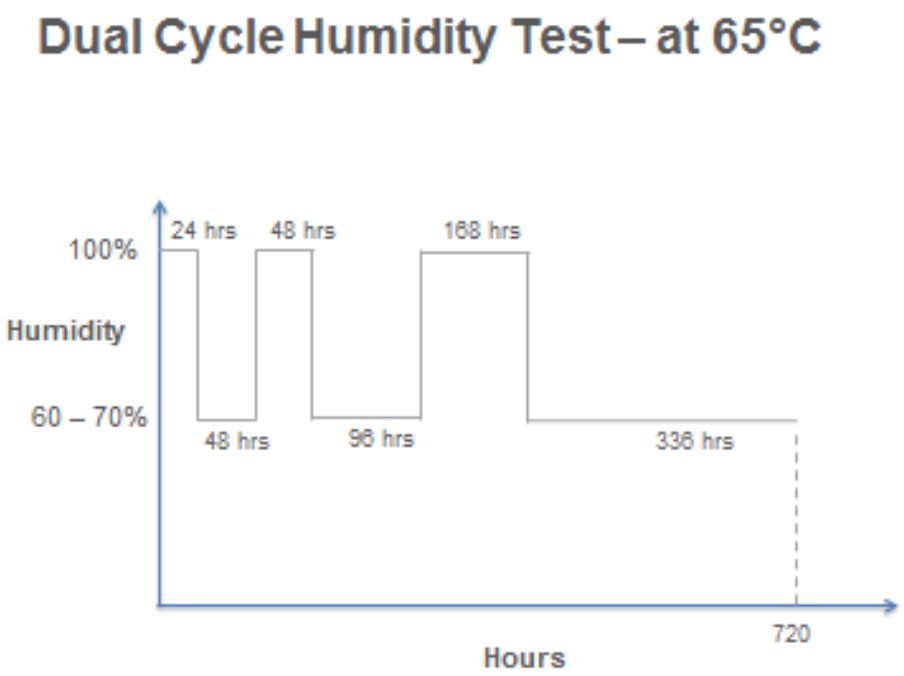
Figure 1: Cyclic humidity corrosion salt spray schedule



This test was performed to consider a specific set of conditions and should not be considered valid outside those conditions. Swagelok Company makes no representation or warranties regarding these selected conditions or the results attained there from. Laboratory tests cannot duplicate the variety of actual operating conditions. Test results are not offered as statistically significant. See the product catalog for technical data.

SAFE PRODUCT SELECTION

When selecting a product, the total system design must be considered to ensure safe, trouble-free performance. Function, material compatibility, adequate ratings, proper installation, operation, and maintenance are the responsibilities of the system designer and user.

Referenced Documents

ASTM D1141: *Standard Practice for the Preparation of Substitute Ocean Water*, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428

ASTM E165-95: *Standard Test Method for Liquid Penetrant Examination*, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428

ASTM B117-95: *Practice for Operating Salt Spray (Fog) Apparatus,* ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428

SAEJ2334: *Cosmetic Corrosion Lab Test*, SAE International, 400 Commonwealth Drive, Warrendale, PA 15096

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APPENDIX

Auto Technology Cyclic Corrosion Chamber

Assembled and Pressurized Tube Fittings Installed in Cyclic Salt Spray Chamber

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TITLE

Chloride Stress Corrosion Cracking (CSCC) Test of 316 Stainless Steel Swagelok® Tube Fittings with Stainless Steel Tubing Using 65°C Cyclic Salt Spray with Substitute Ocean Water

PRODUCT TESTED

Ordering Number	Body Form	Number of Fittings Tested	Test Pressure psig (MPa)	Tubing Size and Wall in.	Tubing Hardness HRB
SS-600-6	Bar stock	4	6500 (44.7)	3/8 × 0.065	81
SS-600-9	Forging	4			
SS-1210-6	Bar stock	4	5800 (39.9)	3/4 × 0.109	74
SS-1210-9	Forging	4			
SS-2000-6	Bar stock	4	4900 (33.7)	1 1/4 × 0.156	80
SS-2000-9	Forging	4			

PURPOSE

Assemblies of 316 stainless steel Swagelok tube fittings with stainless steel tubing were tested under laboratory conditions to observe the effects of an environment that promotes CSCC of 316 stainless steel.

The assemblies were exposed at 65ºC (149ºF) for 720h to alternate cycles of (a) salt spray (substitute ocean water per ASTM D1141) and (b) controlled humidity (60 to 70 %) to encourage concentrating chlorides in surface pits and crevices to particularly accelerate CSCC of 316 SS. Assemblies of one and seven-eighths turns past finger tight (TPFT) were included to increase tensile stress in the tube fitting components to further increase the risk of CSCC.

TEST METHOD

1. Eight samples were prepared for each size. Each tubing assembly was comprised of two fittings, one barstock, and one forging, assembled to a 64 mm (2 1/2 in.) length of tubing.
2. Additional sample fitting components and tubing of each size were set aside to comprise a control group for comparing surface structures before and after the CSCC test.
3. Four each of 3/8 inch and 3/4 inch size sample fittings were assembled according to Swagelok tube fitting installation instructions: one and one-quarter turns past finger-tight (TPFT). The other four of each size were assembled one and seven-eighths TPFT.
4. Four of the 1 1/4 inch size sample fittings were assembled according to Swagelok tube fitting installation instructions: MHSU preswage and one-half TPFT. The other four were assembled MHSU preswage and three-quarter TPFT.
5. Each sample was pressurized with nitrogen to the test pressure and monitored for leakage for 10 minutes prior to the CSCC test.
6. Samples were placed into a salt spray chamber that utilized substitute ocean water per ASTM D1141.
7. Samples were pressurized with water to the test pressure and held at that pressure throughout the CSCC test.

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8. The chamber temperature was elevated to 65°C (149°F) and the following salt spray schedule, derived from SAE J2334 and ASTM B117, was initiated:
    a. continuous salt spray maintained at 65°C for 24 hours
    b. salt spray turned off, 60 % to 70 % relative humidity maintained at 65°C for 48 hours
    c. repeat step a for 48 hours
    d. repeat step b for 96 hours
    e. repeat step a for 168 hours
    f. repeat step b for 336 hours, for a schedule total of 720 hours (see **Figure 1**)
9. Upon completion of the 720 hours, the samples were removed and rinsed in de-ionized water.
10. Each sample was again pressurized with nitrogen to its test pressure and monitored for leakage for 10 minutes.
11. Samples were then disassembled. The components (nut, body, and ferrules) swaged on the tubing were then liquid penetrant examined per ASTM E165 to reveal any cracks.
12. Sample components were then sectioned and metallurgically examined by 100× optical microscope for signs of CSCC.

TEST RESULTS

- All samples (24 ends total) successfully passed 720 hours in the salt spray chamber without loss of pressure.
- All samples successfully passed the pre- and post-salt spray nitrogen gas pressure tests without leakage.
- Liquid penetrant evaluation of the sample components found no evidence of crack formation.
- No evidence of CSCC crack initiation and propagation beyond surface structures of the sample components was observed.

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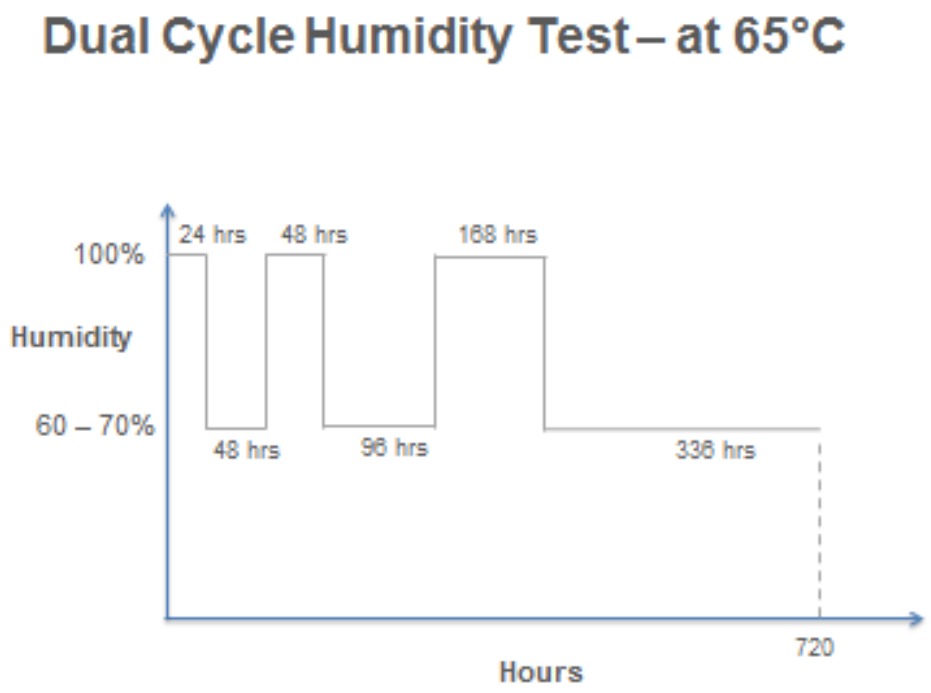
Figure 1: Cyclic humidity corrosion salt spray schedule



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APPENDIX

Auto Technology Cyclic Corrosion Chamber

Assembled and Pressurized Tube Fittings Installed in Cyclic Salt Spray Chamber

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