316L-SCQ®

Applicable specifications: AMS 5653; ASTM A182, A276, A314, A479, D Method

Associated specifications: JIS 4303; MIL-S-862; QQ-S-763; SEMI F19, F20, F105 Spec; UNS S31603

Type analysis

Single figures are nominal except where noted.

Iron	Balance	**Chromium**	16.00–18.00 %	**Nickel**	10.00–14.00 %
Molybdenum	2.00–3.00 %	**Manganese**	0.25–2.00 %	**Silicon**	Max 1.00 %
Phosphorus	Max 0.045 %	**Carbon**	Max 0.03 %	**Sulfur**	0.001–0.015 %

Forms manufactured

Bar-Flats	**Bar-Rounds**	**Custom Shapes**	**Hexagon**	**Wire-Shapes**

Description

316L-SCQ is an austenitic stainless designed for use where extremely good surface finishes are required. The corrosion resistance and mechanical properties of 316L-SCQ are similar to 316L. Typical specifications for bar products are ASTM A276 and SEMI F20.

316L-SCQ is produced to a tightly controlled chemical composition within conventional analysis limits. Carefully selected melt stock is used to restrict the occurrence of typical residual elements. One important element, sulfur, influences inclusion count, machinability, and weldability, and can be varied according to customer specification. The intermediate sulfur range is controlled to 0.001–0.015% for a unique combination of weldability and micro-cleanliness. For the ultra-pure composition, sulfur is held in the range of 0.001–0.004% maximum. Either of the compositions may be melted by air melting + vacuum arc remelting (AOD + VAR) or by vacuum induction melting + vacuum arc remelting (VIM + VAR) depending on the level of micro-cleanliness required.

Key Properties:

- Superior corrosion resistance
- Excellent micro-cleanliness for reduced inclusions
- Good weldability
- Outstanding surface finish

Markets:

- Aerospace
- Energy
- Industrial
- Medical

Applications:

- Thin-wall components
- Pipe fittings
- Instrument valves
- Medical equipment
- Ultra-high vacuum equipment
- Solar components

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Corrosion resistance

Due to its superior corrosion resistance, the use of 316L-SCQ has been extended to handling many of the gasses used in semiconductor manufacturing and chemicals used by chemical process industries.

The alloy is more resistant to pitting than conventional 18-8 alloys.

For optimum corrosion resistance, surfaces must be free of scale, coatings applied for drawing and heading, lubricants and foreign particles. After fabrication of parts, cleaning and/or passivation should be considered.

IMPORTANT NOTE:
The following 4-level rating scale (Excellent, Good, Moderate, Restricted) is intended for comparative purposes only. Corrosion testing is recommended. Factors that affect corrosion resistance include temperature, concentration, pH, impurities, aeration, velocity, crevices, deposits, metallurgical condition, stress, surface finish, and dissimilar metal contact.

Nitric Acid	Good	**Sulfuric Acid**	Moderate
Phosphoric Acid	Moderate	**Acetic Acid**	Good
Sodium Hydroxide	Moderate	**Salt Spray (NaCl)**	Good
Sea Water	Moderate	**Sour Oil/Gas**	Moderate
Humidity	Excellent		

Physical properties

PROPERTY	English Units
SPECIFIC GRAVITY	7.95
DENSITY	0.2870 lb/in^3
MEAN SPECIFIC HEAT	0.1200 Btu/lb/°F
MEAN COEFFICIENT OF THERMAL EXPANSION (CTE)	10.3 x 10^{-6} in/in/°F
ELECTRICAL RESISTIVITY	445.0 ohm-cir-mil/ft

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Heat treatment

Annealing	Heat to 1850/2050°F (1010/1121°C) and water quench. Brinell hardness approximately 150.
Hardening	Cannot be hardened by heat treatment. Hardens only by cold working.

Workability

Hot working	316L-SCQ can be readily forged, upset, and hot headed.
Forging	To forge, heat uniformly to 2100/2300°F (1149/1260°C). Do not forge below 1700°F (927°C). Forgings can be air cooled. Best corrosion resistance is obtained if the forgings are given a final anneal.
Cold working	316L-SCQ can be deep drawn, stamped, headed, and upset without difficulty. Since this alloy work hardens, severe cold forming operations should be followed by an anneal.

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Workability continued

Machinability	316L-SCQ machines with chip characteristics that are tough and stringy. The use of chip curlers and breakers is advised. Since the austenitic stainless grades work harden rapidly, heavy positive feeds should be considered. Many customers prefer a small amount of cold work to enhance machinability and achieve a better chip characteristic and as-machined surface finish. The process of cold drawing increases the yield strength and tensile strength and decreases percent elongation and percent reduction of area. To accommodate cold work to improve machinability, many customer specifications allow a decrease in the percent elongation requirement to 20% minimum. Since machinability means different things to different shops (speeds and feeds, tool life, surface finish, etc.), each shop needs to run comparative tests to establish optimum machining parameters for a particular sulfur level and to generate cost data. Usually, the lower the sulfur levels, the greater the tendency to burnish the surface, which improves surface luster. Also, the lower the inclusion content, the better the surface after electropolishing.
Weldability	316L-SCQ alloys are readily welded using gas tungsten arc, plasma, laser, and electron beam welding techniques. Extra attention should be paid, however, to the weld penetration and bead geometry because of the effects on sulfur on the physics of the weld puddle. The penetration ratio (ratio of depth to bead width) increases with an increase in the sulfur content up to about 0.03%. Conversely, the weld bead will become shallow and broader as the sulfur content decreases. The weld bead geometry and location can be a problem if components with significantly different sulfur levels are joined. Where possible, it is suggested that both components have similar sulfur contents. When this is not possible, good welds are possible between two components with significantly lower sulfur (0.004% vs. 0.008% sulfur) through carefully positioning the welding electrode and selection on the shielding gases. 316L-SCQ can be satisfactorily welded by the shielded fusion and resistance welding processes. Since austenitic welds do not harden on air cooling, the welds should have good toughness. Oxyacetylene welding is not recommended since carbon pickup in the weld may occur. The alloy can be welded without loss of corrosion resistance due to intergranular carbide precipitation. Usually the alloy can be used in the as-welded condition. However, for service in the most severe environments, the welded structure should be reannealed after welding. Where a filler metal is required, AWS E/ER316L welding consumables should be considered.

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Typical feeds and speeds

The feeds and speeds in the following charts are conservative recommendations for initial setup. Higher feeds and speeds may be attainable depending on machining environment.

TURNING — SINGLE-POINT AND BOX TOOLS

CONDITION	DEPTH OF CUT, IN	HIGH-SPEED TOOLS			CARBIDE TOOLS (INSERTS)			
		SPEED, FPM	FEED, IPR	TOOL MATERIAL	SPEED, FPM UNCOATED	SPEED, FPM COATED	FEED, IPR	TOOL MATERIAL
Annealed	.150	50	.010	M-48, T-15	290	330	.010	C-6
	.025	65	.005	M-48, T-15	315	365	.005	C-6
Cold drawn	.150	40	.010	M-48, T-15	275	295	.010	C-6
	.025	55	.005	M-48, T-15	295	325	.005	C-6

TURNING — CUT-OFF AND FORM TOOLS

CONDITION	SPEED, FPM	FEED, IPR — CUT-OFF TOOL WIDTH, IN							TOOL MATERIAL	
		1/16	1/8	1/4	1/2	1	1-1/2	2	HIGH-SPEED TOOLS	CARBIDE TOOLS
Annealed	45	.0010	.0011	.0013	.0018	.0010	.0008	.0005	M-48, T-15	—
	195	.0010	.0011	.0013	.0018	.0010	.0008	.0005	—	C-6
Cold drawn	40	.0010	.0011	.0013	.0018	.0010	.0008	.0005	M-48, T-15	—
	185	.0010	.0011	.0013	.0018	.0010	.0008	.0005	—	C-6

ROUGH REAMING

CONDITION	HIGH-SPEED TOOLS		CARBIDE TOOLS		FEED, IPR, REAMER DIAMETER, IN					
	SPEED, FPM	TOOL MATERIAL	SPEED, FPM	TOOL MATERIAL	1/8	1/4	1/2	1	1-1/2	2
Annealed	20	M-48, T-15	—	—	.0008	.0009	.0009	.0010	.0011	.0013
	—	—	30	C-6	.0008	.0009	.0009	.0010	.0011	—
Cold drawn	15	M-48, T-15	—	—	.0008	.0009	.0009	.0010	.0011	.0013
	—	—	25	C-6	.0008	.0009	.0009	.0010	.0011	—

DRILLING

CONDITION	SPEED, FPM	FEED, IPR — NOMINAL HOLE DIAMETER, IN								TOOL MATERIAL	
		1/16	1/8	1/4	1/2	3/4	1	1-1/2	2	HIGH-SPEED TOOLS	CARBIDE TOOLS
Annealed	20–40	.0008	.001	.002	.004	.006	.007	.007	.008	M-42	—
	50–90	.0007	.001	.002	.004	—	.007	.008	—	—	C-6
Cold drawn	15–35	.0006	.001	.002	.004	.006	.007	.007	.008	M-7	—
	40–80	.0006	.001	.002	.004	—	.007	.008	—	—	C-6

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END MILLING — PERIPHERAL

CONDITION	DEPTH OF CUT, IN	HIGH-SPEED TOOLS						CARBIDE TOOLS					
		SPEED, FPM	FEED, IN PER TOOTH				TOOL MATERIAL	SPEED, FPM	FEED, IPT				TOOL MATERIAL
			CUTTER DIAMETER, IN						CUTTER DIAMETER, IN PER TOOTH				
			1/4	1/2	3/4	1-2			1/4	1/2	3/4	1-2	
Annealed	.050	40	.001	.002	.004	.006	M-48, T-15	150	.001	.002	.004	.006	C-6
Cold drawn	.050	35	.001	.002	.004	.006	M-48, T-15	150	.001	.002	.004	.006	C-6

SLOT MILLING — PERIPHERAL

CONDITION	DEPTH OF CUT, IN	HIGH-SPEED TOOLS			CARBIDE TOOLS		
		SPEED, FPM	FEED, IPR	TOOL MATERIAL	SPEED, FPM	FEED, IPR	TOOL MATERIAL
Annealed	.050	42	.003	M-48, T-15	166	.003	C-6
	.150	35	.0045	—	130	.0045	—
Cold drawn	.050	36	.003	M-48, T-15	150	.003	C-6
	.150	30	.0045	—	115	.0045	—

TAPPING — HIGH-SPEED TOOLS

CONDITION	SPEED, FPM	TOOL MATERIAL
Annealed	10–15	M-7, M-10
Cold drawn	8–13	M-7, M-10

BROACHING — HIGH-SPEED TOOLS

SPEED, FPM	CHIP LOAD, IN PER TOOTH	TOOL MATERIAL
12	.002	M-48, T-15
10	.002	M-48, T-15

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Additional machinability notes

Figures used for all metal removal operations are averaged. On certain work, the nature of the part may require adjustment of speeds and feeds. Each job has to be developed for best production results with optimum tool life. Speeds or feeds should be increased or decreased in small steps.

Micro-cleanness

Cleanness is evaluated by means of a microscopic examination of a sample to establish a JK rating. Carpenter Technology typically conducts this evaluation on billets in accordance with ASTM E-45 Method A with ratings based on Plate III. Samples are rated from the top and bottom of the first, middle, and last ingot of the heat. The maximum JK inclusion ratings in the table below are limits set by SEMI-F20.

MAXIMUM JK INCLUSION RATINGS

TYPE	GENERAL PURPOSE GRADE		HIGH PURITY GRADE		ULTRA-HIGH PURITY GRADE	
	THIN	HEAVY	THIN	HEAVY	THIN	HEAVY
A	2.5	1.0	2.0	1.0	1.5	1.0
B	2.5	1.0	2.0	1.0	1.0	1.0
C	2.5	1.0	2.0	1.0	1.0	1.0
D	2.5	1.0	2.0	1.0	1.0	1.0

Depending on the ordered chemistry, ultra-high purity (UHP) limits may be met with only an air melt + vacuum arc remelt (AOD + VAR).

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MICRO-CLEANNESS SINGLE VACUUM MELT							
SULFIDES		ALUMINA		SILICATES		OXIDES	
THIN	THICK	THIN	THICK	THIN	THICK	THIN	THICK
1-1/2	1	1-1/2	1	1-1/2	1	1-1/2	1

The cleanest version of 316L-SCQ utilizes two vacuum melting techniques, in combination with restricting sulfur to 0.004% maximum. In all other respects, this material has the same chemical balance and mechanical property capability as the single vacuum melted (AOD + VAR) material. However, to illuminate the advantage of combining low sulfur and double vacuum melting, the JK limits displayed apply (VIM + VAR).

MICRO-CLEANNESS DOUBLE VACUUM MELT							
SULFIDES		ALUMINA		SILICATES		OXIDES	
THIN	THICK	THIN	THICK	THIN	THICK	THIN	THICK
1	1	1	1/2	1	1/2	1	1

The two issues most frequently questioned are weldability and machinability. For further information regarding these issues, refer to the machinability and welding sections under the workability section of this datasheet.

Since the manganese in the melt is ultra-low, the alloy can support and prevent the production of manganese fumes during welding to a certain extent.

Considerable experience has demonstrated that the increased purchase price and machining costs associated with double vacuum melted ultra-low sulfur is more than offset by the ability to consistently achieve an exceptional electropolished finish.

For additional information, please contact your nearest sales office:
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