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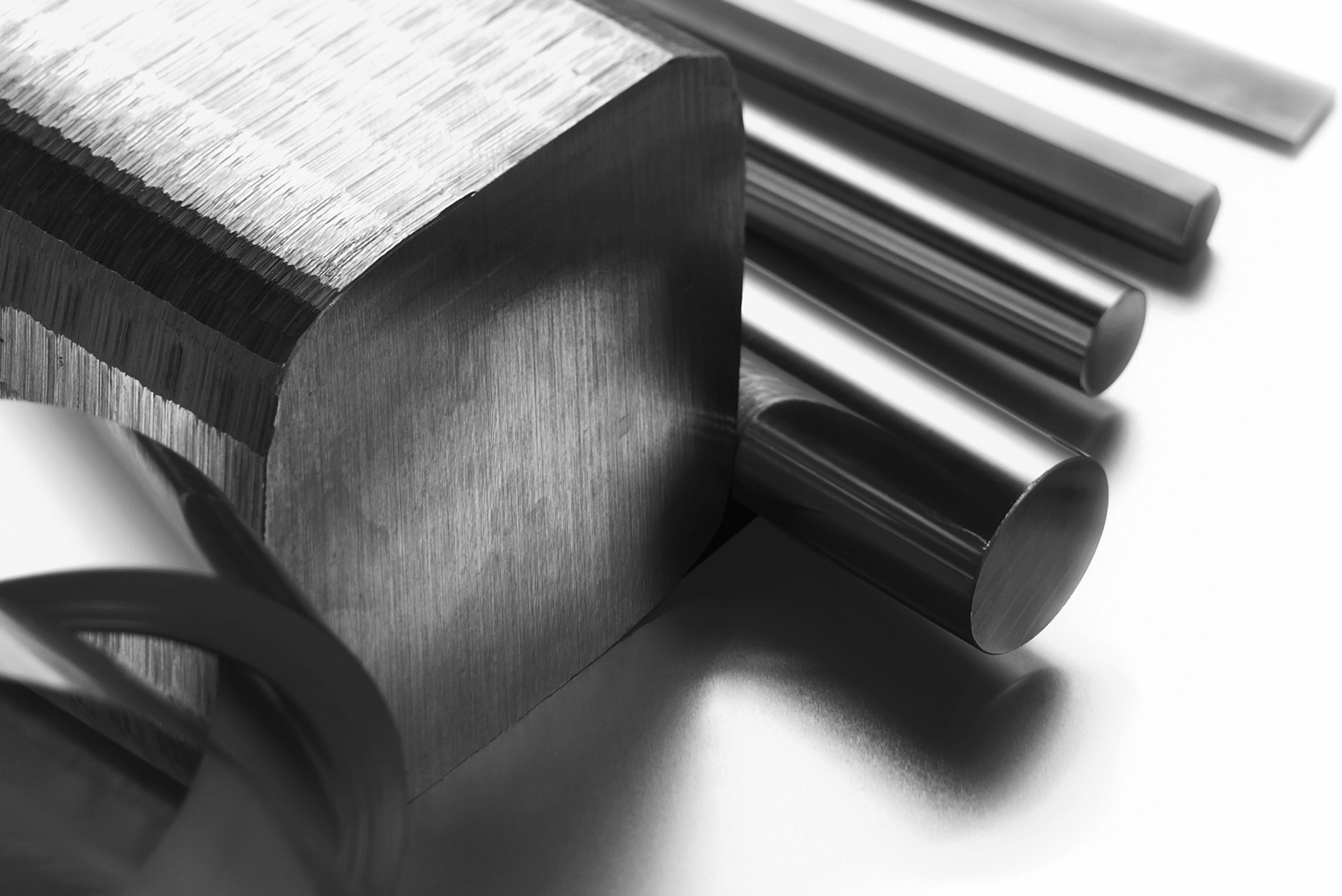
2009 Guide to Selecting Carpenter Specialty Alloys



CARPENTER: A LEADING PRODUCER AND SUPPLIER OF SPECIALTY ALLOYS

For more than a century, Carpenter's high-performance specialty alloys have been meeting the difficult challenges of advancing technologies. Carpenter is around you every day. You'll find that these high-performance materials have been used in jet engines, automotive components, high-definition televisions, medical implants and instruments, and many other demanding applications. Carpenter serves the aerospace, automotive, consumer products, defense, energy, industrial and medical markets.

Carpenter manufactures hundreds of grades of specialty cast-wrought and powder metallurgy alloys including stainless steels, high temperature (nickel-, iron- and cobalt-base) alloys, high strength steels, magnetic and controlled expansion alloys, tool steels and other special purpose alloys.

As a result, Carpenter can offer specialty alloy users many unique advantages—from skilled sales, service and technical professionals to 24/7 access to technical data at **www.cartech.com** to outstanding quality and reliable delivery—wherever and whenever you need high-quality specialty alloys.

In this book, select from stainless steels, superior corrosion-resistant alloys, high-temperature alloys, magnetic and controlled-expansion alloys, tool and die steels and many other special purpose grades. Carpenter alloys are available in a variety of product forms, including bar, rod, wire, fine wire and ribbon, strip, plate, special shapes, hollow bar and billet.

Get instant access to technical data covering Carpenter's wide range of specialty alloys from anywhere in the world, 24 hours a day, at www.cartech.com. Click on Tech Center. Registration is easy, fast and free.

GUIDE TO SELECTING CARPENTER SPECIALTY ALLOYS

CONTENTS

Quality systems are approved to ISO 9001:2000 standards.

EASE OF SELECTION

Evaluate these five key factors before choosing a stainless alloy for a specific application.

1. **Corrosion Resistance —** The primary driver for specifying a stainless steel. Basically, candidate materials must resist corrosion in the service environment.
2. **Mechanical Properties —** Along with alloy strength, consider hardness, fatigue, impact and stress-rupture properties. Together with corrosion resistance, the mechanical properties often indicate the specific alloy type for the application.
3. **Fabrication Operation —** Material processing and machining methods often influence alloy selection. Some alloys are better suited than others for machining, heading, welding or heat treating.
4. **Value/Cost —** The overall value/cost analysis of the material involves material cost, processing cost, added product value and effective life of the finished product, among others. All these considerations play important roles in evaluating cost/value and should be considered for cost-effective design.
5. **Product Availability —** Availability of the material and minimum purchase requirements are also a consideration in choosing material for your application.

   More detailed information on corrosion is available in *Carpenter's Alloys For Corrosive Environments* booklet.

Although these factors are commonly recognized throughout the metalworking industry, we know that the careful consideration of their importance can be a time-consuming and frustrating experience. That's why Carpenter developed its exclusive Selectaloy® method to help you with the selection process.

The Selectaloy chart can help you identify a stainless steel for a variety of applications. The diagram organizes alloys by the combination of corrosion resistance and strength. For example, suppose you are using Type 304 stainless, but you require more corrosion resistance at that same strength level. Simply move up to Type 316 stainless. A move over from Type 304 to Custom 450® stainless increases strength while maintaining comparable corrosion resistance.

If you are looking for an alloy to control severe corrosives, the Alloy Selection Guide at right can help put your material selection process into perspective. It was developed as a guideline to the

NEED HELP?

Carpenter is experienced in the manufacture of many specialty alloys. We excel in the production of special compositions to meet specific requirements. If the type of alloy you desire is not listed in this guide, please contact us to discuss your needs.

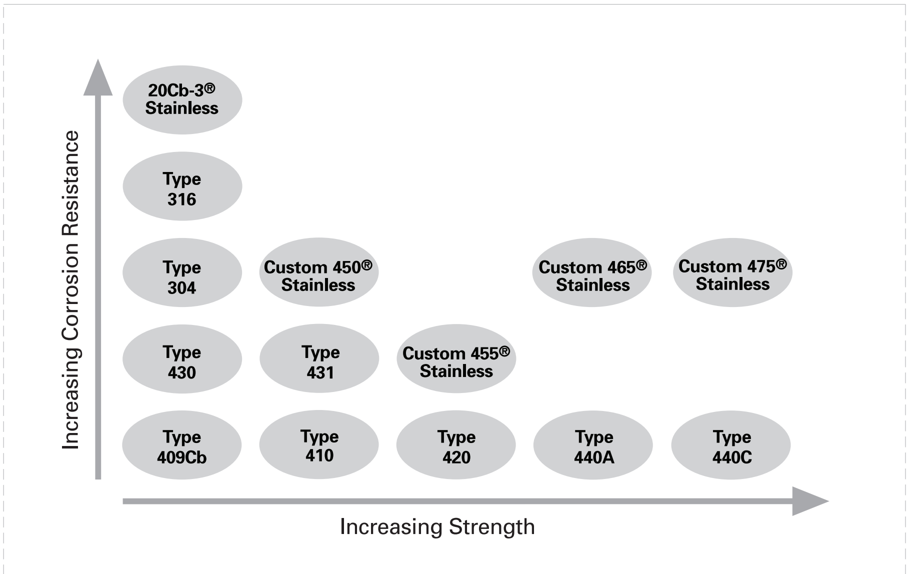
In the U.S., call **1-800-654-6543**. For International sales offices, contact information can be found at **www.cartech.com**.

For technical data on hundreds of alloys, go to www.cartech.com.
Registration is free. It's like having your own metallurgist!

relative potential of each alloy to resist corrosion in specific environments. Use the information in this booklet as a starting point to help determine the alloy that may suit your specific application. Carpenter's online technical information database is another useful tool in researching alloys. Registration is easy, fast and free at www.cartech.com.

If you would like to receive a quote, need technical assistance or have a question about selecting a Carpenter alloy, contact us toll-free in the U.S. at **1-800-654-6543** or visit us at **www.cartech.com.**

SELECTALOY® DIAGRAM



ALLOY COMPARISONS

IMPROVING LEVELS OF CORROSION RESISTANCE	CHLORIDE PITTING AND CREVICE CORROSION	CHLORIDE STRESS CORROSION CRACKING	SULFURIC ACID	MEDICAL (ORTHOPEDIC)	MAGNETIC APPLICATIONS (Water and mild Chemicals)	OIL FIELD ENVIRONMENTS	HIGH STRENGTH WIRE (Cold drawn or cold drawn & aged)
OUTSTANDING	C-276 Custom Age 625 PLUS®[1] and Pyromet® 625	C-276 Custom Age 625 PLUS[1] and Pyromet® 625 Ni-Cu 400[2]	C-276 20Cb-3®	BioDur® CCM Plus® CCM Alloys MP35N[4] Carpenter L-605	Chrome Core® 29	C-276 Custom Age 625 PLUS[1] and Pyromet® 625	C-276 MP35N[1,4] Custom Age 625 PLUS[1] 20Mo-6® HS
SUPERIOR	SCF 19® 25Ni-20Cr-6Mo	925[1] 20Cb-3®	Custom Age 625 PLUS[1] and Pyromet® 625 20Mo-6 Ni-Cu 400[2]	BioDur 108 and 22Cr-13Ni-5Mn BioDur 734	Chrome Core 18-FM Types 430F and 430FR	Pyromet® 718 Pyromet® 706	Pyromet® 718[1]
EXCELLENT	7-Mo PLUS® and 2205 22Cr-13Ni-5Mn	SCF 19® 25Ni-20Cr-6Mo 7-Mo PLUS® and 2205		Type 316, BioDur 316LS Gall-Tough® PLUS	Chrome Core 13-FM Chrome Core 12-FM	925[1] 25Ni-20Cr-6Mo SCF 19® 20Cb-3®	925[1]
GOOD	925[1] Ni-Cu 400[2] 20Cb-3® Type 316	22Cr-13Ni-5Mn Type 316	25Ni-20Cr-6Mo 7-Mo PLUS® 22Cr-13Ni-5Mn 2205 Type 316	Types 304, 304L Gall-Tough®, Custom 450 and Custom 630	Chrome Core 8 Chrome Core 8-FM	22Cr-13Ni-5Mn Type 316, A-286[1] and 2205 15-15LC® Mod and 15-15HS[3] Max Custom 450®	22Cr-13Ni-5Mn A-286[1]

[1]Aged Condition. [2]Resistance varies considerably with aeration or oxidizing impurities. [3]Candidates for drilling applications. [4]MP35N is a registered trademark of SPS Technologies, Inc. MP is a registered trademark of SPS Technologies, Inc.

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Some grades may require the purchase of a minimum heat lot quantity.

STAINLESS STEELS

Each of these Carpenter stainless alloys is produced to provide a specific combination of corrosion resistance, strength characteristics and fabrication qualities. We have arranged the alloys in this section according to their most common end-use application.

Type analyses are shown as percentages.

▸ Standard Grades

CARPENTER STAINLESS TYPE 302 (UNS S30200)

0.15 C	0.045 P	1.00 Si	8.00/10.00 Ni
2.00 Mn	0.03 S	17.00/19.00 Cr	Bal. Fe

(single figures are maximums)

Austenitic, non-magnetic, extremely tough and ductile, this is one of the most widely used of the chrome-nickel stainless and heat-resisting steels. Non-hardenable by heat treating.

CARPENTER STAINLESS TYPE 304 (UNS S30400)

0.08 C	0.045 P	1.00 Si	8.00/10.50 Ni
2.00 Mn	0.030 S	18.00/20.00 Cr	Bal. Fe

(single figures are maximums)

Type 304 is the most widely used chromium-nickel austenitic stainless steel. It is non-magnetic in the annealed condition and becomes slightly magnetic when cold worked. It has excellent fabricability and weldability characteristics. Non-hardenable by heat treating.

CARPENTER STAINLESS TYPE 304L (UNS S30403)

0.03 C	0.045 P	1.00 Si	8.00/12.00 Ni
2.00 Mn	0.030 S	18.00/20.00 Cr	Bal. Fe

(single figures are maximums)

Low-carbon content minimizes problem of carbide precipitation during welding and has permitted use of this alloy in corrosive service in the as-welded condition.

CARPENTER STAINLESS TYPE 316 (UNS S31600)

0.08 C	0.030 S	16.00/18.00 Cr	2.00/3.00 Mo
2.00 Mn	1.00 Si	10.00/14.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

A molybdenum-bearing austenitic stainless which offers better corrosion resistance in chlorides and many other environments than Type 304. It also has higher tensile and creep strength at elevated temperatures than the conventional 18% chromium–8% nickel alloys.

CARPENTER STAINLESS TYPE 316L (UNS S31600)

0.03 C	0.030 S	16.00/18.00 Cr	2.00/3.00 Mo
2.00 Mn	1.00 Si	10.00/14.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

Low-carbon modification of Type 316 stainless permits use in the as-welded condition and minimizes carbide precipitation during welding and exposure to elevated temperatures.

CARPENTER STAINLESS TYPE 321 (UNS S32100)

0.08 C	0.030 S	17.00/19.00 Cr	5 x C min. Ti
2.00 Mn	1.00 Si	9.00/12.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

Austenitic chrome-nickel stainless, titanium added, for parts intermittently heated to temperatures between 800/1650°F (427/899°C). Designed to eliminate intergranular corrosion in the as-welded condition.

CARPENTER STAINLESS TYPE 347 (UNS S34700)

0.08 C	0.030 S	17.00/19.00 Cr	10 x C min. Cb + Ta
2.00 Mn	1.00 Si	9.00/13.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

Columbium-stabilized austenitic stainless steel which resists carbide precipitation during welding and intermittent heating to 800/1650°F (427/899°C). Good high-temperature scale resistance.

CARPENTER STAINLESS TYPE 410 (UNS S41000)

0.15 C	0.040 P	1.00 Si	Bal. Fe
1.00 Mn	0.030 S	11.50/13.00 Cr	

(single figures are maximums)

Hardenable martensitic stainless alloy used for highly stressed parts needing good corrosion resistance and strength. Can be heat-treated to obtain high-strength properties with good ductility.

Some grades may require the purchase of a minimum heat lot quantity.

CARPENTER STAINLESS TYPE 430 (UNS S43000)

0.12 C	0.04 P	1.00 Si	Bal. Fe
1.00 Mn	0.03 S	16.00/18.00 Cr	

(single figures are maximums)

Corrosion- and heat-resisting chrome steel. Has been useful for many types of decorative trim. Hardness can be moderately increased by cold-working, but the alloy cannot be hardened by heat-treating.

Super-Clean Quality (SCQ) Grades

304-SCQ™ STAINLESS

0.08 C nom.	0.045 P	1.00 Si	8.00/10.50 Ni
2.00 Mn	0.010 S	18.00/20.00 Cr	Bal. Fe

(single figures are maximums)

Premium remelted version of Type 304 stainless. Useful where enhanced metal cleanness contributes to improved internal soundness which increases product quality and yields. If greater corrosion resistance is required, consider 316L-SCQ® stainless.

316L-SCQ® STAINLESS

0.03 C	0.005/0.015 S	16.00/18.00 Cr	2.00/3.00 Mo
2.00 Mn	1.00 Si	10.00/14.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

Premium melted derivative of Type 316L with similar corrosion resistance, machinability, weldability and improved electropolishing characteristics. Available in sulfur ranges between .005 to .015. Useful where enhanced metal cleanness contributes to improved product quality and yields. Could be considered for manufacturing applications in pharmaceutical and semi-conductor industries.

Machining Grades

PROJECT 70+® TYPE 303 STAINLESS
(U.S. PATENT NOS. 5,482,674 AND 5,837,190) (UNS S30300)

0.12 C	0.20 P	1.00 Si	8.00/10.00 Ni
2.00 Mn	0.15 min. S	17.00/19.00 Cr	Bal. Fe

(single figures are maximums)

Has been designed to reduce tool wear and increase machine speeds and feeds to help improve productivity and reduce part costs. It is a good general purpose product for simple as well as complex parts at a wide range of machining speeds. It may be considered for use in applications such as shafts, valve bodies, valves, valve trim and fittings.

PROJECT 70+ TYPE 304/304L STAINLESS
(U.S. PATENT NO. 5,512,238) (UNS S30400 / UNS S30403)

0.03 C (304L)	0.045 P	1.00 Si	8.00/10.50 Ni
2.00 Mn	0.030 S	18.00/20.00 Cr	Bal. Fe

(single figures are maximums)

An improved-machining version of conventional Type 304/304L stainless, this alloy has been designed to reduce tool wear and increase machine speeds and feeds to help improve productivity and reduce part costs. Customers may be able to attain machining speed improvements of up to 50% and higher over AISI Type 304/304L.

May be considered for use in a wide range of food processing, dairy and dyeing industry applications. Is non-magnetic when annealed and is non-hardenable by heat treating. The low carbon version, Project 70+ Type 304L stainless, minimizes carbide precipitation during welding and permits the alloy's use in the as-welded condition. Carpenter's analysis permits certification to both chemistry requirements and meets the mechanical property requirements for both grades.

PROJECT 70+ TYPE 316/316L STAINLESS
(U.S. PATENT NO. 5,512,238) (UNS S31600 / UNS S31603)

0.03 C	0.030 S	16.00/18.00 Cr	2.00/3.00 Mo
2.00 Mn	1.00 Si	10.00/14.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

This molybdenum-containing austenitic stainless alloy offers generally better pitting and corrosion resistance in chloride-containing and other environments when compared to Type 304 stainless. Low magnetic permeability in the annealed condition. Non-hardenable by heat treating. Low carbon Type 316L minimizes carbide precipitation during welding and permits this alloy's use in corrosive service in the as-welded condition. Carpenter's analysis permits certification to both chemistry requirements and meets the mechanical property requirements of both grades.

Has been designed to reduce tool wear and increase machine speeds and feeds to help improve productivity and reduce part costs.

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Some grades may require the purchase of a minimum heat lot quantity.

PROJECT 70+® TYPE 416 STAINLESS (U.S. PATENT NO. 6,146,475) (UNS S41600)

0.15 C	0.06 P	1.00 Si	Bal. Fe
1.25 Mn	0.15 S min.	12.00/14.00 Cr	

(single figures are maximums)

An improved modification of Carpenter Stainless No. 5. The low frictional properties of Carpenter Project 70+ Type 416 stainless have minimized scratching and galling in service. It may be considered for parts requiring considerable machining.

This grade is available in machining bar stock in the Annealed Condition (A), and also Mill Treated in the Intermediate Temper Condition (T), and Hard Temper Condition (H).

PROJECT 70+ CUSTOM 630 STAINLESS (UNS S17400)

0.07 C	0.03 S	3.00/5.00 Ni	0.15/0.45 Cb + Ta
1.00 Mn	1.00 Si	3.00/5.00 Cu	Bal. Fe
0.04 P	15.00/17.50 Cr		

(single figures are maximums)

An improved-machining version of conventional Stainless Type 17Cr-4Ni. It has good fabricating characteristics and can be age hardened by a single-step, low temperature treatment.

Has been used for a variety of applications including oil field valve parts, chemical process equipment, aircraft fittings, fasteners, pump shafts, nuclear reactor components, gears, paper mill equipment, missile fittings and jet engine parts.

PROJECT 70+ 15CR-5NI STAINLESS (U.S. PATENT NO. 6,576,186) (UNS S15500)

0.07 C	0.015 S	3.50/5.50 Ni	0.15/0.45 Cb/Nb
1.00 Mn	1.00 Si	0.50 Mo	Bal. Fe
0.03 P	14.00/15.50 Cr	2.50/4.50 Cu	

(single figures are maximums)

Project 70+® 15Cr-5Ni stainless is an optimized 15Cr-5Ni stainless designed to provide superior machinability compared with other brands, meeting all aspects of Aerospace Material Specification AMS 5659 covering bars, wire, forgings, rings and extrusions. Consequently, Project 70+ 15Cr-5Ni stainless may be considered for all usual 15-5 applications.

Applications have included a variety of aerospace components requiring conformance to Aerospace Material Specification AMS 5659, particularly those which involve significant machining operations.

302HQ-FM® STAINLESS (UNS S30431)

0.06 C	0.14 S	16.00/19.00 Cr	1.30/2.40 Cu
2.00 Mn	1.00 Si	9.00/11.00 Ni	Bal. Fe
0.040 P			

(single figures are maximums)

A machinable modification of Custom Flo 302HQ. As such, it can be cold headed into a variety of parts and then easily machined in secondary operations such as drilling, slotting and tapping. It has been run in bar form on automatic screw machines to produce parts where thread rolling or cold form tapping operations are critical.

CARPENTER STAINLESS TYPE 303 SE (UNS S30323)

0.12 C	0.12/0.17 P	1.00 Si	8.00/10.00 Ni
2.00 Mn	0.15/0.35 Se	17.00/19.00 Cr	Bal. Fe

(single figures are maximums)

Selenium-bearing, free machining 18-8 chromium-nickel steel. Machinability similar to Type 303 but with improved formability. May also be considered for applications that involve cold-forming operations.

STAINLESS TYPE 309 (U.S. PATENT NOS. 4,959,513 AND 5,087,414) (UNS S30900)

0.08 C	0.030 S	22.00/24.00 Cr	Bal. Fe
0.045 P	1.00 Si	12.00/15.00 Ni	

(single figures are maximums)

Austenitic chromium-nickel stainless alloy with superior heat- and corrosion-resistance properties, and with improved machinability as compared to conventional Type 309 or Type 309S. This alloy may be considered for automatic screw machine operations where the longer tool life results in more productive machine time. Applications have included those for Type 309 or Type 309S which require machining.

CARPENTER STAINLESS TYPE 321 (UNS S32100)

0.08 C	0.030 S	17.00/19.00 Cr	5 x C min. Ti
2.00 Mn	1.00 Si	9.00/12.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

An austenitic chrome-nickel stainless stabilized with titanium. Has found use in applications subject to intermittent heating to 800/1650°F (427/899°C). Designed to control intergranular corrosion in the as-welded condition.

CARPENTER STAINLESS TYPE 347 (UNS S34700)

0.08 C	0.030 S	17.00/19.00 Cr	10 x C min. Cb + Ta
2.00 Mn	1.00 Si	9.00/13.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

Offers significantly improved machinability characteristics compared to those offered by conventional Type 347. An austenitic chrome-nickel stainless stabilized with columbium plus tantalum. Has found use in applications subject to intermittent heating to 800/1650°F (427/899°C). Designed to control intergranular corrosion in the as-welded condition.

Some grades may require the purchase of a minimum heat lot quantity.

CARPENTER STAINLESS TYPE 416 (NO. 5) (UNS S41600)

0.15 C	0.06 P	1.00 Si	Bal. Fe
1.25 Mn	0.15 S min.	12.00/14.00 Cr	

(single figures are maximums)

The original free-machining version of Type 410 stainless. Provides quenched hardness capability between that of Project 70+ Type 416 stainless and Type 416 BQ stainless.

CARPENTER STAINLESS TYPE 416 BQ (NO. 5BQ) (UNS S41600)

0.15 C	0.06 P	1.00 Si	Bal. Fe
1.25 Mn	0.15 S min.	12.00/14.00 Cr	

(single figures are maximums)

A balanced version of standard Type 416 stainless capable of producing a minimum hardness of Rockwell C 40 when bright hardened. Can be cut rapidly and cleanly with regular metal cutting tools.

NO. 5-F STAINLESS (UNS S41600)

0.10 C	0.06 P	1.00 Si	0.50 Ni
1.00 Mn	0.30 S min.	13.00/14.00 Cr	Bal. Fe

(single figures are maximums)

This modification of Carpenter Stainless Type 416 is designed for optimum machinability with good corrosion resistance. This specially balanced composition is essentially non-hardenable.

TYPE 420F STAINLESS (UNS S42020)

0.15 C min.	0.06 P	1.00 Si	0.60 Mo
1.25 Mn	0.15 S min.	12.00/14.00 Cr	Bal. Fe

(single figures are maximums)

This free-machining version of Type 420 is a hardenable 12% chrome steel with higher strength, hardness and wear resistance than Type 410.

TYPE 430F STAINLESS (UNS S43020)

0.12 C	0.06 P	1.00 Si	0.60 Mo
1.25 Mn	0.15 S min.	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

May be considered when making machined articles from a 17% chromium steel. Does not harden by heat treatment. It has been used in automatic screw machines for parts requiring good corrosion resistance such as aircraft parts and gears.

TYPE 440F-SE STAINLESS (UNS S44020)

0.95/1.20 C	0.04 P	1.00 Si	0.60 Mo
1.25 Mn	0.15 S or Se min.	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

This high-carbon chromium steel is designed to provide stainless properties with maximum hardness; approximately Rockwell C 59 after heat treatment. May be considered for machined parts which require higher hardness values than possible with other free-machining grades.

▸ Heading Grades

CARPENTER TYPE 204-CU STAINLESS

0.15 C	0.060 P	1.50/3.50 Ni	0.05/0.25 N
6.50/9.00 Mn	0.030 S	2.00/4.00 Cu	Bal. Fe
1.00 Si	15.50/17.50 Cr		

(single figures are maximums)

A copper-containing, low-nickel, nitrogen-strengthened, austenitic stainless steel. The nitrogen addition results in higher annealed strength than Type 304; however, the copper addition reduces the work hardening rate to provide cold worked properties similar to Type 304. The alloy is non-magnetic in the annealed condition and remains non-magnetic after cold working. Cold forming characteristics are superior to 200 series stainless steels and similar to Type 304.

302HQ-FM® STAINLESS (UNS S30431)

0.06 C	0.14 S	16.00/19.00 Cr	1.30/2.40 Cu
2.00 Mn	1.00 Si	9.00/11.00 Ni	Bal. Fe
0.040 P			

(single figures are maximums)

A machinable modification of Custom Flo 302HQ. As such, it can be cold-headed into a variety of parts and then easily machined in secondary operations such as drilling, slotting and tapping. It has been run in bar form on automatic screw machines to produce parts where thread rolling or cold form tapping operations are critical.

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Some grades may require the purchase of a minimum heat lot quantity.

CARPENTER 302HQ-SFQ STAINLESS (UNS S30430)

0.08 C	0.03 S	17.0019.00 Cr	3.00/4.00 Cu
2.00 Mn	1.00 Si	8.00/10.0 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

Has the same chemistry as the time tested Custom Flo 302HQ heading wire but is manufactured to a less restrictive surface defect requirement. Can be considered as a candidate for standard fastener production, where upsets are not severe.

CARPENTER STAINLESS TYPE 304 (UNS S30400)

0.08 C	0.045 P	1.00 Si	8.00/10.50 Ni
2.00 Mn	0.030 S	18.00/20.00 Cr	Bal. Fe

(single figures are maximums)

The most widely used chromium-nickel austenitic stainless steel. It is non-magnetic in the annealed condition and becomes slightly magnetic when cold worked. Possesses excellent fabricability and weldability characteristics. Non-hardenable by heat-treating.

CARPENTER STAINLESS TYPE 305 (UNS S30500)

0.12 C	0.045 P	1.00 Si	10.50/13.00 Ni
2.00 Mn	0.03 S	17.00/19.00 Cr	Bal. Fe

(single figures are maximums)

Chromium-nickel austenitic stainless steel that has been used extensively for cold heading, severe deep drawing and spinning operations. High nickel content slows work hardening. Maintains low magnetic permeability after cold-working.

CUSTOM FLO 302HQ STAINLESS (UNS S30430)

0.08 C	0.03 S	17.00/19.00 Cr	3.00/4.00 Cu
2.00 Mn	1.00 Si	8.00/10.00 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

A slow work-hardening, austenitic stainless steel. Has been used for severe cold-heading applications such as nuts and recessed headed fasteners. Resistant to atmospheric corrosion and a wide variety of inorganic chemicals. Non-hardenable by heat-treating.

CARPENTER STAINLESS NO. 10 (TYPE 384)

0.08 C	0.045 P	1.00 Si	17.00/19.00 Ni
2.00 Mn	0.030 S	15.00/17.00 Cr	Bal. Fe

(single figures are maximums)

Modified austenitic, chrome-nickel steel with exceptionally slow work-hardening and good corrosion resistance. Has been used for cold-headed and upset parts.

CARPENTER STAINLESS TYPE 410 (UNS S41000)

0.15 C	0.040 P	1.00 Si	Bal. Fe
1.00 Mn	0.030 S	11.50/13.00 Cr	

(single figures are maximums)

Hardenable martensitic stainless alloy used for highly stressed parts needing good corrosion resistance and strength. Can be heat-treated to obtain high-strength properties with good ductility.

CARPENTER STAINLESS TYPE 430 (UNS S43000)

0.12 C	0.04 P	1.00 Si	Bal. Fe
1.00 Mn	0.03 S	16.00/18.00 Cr	

(single figures are maximums)

Corrosion- and heat-resisting chrome steel. Has been useful for many types of decorative trim. Hardness can be moderately increased by cold-working, but the alloy cannot be hardened by heat-treating.

TRIMRITE® STAINLESS (UNS S42010)

0.15/0.30 C	0.03 S	13.50/15.00 Cr	0.40/1.00 Mo
1.0 Mn	1.0 Si	0.25/1.00 Ni	Bal. Fe
0.04 P			

(single figures are maximums)

Quench-hardenable stainless steel with hardness capability of Type 420, but with superior corrosion resistance and ductility. Has been used for self-drilling, self-tapping fasteners, cutlery and valve shafts.

TRINAMET® STAINLESS

Refer to High-Strength Grades on page 10.

TYPE 409CB STAINLESS (U.S. PATENT NO. 5,707, 586) (UNS S40940)

0.06 C	0.04 S	10.50/11.75 Cr	10xC min/0.75% Cb
1.00 Mn	1.00 Si	0.50 Ni	Bal. Fe
0.045 P			

(single figures are maximums)

This alloy has been extensively used in the automotive industry for muffler hangers and brackets, antenna wire, catalytic converter weld wire and in oxygen sensor components.

Some grades may require the purchase of a minimum heat lot quantity.

Heat Resisting Grades

TYPE 309 STAINLESS (UNS S30900)

0.20 C	0.045 P	1.00 Si	12.00/15.00 Ni
2.00 Mn	0.030 S	22.00/24.00 Cr	Bal. Fe

(single figures are maximums)

An austenitic chromium-nickel alloy that is a modification of Type 304 stainless. It has superior heat-resisting characteristics, slightly better corrosion resistance and improved creep strength. Has been used for furnace parts, fire box sheets, high-temperature containers and weld wire.

TYPE 310 STAINLESS (UNS S31000)

0.25 C	0.045 P	1.50 Si	19.00/22.00 Ni
2.00 Mn	0.030 S	24.00/26.00 Cr	Bal. Fe

(single figures are maximums)

An austenitic chromium-nickel stainless steel having excellent oxidation resistance superior to Type 309. Resists temperature up to 2100°F (1140°C) in continuous service, and provides good resistance to carburizing and reducing environments.

TYPE 330 STAINLESS

0.08 C	0.030 P	18/19 Cr	0.75 Mo
1.0/2.0 Mn	0.005 S	34.5/36.0 Ni	Bal. Fe
0.75/1.25 Si			

(single figures are maximums)

Austenitic, non-hardenable, heat- and corrosion-resistant alloy, weldable and machinable. Has good resistance to carburization, thermal shock and high-temperature oxidation.

TYPE 446 STAINLESS

0.20 C	0.04 P	1.00 Si	0.25 N
1.50 Mn	0.03 S	23.00/27.00 Cr	Bal. Fe

(single figures are maximums)

Non-hardenable, chromium steel with good resistance to corrosion and oxidation at high temperatures where stress conditions are low. Has been used for furnace parts, kiln linings and annealing boxes.

High Strength Grades

Conventionally-Hardened Grades

CARPENTER STAINLESS TYPE 410 (UNS S41000)

0.15 C	0.040 P	1.00 Si	Bal. Fe
1.00 Mn	0.30 S	11.50/13.00 Cr	

(single figures are maximums)

Hardenable martensitic stainless alloy used for highly stressed parts needing good corrosion resistance and strength. Can be heat-treated to obtain high-strength properties with good ductility.

CARPENTER STAINLESS TYPE 416 (UNS S41600)

0.15 C	0.06 P	1.00 Si	Bal. Fe
1.25 Mn	0.15 S min.	12.00/14.00 Cr	

(single figures are maximums)

The original free-machining version of Type 410 stainless. Provides quenched hardness capability between that of Project 70+® Type 416 stainless and Type 416 BQ stainless.

CARPENTER STAINLESS TYPE 416BQ (NO. 5 BQ) (UNS S41600)

0.15 C	0.06 P	1.00 Si	Bal. Fe
1.25 Mn	0.15 S min.	12.00/14.00 Cr	

(single figures are maximums)

A balanced version of standard Type 416 stainless capable of producing a minimum hardness of Rockwell C 40 when bright hardened. Can be cut rapidly and cleanly with regular metal-cutting tools.

CARPENTER STAINLESS TYPE 420 (UNS S42000)

0.15 C	0.04 P	1.00 Si	Bal. Fe
1.00 Mn	0.03 S	12.00/14.00 Cr	

(single figures are maximums)

Type 420 is a hardenable 12% chrome steel with higher strength, hardness and wear resistance than Type 410. Has been used for cutlery, surgical instruments, magnets, molds, shafts, valves and many other products.

Some grades may require the purchase of a minimum heat lot quantity.

CARPENTER STAINLESS TYPE 420F (UNS S42020)

0.15 C min.	0.06 P	1.00 Si	0.60 Mo
1.25 Mn	0.15 S min.	12.00/14.00 Cr	Bal. Fe

(single figures are maximums)

This free-machining version of Type 420 is a hardenable 12% chrome steel with higher strength, hardness and wear resistance than Type 410.

CARPENTER STAINLESS TYPE 431 (UNS S43100)

0.20 C	0.04 P	1.00 Si	1.25/2.50 Ni
1.00 Mn	0.03 S	15.00/17.00 Cr	Bal. Fe

(single figures are maximums)

Provides improved corrosion resistance and toughness (impact strength) in a quench-hardenable stainless steel. Has been used for fasteners and fittings, structural components exposed to marine atmosphere and for highly stressed aircraft components.

TRIMRITE® STAINLESS (UNS S42010)

0.15/0.30 C	0.03 S	13.50/15.00 Cr	0.40/1.00 Mo
1.00 Mn	1.00 Si	0.25/1.00 Ni	Bal. Fe
0.04 P			

(single figures are maximums)

Quench-hardenable stainless steel with hardness capability of Type 420, but with superior corrosion resistance and ductility. Has been used for self-drilling, self-tapping fasteners, cutlery and valves shafts.

TRINAMET® STAINLESS

0.30 C	0.040 P	1.00 Si	1.00/3.00 Mo
1.00 Mn	0.030 S	12.00/14.00 Cr	Bal. Fe
		2.00/3.00 Cu	

(single figures are maximums)

A hardenable martensitic stainless steel that combines a high level of corrosion resistance with good cold formability and a hardness up to 53 HRC. The alloy can be hot worked, cold worked, machined and heat-treated using the same equipment and methods used for Type 410 stainless steel. May be considered for fastener applications including sheet metal screws, self-drilling construction fasteners, and other various bolts and fasteners exposed to atmospheric conditions.

CARPENTER STAINLESS TYPE 440A (UNS S44002)

0.60/0.75 C	0.04 P	1.00 Si	0.75 Mo
1.00 Mn	0.03 S	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

High-carbon chromium steel. Provides stainless properties with excellent hardness. Attains a hardness of Rockwell C 56 and maximum toughness when heat-treated.

CARPENTER STAINLESS TYPE 440B

0.75/0.95 C	0.040 P	1.00 Si	0.75 Mo
1.00 Mn	0.030 S	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

This high-carbon chromium steel attains hardness of Rockwell C58 when heat-treated. Has been used for cutlery, hardened balls and similar parts.

CARPENTER STAINLESS TYPE 440C (UNS S44004)

0.95/1.20 C	0.040 P	1.00 Si	0.75 Mo
1.00 Mn	0.030 S	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

Capable of attaining very high hardness; approximately Rockwell C 59. Provides good corrosion resistance. This stainless principally has been used in bearing assemblies, including bearing balls and races.

MICRO-MELT® 440C ALLOY (UNS S44004)

0.95/1.20 C	0.040 Ph	1.00 Si	0.75 Mo
1.00 Mn	0.030 S	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

A powder metallurgy version of T440C cast/wrought alloy possessing a refined microstructure consisting of a uniform distribution of small carbides and a fine grain size. Possesses improved hardness capability, machinability and galling resistance compared with cast-wrought 440C alloy.

MICRO-MELT 440-XH® ALLOY (U.S. PATENT NO. 5,370,750)

1.60 C	0.40 Si	0.35 Ni	0.45 V
0.50 Mn	16.00 Cr	0.80 Mo	Bal. Fe

(nominal analysis)

An air hardening, high carbon, high chromium, corrosion resistant alloy that can be described as either a high hardness Type 440C stainless steel or a corrosion resistant D2 tool steel. Possesses corrosion resistance equivalent to Type 440C stainless but can attain a maximum hardness of 64 HRC, approaching that of D2 tool steel.

Some grades may require the purchase of a minimum heat lot quantity.

TYPE 440F-SE STAINLESS (UNS S44020)

0.95/1.20 C	0.040 P	1.00 Si	0.60 Mo
1.25 Mn	0.15 S or Se min.	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

This high-carbon chromium steel is designed to provide stainless properties with maximum hardness; approximately Rockwell C 60 after heat treatment. May be considered for machined parts which require higher hardness values than possible with other free-machining grades.

Carburizing Grades

PYROWEAR® ALLOY 53 (UNS K71040)	Refer to Gear Alloys on page 25.
PYROWEAR® 675 STAINLESS (U.S. PATENT NO. 5,002,729)	Refer to Gear Alloys on page 26.
VIM-VAR 9310 (AISI TYPE 9310) (UNS T51606)	Refer to Gear Alloys on page 26.
VIM-VAR M-50 NIL (UNS K88165)	Refer to Bearing Alloys on page 24.

Nitrogen-Strengthened Grades

CARPENTER STAINLESS TYPE 201 MODIFIED

0.15 C	0.030 S	16.00/18.00 Cr	0.25 N
5.50/7.50 Mn	1.00 Si	3.50/5.50 Ni	Bal. Fe
0.060 P			

(single figures are maximums)

An austenitic stainless that has considerably higher tensile and yield strengths in the annealed condition than Type 301, while being comparable in corrosion resistance. Can be cold worked to high-strength levels. Is non-magnetic as annealed and becomes somewhat magnetic after cold work.

CARPENTER TYPE 204-CU STAINLESS

0.15 C	0.060 P	1.50/3.50 Ni	0.05/0.25 N
6.50/9.00 Mn	0.030 S	2.00/4.00 Cu	Bal. Fe
1.00 Si	15.50/17.50 Cr		

(single figures are maximums)

A copper-containing, low-nickel, nitrogen-strengthened, austenitic stainless steel. The nitrogen addition results in higher annealed strength than Type 304; however, the copper addition reduces the work hardening rate to provide cold worked properties similar to Type 304. Is non-magnetic in the annealed condition and remains non-magnetic after cold working. Cold forming characteristics are superior to 200 series stainless steels and similar to Type 304.

CARPENTER 18CR-2NI-12MN STAINLESS (UNS S24100)

0.15 C	0.03 S	16.50/19.00 Cr	0.20/0.45 N
11.00/14.00 Mn	1.00 Si	0.50/2.50 Ni	Bal. Fe
0.06 P			

(single figures are maximums)

Nitrogen-strengthened austenitic stainless steel which provides higher yield and tensile strength than Type 304. Corrosion resistance is between that of Types 430 and 304.

CARPENTER 21CR-6NI-9MN STAINLESS (UNS S21904)

0.03 C	0.03 S	19.00/21.50 Cr	0.15/0.40 N
8.00/10.00 Mn	1.00 Si	5.50/7.50 Ni	Bal. Fe
0.04 P			

(single figures are maximums)

Nitrogen-strengthened austenitic stainless steel with good high-temperature strength and resistance to oxidation. Readily cold formable and weldable.

CARPENTER 22CR-13NI-5MN STAINLESS (UNS S20910)

0.06 C	0.030 S	11.50/13.50 Ni	0.10/0.30 V
4.00/6.00 Mn	1.00 Si	1.50/3.00 Mo	0.20/0.40 N
0.040 P	20.50/23.50 Cr	0.10/0.30 Cb	Bal. Fe

(single figures are maximums)

Nitrogen-strengthened austenitic stainless alloy, superior in corrosion resistance to Type 316, with twice the yield strength. Resists chloride pitting.

SEAFAST® 50 STAINLESS (UNS S20910)

0.06 C	0.030 S	11.50/13.50 Ni	0.10/0.30 V
4.00/6.00 Mn	1.00 Si	1.50/3.00 Mo	0.20/0.40 N
0.040 P	20.50/23.50 Cr	0.10/0.30 Cb + Nb	Bal. Fe

(single figures are maximums)

A nitrogen-strengthened austenitic stainless steel that provides very good corrosion resistance in combination with high strength, toughness and rigidity. The alloy has better corrosion resistance than Type 316 with approximately twice the yield strength. It remains non-magnetic after severe cold work. The alloy has been successfully used for various marine applications including yacht rigging rod for mast stabilization.

Some grades may require the purchase of a minimum heat lot quantity.

25CR-20NI-6MO STAINLESS

0.03 C	0.030 S	23.500/25.50 Ni	0.18/0.25 N
2.00 Mn	1.00 Si	6.00/7.00 Mo	Bal. Fe
0.040 P	20.00/22.00 Cr	0.75 Cu	

(single figures are maximums)

Super-austenitic stainless steel for use in environments where chloride pitting or stress-corrosion cracking is a concern. Higher yield and ultimate tensile strength than conventional austenitic alloys. Has found application in sea water and brackish water environments, and in numerous chemical and allied industrial environments.

7-MO PLUS STAINLESS (UNS S39295)

0.03 C	0.010 S	3.50/5.20 Ni	0.15/0.35 N
2.00 Mn	0.60 Si	1.00/2.50 Mo	Bal. Fe
0.035 P	26.00/29.00 Cr		

(single figures are maximums)

Duplex alloy with austenite distributed within a ferrite matrix. Has good corrosion resistance to oxidizing media such as nitric acid. Chromium and molybdenum impart a high level of resistance to pitting and crevice corrosion. Yield strength more than twice that of Type 316. Not hardenable by heat treatment.

GALL-TOUGH® STAINLESS (UNS S20161)

0.15 C	0.040 S	15.00/18.00 Cr	0.08/0.20 N
4.00/6.00 Mn	3.00/4.00 Si	4.00/6.00 Ni	Bal. Fe
0.040 P			

(single figures are maximums)

A high-silicon, high-manganese, nitrogen-strengthened austenitic stainless steel that possesses superior self-mated galling and metal-to-metal wear resistance. Has higher strength and higher temperature oxidation resistance than Type 304 with comparable corrosion resistance, depending on the environment. May be considered for applications where parts are in relative motion without lubricants, such as chain-link conveyor belts and valve components.

GALL-TOUGH PLUS STAINLESS (U.S. PATENT NO. 5,340,534) (UNS S21800 AND S20162)

0.15 C	0.040 S	6.00/10.00 Ni	0.05/0.25 N
4.00/8.00 Mn	2.50/4.50 Si	0.50/2.50 Mo	Bal. Fe
0.040 P	16.50/21.00 Cr		

(single figures are maximums)

This high-silicon, high-manganese, nitrogen-strengthened, austenitic stainless alloy exhibits superior self-mated galling and metal-to-metal wear resistance. Higher strength and chloride corrosion resistance is equal to or better than Type 316, along with equivalent high-temperature oxidation resistance.

15-15LC® MODIFIED STAINLESS (U.S. PATENT NOS. 5,094,812 AND 5,308,577)

0.04 C nom.	0.05 P	3.00 Ni	0.20/0.80 N
15.00/19.00 Mn	0.05 S	0.50/3.00 Mo	Bal. Fe
1.00 Si	16.00/21.00 Cr		

(single figures are maximums)

Austenitic, nitrogen-strengthened stainless steel that may be considered for oil and gas industry applications such as non-magnetic drill collars. Low carbon content provides improved resistance to intergranular stress-corrosion cracking. A post-machining ID compressive stress treatment for drill collars further improves the resistance to intergranular stress-corrosion cracking. High nitrogen content and warm working results in high yield strength.

15-15HS® STAINLESS (U.S. PATENT NO. 5,094,812)

0.040 C nom.	0.050 P	3.00 Ni	0.50/0.80 N
16.00/19.00 Mn	0.050 S	0.50/3.0 Mo	Bal. Fe
1.00 Si	18.0/21.0 Cr		

(single figures are maximums)

An austenitic, nitrogen-strengthened stainless steel that may be considered for oil and gas industry applications such as non-magnetic drill collars, stabilizers and MWD/LWD housings. Lower carbon content provides improved resistance to intergranular stress-corrosion cracking. Nickel, chromium, nitrogen, manganese and molybdenum are controlled to enhance resistance to transgranular attack, stress-corrosion cracking and pitting. A post-machining ID compressive stress treatment for drill collars further improves resistance to stress-corrosion cracking. Warm working results in higher strength.

15-15HS® MAX STAINLESS (U.S. PATENT NO. 5,094,812)

0.04 C	0.050 P	3.00 Ni	0.50/0.80 N
16.00/19.00 Mn	0.050 S	0.50/3.00 Mo	Bal. Fe
1.00 Si	18.00/21.00 Cr		

(single figures are maximums)

An austenitic, nitrogen-strengthened stainless steel with an improved strength profile and pitting resistance over 15-15HS. Lower carbon content provides improved resistance to intergranular stress-corrosion cracking. Nickel, chromium, nitrogen, manganese and molybdenum are controlled to enhance resistance to transgranular attack, stress-corrosion cracking and pitting. A post-machining ID compressive stress treatment for drill collars further improves resistance to stress-corrosion cracking. Warm working results in higher strength. It can be considered for oil and gas industry applications such as non-magnetic drill collars, stabilizers, and MWD/LWD housings, especially when high strength 140 ksi (966 MPa) minimum yield strength is desired.

Some grades may require the purchase of a minimum heat lot quantity.

SCF 19® ALLOY

0.03 C	0.003 S	18.00 Ni	Bal. Fe
5.00 Mn	0.40 Si	5.00 Mo	
0.025 P	20.00 Cr	0.35 N	

(nominal analysis)

SCF 19® alloy is an austenitic, nitrogen-strengthened stainless steel. Because of its combination of stress-corrosion cracking resistance, high strength and low magnetic permeability, it has been used as a non-magnetic drill collar and MWD/LWD housing alloy.

Precipitation-Hardenable Grades

CARPENTER 15CR-5NI STAINLESS (UNS S15500)

0.07 C	0.03 S	3.50/5.50 Ni	0.15/0.45 Cb + Ta
1.00 Mn	1.00 Si	2.50/4.50 Cu	Bal. Fe
0.04 P	14.00/15.00 Cr		

(single figures are maximums)

A martensitic age-hardenable stainless steel with similar strength and corrosion resistance to that of Custom 630 (17Cr-4Ni) stainless, but with improved forgeability and transverse toughness.

(See page 6 for enhanced machining version of this grade.)

CARPENTER 15-7PH STAINLESS (UNS S15700)

0.09 C	0.03 S	6.50/7.75 Ni	0.75/1.50 Al
1.00 Mn	1.00 Si	2.00/3.00 Mo	Bal. Fe
0.04 P	14.00/16.00 Cr		

(single figures are maximums)

Precipitation hardening stainless that is more easily formed in the annealed condition because of its austenitic structure, but capable of high strength via cold working and/or thermal treatment to a martensitic structure.

CUSTOM 450® STAINLESS (UNS S45000)

0.05 C	0.03 S	5.00/7.00 Ni	8 x C min. Cb
2.00 Mn	1.00 Si	0.50/1.00 Mo	Bal. Fe
0.03 P	14.00/16.00 Cr	1.25/1.75 Cu	

(single figures are maximums)

A martensitic age-hardenable stainless steel combining the very good corrosion resistance characteristics of Type 304 stainless and the moderate strength characteristics of Type 410 stainless. Easy material to fabricate. Can be used in the annealed or hardened condition.

CUSTOM 455® STAINLESS (UNS S45500)

0.05 C	0.030 S	7.50/9.50 Ni	1.50/2.50 Cu
0.50 Mn	0.50 Si	0.80/1.40 Ti	0.50 Mo
0.040 P	11.00/12.50 Cr	0.10/0.50 Cb + Ta	Bal. Fe

(single figures are maximums)

A martensitic age-hardening stainless steel offering higher strength and hardness capability versus Custom 450 stainless. Hardness capability of approximately HRC 50. Good corrosion resistance coupled with ease of fabrication.

CUSTOM 465® STAINLESS (U.S. PATENT NOS. 5,681,528 AND 5,855,844)

0.02 C	0.015 P	10.75/11.25 Ni	1.5/1.8 Ti
0.25 Mn	0.010 S	0.75/1.25 Mo	Bal. Fe
0.25 Si	11.00/12.50 Cr		

(single figures are maximums)

A premium quality high-strength, age-hardening stainless alloy designed for improved notch tensile strength, fracture toughness and fabricability over Custom 455 stainless. Excellent resistance to stress corrosion cracking. In the H 1000 condition, Custom 465 stainless has comparable stress corrosion cracking resistance to Carpenter 13-8 in the H 1050 condition, at a higher strength level.

CUSTOM 475® STAINLESS (U.S. PATENT NO. 6,630,103)

0.015 C	0.010 S	10.50/11.50 Cr	4.50/5.50 Mo
0.50 Mn	0.50 Si	8.00/9.00 Co	1.00/1.50 Al
0.015 P			Bal. Fe

(single figures are maximums)

A premium-melted, high-strength martensitic precipitation-hardenable alloy that provides good corrosion resistance to atmospheric environments. Is capable of the highest strength levels of any commercially available precipitation hardening stainless steel, reaching over 280 ksi without the benefit of strain hardening prior to aging. Higher strength levels are possible if the material is strain hardened prior to aging.

CARPENTER 275 STAINLESS (U.S. PATENT NOS. 5,681,528 AND 5,855,844)

0.02 C	0.010 S	10.75/11.25 Ni	0.15/0.30 Nb
0.25 Mn	0.25 Si	0.75/1.25 Mo	Bal. Fe
0.015 P	11.00/12.50 Cr	1.55/1.80 Ti	

(single figures are maximums)

Carpenter 275 stainless is a premium melted, high-strength martensitic, precipitation-hardenable steel which provides good corrosion resistance to atmospheric environments. The alloy is a modification of Custom 465® stainless designed to provide higher strength and hardness.

Some grades may require the purchase of a minimum heat lot quantity.

CARPENTER STAINLESS CUSTOM 630 (UNS S17400)

0.07 C	0.03 S	3.00/5.00 Ni	0.15/0.45 Cb + Ta
1.00 Mn	1.00 Si	3.00/5.00 Cu	Bal. Fe
0.04 P	15.00/17.50 Cr		

(single figures are maximums)

Martensitic precipitation/age-hardenable stainless alloy offering high strength and hardness, excellent corrosion resistance and good fabricating characteristics.

CARPENTER STAINLESS CUSTOM 631 (17CR-7NI) (UNS S17700)

0.09 C	0.03 S	16.00/18.00 Cr	0.75/1.50 Al
1.00 Mn	1.00 Si	6.50/7.75 Ni	Bal. Fe
0.04 P			

(single figures are maximums)

This precipitation hardening stainless is more easily formed in the annealed condition because of its austenitic structure, but is capable of high strength via cold working and/or thermal treatment to a martensitic structure.

CARPENTER 13-8 STAINLESS (UNS S13800)

0.05 C	0.008 S	7.50/8.50 Ni	0.01 N
0.10 Mn	0.10 Si	0.90/1.35 Al	Bal. Fe
0.01 P	12.25/13.25 Cr	2.00/2.50 Mo	

(single figures are maximums)

A martensitic precipitation/age-hardening stainless steel capable of high strength and hardness along with good levels of resistance to both general corrosion and stress-corrosion cracking. Generally, this alloy may be considered where high strength, toughness, corrosion resistance and resistance to stress-corrosion cracking are required in a steel showing minimal directionality in properties.

ALLOY A-286 (AISI NO. 660) (DIN-1.4980) (UNS S66286)

0.08 C	13.50/16.00 Cr	1.90/2.30 Ti	0.003/0.010 B
2.00 Mn	24.00/27.00 Ni	0.10/0.50 V	Bal. Fe
1.00 Si	1.00/1.50 Mo	0.35 Al	

(single figures are maximums)

Iron-base austenitic stainless steel that has notched rupture strength superior to any other alloy with comparable high-temperature properties. Can be precipitation hardened and strengthened by heat treatment. Good for service at temperatures to 1300°F (704°C). Has been used for numerous jet engine applications. Non-magnetic.

PYROMET ALLOY 350® (UNS S35000)

0.07/0.11 C	0.03 S	4.00/5.00 Ni	0.07/0.13 N
0.50/1.25 Mn	0.50 Si	2.50/3.25 Mo	Bal. Fe
0.04 P	16.00/17.00 Cr		

(single figures are maximums)

Chromium-nickel-molybdenum stainless alloy hardenable by martensitic transformation and precipitation hardening. Offers superior corrosion resistance to other quench-hardenable martensitic stainless steels. Good high-temperature strength.

PYROMET ALLOY 355 (UNS S35500)

0.10/0.15 C	0.03 S	4.00/5.00 Ni	0.07/0.13 N
0.50/1.25 Mn	0.50 Si	2.50/3.25 Mo	Bal. Fe
0.04 P	15.00/16.00 Cr		

(single figures are maximums)

Chromium-nickel-molybdenum stainless alloy hardenable by martensitic transformation and precipitation hardening. Has been used for parts requiring high strength at moderately elevated temperatures. Offers good resistance to atmospheric corrosion and to a number of other mild chemical environments.

SUPERIOR CORROSION RESISTANT ALLOYS

Some environments require corrosion resistance greater than that provided by the conventional stainless steels. By adding or increasing the levels of elements such as nickel, molybdenum, copper, cobalt or chromium, Carpenter is able to produce these highly alloyed materials with superior corrosion resistance for use in a wide variety of applications, including chemical processing and oil field environments.

CARPENTER ALLOY 925 (UNS N09925)

0.03 C	0.030 S	1.50/3.00 Cu	0.50 Cb + Nb
1.00 Mn	38.00/46.00 Ni	2.50/3.50 Mo	0.10/0.50 Al
0.50 Si	19.50/23.50 Cr	1.90/2.40 Ti	22.00 Fe (min.)

single figures are maximums except where noted)

An age-hardenable nickel-iron-chromium alloy designed to resist corrosion while providing high strength. Provides excellent resistance to stress-corrosion cracking, pitting and crevice corrosion, and oxidizing and reducing environments. Applications that may be considered include down-hole and surface gas well components, shafting products and fasteners.

Some grades may require the purchase of a minimum heat lot quantity.

20CB-3® STAINLESS (UNS N08020)

0.06 C	0.035 S	32.50/35.00 Ni	8 x C min./1.00
2.00 Mn	1.00 Si	2.00/3.00 Mo	max. Cb + Ta
0.035 P	19.00/21.00 Cr	3.00/4.00 Cu	Bal. Fe

(single figures are maximums)

An austenitic stainless steel with excellent resistance to hot sulfuric acid and many aggressive environments which readily attack Type 316 stainless. Excellent resistance to stress-corrosion cracking. Weldable, machinable and cold formable.

20MO-6 HS STAINLESS (U.S. PATENT NO. 4,201,575) (UNS N08036)

0.06 C	0.03 S	22.00/26.00 Cr	1.00/3.00 Cu
1.00 Mn	0.50 Si	33.00/37.00 Ni	Bal. Fe
0.03 P	0.17/0.40 N	5.00/6.70 Mo	

(single figures are maximums)

A 6% Mo austenitic stainless alloy possessing a unique combination of corrosion resistance and ultra-high tensile strength capability (up to 280 ksi [1930 MPa]) with good ductility. This alloy is the result of compositional and processing modifications made to 20Mo-6 stainless for enhanced work hardening response. The HS grade achieves high strength through cold work, not by heat treatment. In the cold-worked condition, 20Mo-6 HS stainless retains excellent resistance to environmental cracking and chloride-induced pitting and crevice corrosion while remaining non-magnetic.

22CR-13NI-5MN STAINLESS (UNS S20910)

0.06 C	0.030 S	11.50/13.50 Ni.	0.10/0.30 V
4.00/6.00 Mn	1.00 Si	1.50/3.00 Mo	0.20/0.40 N
0.040 P	20.50/23.50 Cr	0.10/0.30 Cb	Bal. Fe

(single figures are maximums)

A nitrogen-strengthened, austenitic stainless alloy, superior in corrosion resistance to Type 316, with twice the yield strength. Resists chloride pitting.

SEAFAST® 50 STAINLESS (UNS S20910)

0.06 C	0.030 S	11.50/13.50 Ni	0.10/0.30 V
4.00/6.00 Mn	1.00 Si	1.50/3.00 Mo	0.20/0.40 N
0.040 P	20.50/23.50 Cr	0.10/0.30 Cb + Nb	Bal. Fe

(single figures are maximums)

A nitrogen-strengthened austenitic stainless steel that provides very good corrosion resistance in combination with high strength, toughness and rigidity. The alloy has better corrosion resistance than Type 316 with approximately twice the yield strength. It remains non-magnetic after severe cold work. The alloy has been successfully used for various marine applications including yacht rigging rod for mast stabilization.

25NI-20CR-6MO STAINLESS

0.03 C	0.030 S	23.500/25.50 Ni	0.18/0.25 N
2.00 Mn	1.00 Si	6.00/7.00 Mo	Bal. Fe
0.040 P	20.00/22.00 Cr	0.75 Cu	

(single figures are maximums)

Super-austenitic stainless steel for use in environments where chloride pitting or stress-corrosion cracking is a concern. Higher yield and ultimate tensile strength than conventional austenitic alloys. Has found application in sea water and brackish water environments, and in numerous chemical and allied industrial environments.

CARPENTER ALLOY C-276 (UNS N10276)

0.02 C	0.030 P	15.00/17.00 Mo	2.50 Co
1.00 Mn	0.030 S	0.35 V	4.00/7.00 Fe
0.080 Si	14.50/16.50 Cr	3.00/4.50 W	Bal. Ni

(single figures are maximums)

Exceptional corrosion resistance to a wide variety of chemical processing environments including strong reducing environments, chloride-contaminated media, chlorine and sea water. Excellent resistance to pitting and stress-corrosion cracking.

CUSTOM AGE 625 PLUS® ALLOY (U.S. PATENT NO. 5,556,594) (UNS N07716)

0.03 C	0.010 S	59.00/63.00 Ni	1.00/1.60 Ti
0.20 Mn	0.20 Si	7.00/9.50 Mo	0.35 Al
0.015 P	19.00/22.00 Cr	2.75/4.00 Cb	Bal. Fe

(single figures are maximums)

This precipitation-hardenable, nickel-base alloy provides high levels of strength while maintaining corrosion resistance, even in applications where large-section size or intricate shape precludes warm or cold working. Offers exceptional resistance to pitting, crevice and general corrosion, as well as stress-corrosion cracking in the age-hardened (high-strength) condition. Capable of yield strength up to 260 ksi (1793 MPa) with cold work and age.

7-MO PLUS STAINLESS (UNS S39295)

0.03 C	0.010 S	3.50/5.20 Ni	0.15/0.35 N
2.00 Mn	0.60 Si	1.00/2.50 Mo	Bal. Fe
0.035 P	26.00/29.00 Cr		

(single figures are maximums)

Duplex alloy with austenite distributed within a ferrite matrix. Has good corrosion resistance to oxidizing media such as nitric acid. Chromium and molybdenum impart a high level of resistance to pitting and crevice corrosion. Not hardenable by heat treatment.

CARPENTER

Some grades may require the purchase of a minimum heat lot quantity.

DUPLEX ALLOY 255 (UNS S32550)

0.04 C	0.030 S	4.50/6.50 Ni.	0.10/0.25 N
1.50 Mn	1.00 Si	2.90/3.90 Mo	Bal. Fe
0.04 P	24.00/27.00 Cr	1.50/2.50 Cu	

(single figures are maximums)

A duplex alloy with austenite distributed within a ferrite matrix. Good general corrosion resistance to a variety of media, with a high level of resistance to chloride pitting and stress-corrosion cracking. Useful service limited to 500°F (260°C) maximum.

CARPENTER L-605 ALLOY (UNS R30605)

0.05/0.15 C	0.030 P	9.00/11.00 Ni	3.00 Fe
1.00/2.00 Mn	0.3 S	14.00/16.00 W	Bal. Co
0.040 Si	19.00/21.00 Cr		

(single figures are maximums)

A non-magnetic, solid-solution strengthened cobalt-base alloy that has good oxidation-corrosion resistance as well as high strength at elevated temperatures. Has been used for gas turbine rotors, nozzle diaphragm valves, springs, etc.

MP35N ALLOY (Registered trademark of SPS Technologies) (UNS R30035)

0.025 C	0.015 P	33.00/37.00 Ni	1.00 Fe
0.15 Mn	0.010 S	9.00/10.50 Mo	0.010 B
0.15 Si	19.00/21.00 Cr	1.00 Ti	Bal. Co

(single figures are maximums)

A non-magnetic, nickel-cobalt-chromium-molybdenum alloy with a unique combination of properties, including strength to 300 ksi (2068 MPa), good ductility and toughness, and excellent corrosion resistance. Properties are developed by work-hardening and aging. When used in work-hardened-plus-aged condition, service temperatures up to 750°F (400°C) are suggested.

PYROMET® ALLOY 625 (UNS N06625)

0.10 C	0.50 Si	5.00 Fe	3.15/4.15 Cb + Ta
0.50 Mn	20.00/23.00 Cr	0.40 Ti	0.40 Al
0.015 P	8.00/10.00 Mo	1.00 Co	Bal. Ni
0.015 S			

(single figures are maximums)

Solid-solution strengthened nickel-base alloy that exhibits outstanding strength and toughness from cryogenic to 2000°F (1093°C) temperature range. Has excellent fatigue strength and stress-corrosion cracking resistance to chloride ions. Has been used for gas turbine engine components, furnace hardware, chemical plant hardware, and sour brine applications.

PYROMET ALLOY 718 (UNS N07718)

0.10 C	0.015 S	4.75/5.50 Cb + Ta	0.001/0.006 B
0.35 Mn	17.00/21.00 Cr	0.65/1.15 Ti	0.15 Cu
0.35 Si	50.00/55.00 Ni+Co	0.35/0.85 Al	Bal. Fe
0.015 P	2.80/3.30 Mo		

(single figures are maximums)

A precipitation-hardened, nickel-base alloy designed to display exceptionally high yield, tensile and creep-rupture properties up to 1300°F (704°C). Has been used for jet engine and high-speed airframe parts such as wheels, buckets, and spacers, and high-temperature bolts and fasteners. Also has been used in oil and gas exploration and completion.

CARPENTER NICKEL-COPPER 400 (UNS N04400)

0.2 C	0.5 Si	63.0/70.0 Ni	Bal. Cu
2.0 Mn	0.015 S	2.50 Fe	

(single figures are maximums)

A nickel-copper solid-solution alloy that has been used up to 800°F (427°C) in a variety of applications, including chemical processing and marine applications. Can be strengthened by cold working.

SCF 19® ALLOY

Refer to Nitrogen-Strengthened Grades on page 13.

ALLOY 2 (AMS 5842) (UNS R30159)

0.04 C max.	0.010 S max.	36.00 Co	0.20 Al
0.20 Mn max.	0.03 B max.	7.00 Mo	9.00 Fe
0.20 Si max.	19.00 Cr	0.50 Cb	
0.020 P max.	25.00 Ni	3.00 Ti	

(weight percent)

A cobalt-base alloy with a unique combination of ultra-high-strength, ductility, corrosion resistance and temperature resistance up to about 1100°F. The alloy is strengthened to ultimate tensile strength levels above 260 ksi by cold working followed by aging.

MICRO-MELT® CCW ALLOY

0.15 C	28.00 Cr	0.80 Ta	0.15 N
1.00 Mn	10.00 Ni	4.50 W	2.00 Fe
1.00 Si	5.50 Mo		

(figures are nominal)

A high wear- and corrosion-resistant cobalt-base alloy produced by Carpenter's Micro-Melt gas atomization powder metallurgy process. Provides a combination of excellent wear and corrosion resistance for a variety of applications. Has been shown to combat the wear and corrosion environment encountered by oil platform structural components.

Some grades may require the purchase of a minimum heat lot quantity.

MEDICAL ALLOYS

Carpenter has supplied the medical industry for many years with specially processed alloys that have been used in medical and surgical devices. Both standard and Micro-Melt® powder metal grades are available. All of these alloys are premium melted to ensure the high degree of cleanness specified for these types of applications.

While the alloys described in this section are medically specific, many other Carpenter specialty steels described throughout this guide have been used in a wide variety of applications in the medical industry.

BIODUR® 108 ALLOY (UNS S29108)

0.08 C max.	0.03 P max.	0.30 Ni max.	0.97 N
23.00 Mn	0.01 S max.	0.70 Mo	Bal. Fe
0.75 Si max.	21.00 Cr	0.25 Cu max.	

(Weight Percent)

An essentially nickel-free austenitic stainless alloy with high nitrogen content to maintain its austenitic structure. The alloy's tensile and fatigue strength are superior to that of Type 316L (ASTM F138), 22Cr-13Ni-5Mn (ASTM F1314) and 734 alloy. Its pitting and crevice corrosion resistance is superior to Type 316L and equivalent to 22Cr-13Ni-5Mn and 734 alloy. Non-magnetic and essentially free of ferrite phase.

BIODUR TYPE 316LS STAINLESS

0.030 C	0.025 P	13.00/15.00 Ni	0.10 N
2.00 Mn	0.010 S	2.25/3.50 Mo*	Bal. Fe
0.75 Si	17.00/19.00 Cr*	0.50 Cu	

(*3.3 x Mo + Cr 26.00)

(single figures are maximums)

A vacuum arc remelted, low carbon, high nickel and molybdenum version of Type 316 that has been used for producing surgical implant devices. The chemistry modifications are designed to maximize the corrosion resistance of this alloy and provide a ferrite-free microstructure. Meets the requirements of ASTM F138 Grade 2, ASTM F139 Grade 2 and ISO 5832-1 Composition D.

BIODUR 22CR-13NI-5MN STAINLESS

0.06 C	1.50/3.00 Mo	0.040 P	0.20/0.40 N
11.50/13.50 Ni	1.00 Si	0.10/0.30 V	20.50/23.50 Cr
4.00/6.00 Mn	0.10/0.30 Cb	0.030 S	

(single figures are maximums)

A nitrogen-strengthened, austenitic stainless steel with superior corrosion resistance to Type 316 with approximately twice the yield strength. ElectroSlag remelted material has been used in medical implant devices.

BIODUR 734 STAINLESS

0.08 C	0.025 P	9.00/11.00 Ni	0.25/0.50 N
2.00/4.25 Mn	0.01 S	2.00/3.00 Mo	0.25/0.80 Cb
0.75 Si	19.50/22.00 Cr	0.25 Cu	

(single figures are maximums)

Nitrogen strengthened, austenitic stainless steel with improved tensile strength, impact strength, fatigue strength, and crevice and pitting corrosion resistance compared with standard Type 316L. Microstructural integrity and cleanness is accomplished through ElectroSlag Remelting. Non-magnetic and essentially free of ferrite. Commonly used in implantable orthopaedic components, such as bone plates, bone screws, and hip and knee replacements typically fabricated by forging and machining.

TRIMRITE® STAINLESS (UNS S42010)

0.15/0.30 C	0.03 S	13.50/15.00 Cr	0.40/1.00 Mo
1.0 Mn	1.0 Si	0.25/1.00 Ni	Bal. Fe
0.04 P			

(single figures are maximums)

A quench-hardenable stainless steel with hardness capability of Type 420, but with superior corrosion resistance and ductility. Has been used in medical and surgical applications for cutting and scraping tools.

CUSTOM 450® STAINLESS (UNS S45000)

0.05 C	0.03 S	5.00/7.00 Ni	8 x C min. Cb
2.00 Mn	1.00 Si	0.50/1.00 Mo	Bal. Fe
0.03 P	14.00/16.00 Cr	1.25/1.75 Cu	

(single figures are maximums)

Martensitic age-hardenable stainless steel combining the very good corrosion resistance characteristics of Type 304 stainless and the moderate strength characteristics of Type 410 stainless. Easy material to fabricate. Can be used in the annealed or hardened condition.

CARPENTER

Some grades may require the purchase of a minimum heat lot quantity.

CUSTOM 455® STAINLESS (UNS S45500)

0.05 C	0.030 S	7.50/9.50 Ni	1.50/2.50 Cu
0.50 Mn	0.50 Si	0.80/1.40 Ti	0.50 Mo
0.040 P	11.00/12.50 Cr	0.10/0.50 Cb + Ta	Bal. Fe

(single figures are maximums)

Martensitic age-hardening stainless steel offering higher strength and hardness capability versus Custom 450 stainless. Hardness capability of approximately HRC 50. Good corrosion resistance coupled with ease of fabrication.

CUSTOM 465® STAINLESS (U.S. PATENT NO. 6,238,455)

0.02 C	0.015 P	10.75/11.25 Ni	1.5/1.8 Ti
0.25 Mn	0.010 S	0.75/1.25 Mo	Bal. Fe
0.25 Si	11.00/12.50 Cr		

(single figures are maximums)

Premium quality high-strength, age-hardening stainless alloy designed for improved notch tensile strength, fracture toughness and fabricability versus Custom 455 stainless. Excellent resistance to stress corrosion cracking. Custom 465 stainless in the H 1000 condition is comparable to Carpenter 13-8 in the H 1050 condition.

CUSTOM 475® STAINLESS (U.S. PATENT NO. 6,630,103)

0.01 C	0.010 S	7.50/8.50 Ni	1.00/1.50 Al
0.50 Mn	0.50 Si	4.50/5.50 Mo	Bal. Fe
0.015 Ph	10.50/11.50 Cr	8.00/9.00 Co	

(single figures are maximums)

A premium-melted, high-strength martensitic precipitation-hardenable alloy that provides good corrosion resistance to atmospheric environments. Capable of the highest strength levels of any commercially available precipitation hardening stainless steel, reaching over 280 ksi without the benefit of strain hardening prior to aging. Higher strength levels are possible if the material is strain hardened prior to aging.

MICRO-MELT® BIODUR® CUSTOM 470 FM ALLOY (U.S. PATENT NO. 6,238,455)

0.02 C (Max.)	0.05 S (Max.)	11.00 Ni	1.65 Ti
0.25 Mn (Max.)	0.25 Si (Max.)	1.00 Mo	Bal. Fe
0.015 P (Max.)	11.75 Cr		

(single figures nominal except where noted)

A powder metallurgy, free-machining version of Custom 465® stainless steel. Offers improved drillability over Custom 465® stainless and Custom 455® stainless. Initial use in medical and surgical applications is in the manufacture of surgical needle wire as a replacement for Custom 455 stainless and Type 420F stainless.

CUSTOM 630 STAINLESS (UNS S17400)

0.07 C	0.03 S	3.00/5.00 Ni	0.15/0.45 Cb + Ta
1.00 Mn	1.00 Si	3.00/5.00 Cu	Bal. Fe
0.04 P	15.00/17.50 Cr		

Martensitic precipitation/age-hardenable stainless alloy offering high strength and hardness, excellent corrosion resistance and good fabricating characteristics.

BIODUR CARPENTER CCM® ALLOY

0.10 C	26.00/30.00 Cr	1.00 Ni	0.75 Fe
1.00 Mn	5.00/7.00 Mo	0.25 N	Bal. Co
1.00 Si			

(single figures are maximums)

A vacuum induction melted and electro-slag remelted non-magnetic cobalt-chromium-molybdenum alloy exhibiting high strength, corrosion resistance and wear resistance. Is a high nitrogen, low carbon, wrought version of ASTM F75 cast alloy. Meets the requirements of ASTM F799, ASTM F1537, ISO 5832-4 and ISO 5832-12. Equivalent to ASTM F 1537 Alloy #1. Has been used in the orthopedic implant industry.

MICRO-MELT® BIODUR CARPENTER CCM ALLOY

0.10 C	26.00/30.00 Cr	1.00 Ni	0.75 Fe
1.00 Mn	5.00/7.00 Mo	0.25 N	Bal. Co
1.00 Si			

(single figures are maximums)

BioDur Carpenter CCM alloy is produced by Carpenter Powder Products' Micro-Melt powder metallurgy process. A vacuum induction melted, powder metal, non-magnetic, cobalt-chromium-molybdenum alloy exhibiting high strength, corrosion resistance and wear resistance. The Micro-Melt version exhibits a more uniform microstructure and finer grain structure after forging than its wrought counterpart. Meets the requirements of ASTM F799, ASTM F1537, ISO 5832-4 and ISO 5832-12. Equivalent to ASTM F 1537 Alloy #1. Has been used in surgical implant devices, including pins and screws.

BIODUR CCM PLUS® ALLOY (U.S. PATENT NO. 5,462,575)

0.20/0.30 C	5.00/7.00 Mo	0.15/0.20 N	Bal. Co
26.00/30.00 Cr			

(single figures are maximums)

High-carbon version of Carpenter CCM alloy produced by Carpenter's Micro-Melt powder metallurgy process. A vacuum induction melted, powder metal, non-magnetic, cobalt-chromium-molybdenum alloy exhibiting high strength, corrosion resistance and wear resistance. Meets the requirements of ASTM F799, ASTM F1537, ISO 5832-4 and ISO 5832-12. Equivalent to ASTM F 1537 Alloy #2. Has been used in surgical implant devices.

Some grades may require the purchase of a minimum heat lot quantity.

REINFORCING BAR ALLOYS

These alloys have been used in concrete structures such as bridges to extend service life.

ENDURAMET® 32 STAINLESS (UNS S24100)

0.15 C	1.00 Si	16.50/19.00 Cr	0.20/0.45 N
11.00/14.00 Mn	0.030 S	0.50/2.50 Ni	Bal. Fe
0.060 P			

(single figures are maximums)

A high-manganese, low-nickel, nitrogen-strengthened austenitic stainless steel. By means of solid solution strengthening, the nitrogen provides significantly higher yield and tensile strength as annealed than conventional austenitic stainless steels such as Type 304 and Type 316, without adversely affecting ductility, corrosion resistance or non-magnetic properties.

ENDURAMET 2205 STAINLESS (UNS S31803)

0.03 C	0.02 S	4.50/6.50 Ni	0.08/0.20 N
2.00 Mn	1.00 Si	2.50/3.50 Mo	Bal. Fe
0.030 P	21.00/23.00 Cr		

(single figures are maximums)

This duplex stainless steel has a microstructure consisting of austenite and ferrite phases. Offers an excellent combination of strength and corrosion resistance. Has twice the annealed yield strength of typical austenitic stainless steels like Type 304 and 316. Possesses good resistance to general corrosion in many acid environments and has excellent resistance to chloride stress corrosion cracking, pitting and crevice corrosion.

ENDURAMET 316LN STAINLESS (UNS S31653)

0.03 C	0.03 S	10.00/14.00 Ni	0.10/0.16 N
2.00 Mn	1.00 Si	2.00/3.00 Mo	Bal. Fe
0.045 P	16.00/18.00 Cr		

(single figures are maximums)

A nitrogen-strengthened version of Type 316L stainless. By means of solid solution strengthening, the nitrogen provides significantly higher yield and tensile strength as annealed than Type 316L without adversely affecting ductility, corrosion resistance or non-magnetic properties.

ENDURAMET 33 STAINLESS (UNS S24000)

0.08 C	0.03 S	17.00 to 19.00 Cr	0.20/0.40 N
12.00/15.00 Mn	1.00 Si	2.50/3.75 Ni	Bal. Fe
0.060 P			

(single figures are maximums)

A high-manganese, nitrogen-strengthened austenitic stainless steel that provides substantially higher yield and tensile strengths than Type 304 and has general corrosion resistance between that of Type 430 and Type 304 stainless. It can be welded, machined and cold worked using the same equipment and methods used for the conventional 300 series austenitic stainless steels. Provides an excellent combination of toughness, ductility, strength, corrosion resistance and fabricability.

AEROSPACE AND HIGH TEMPERATURE ALLOYS

Carpenter aerospace and high-temperature alloys are versatile materials that have been used for components in elevated temperature applications, as well as environments demanding high strength and corrosion resistance.

The alloys in this section are listed according to their maximum service temperatures.

▶ Alloys With Maximum Service Temperatures to 750°F (399°C)

AERMET® 100 ALLOY (U.S. PATENT NOS. 5,087,415 AND 5,268,044) (UNS K92580)

0.23 C	11.10 Ni	13.40 Co	Bal. Fe
3.10 Cr	1.20 Mo		

(nominal analysis)

An alloy providing high hardness and strength combined with exceptional ductility and toughness. This alloy may be considered for aircraft and aerospace structural components requiring high strength, high fracture toughness and exceptional stress corrosion cracking resistance. May be considered for use up to about 800°F (427°C). This alloy is not subject to the same restrictions as AF1410; thus may be considered a substitute.

AERMET 310 ALLOY (U.S. PATENT NO. 5,866,066)

0.25 C	11.0 Ni	15.0 Co	Bal. Fe
2.40 Cr	1.40 Mo		

(nominal analysis)

Possesses higher hardness and strength than AerMet 100 alloy while maintaining exceptional ductility and toughness. At a 310 ksi (2137 MPa) ultimate tensile strength, AerMet 310 exhibits toughness values equivalent to alloys 20 ksi (138 MPa) lower in strength. May be considered as a candidate for use in components requiring high strength, high fracture toughness and exceptional resistance to stress corrosion cracking and fatigue.

AF1410/HIGH CARBON AF1410

0.17 or 0.20 C	0.003 P	14.2/14.40 Co	2.0 Cr
0.10 Mn	0.001 S	1.0 Mo	Bal. Fe
0.10 Si	10/10.30 Ni		

(single figures are maximums)

This alloy is available only in the United States to DOD approved/funded projects. Please contact your nearest Carpenter service center for more details. (AerMet® 100 alloy may be considered as a substitute for AF1410, without restrictions.)

Some grades may require the purchase of a minimum heat lot quantity.

MP35N ALLOY (Registered trademark of SPS Technologies) (UNS R30035)

0.025 C	0.015 P	33.00/37.00 Ni	1.00 Fe
0.15 Mn	0.010 S	9.00/10.50 Mo	0.010 B
0.15 Si	19.00/21.00 Cr	1.00 Ti	Bal. Co

(single figures are maximums)

A non-magnetic, nickel-cobalt-chromium-molybdenum alloy with a unique combination of properties, including strength to 300 ksi (2068 MPa), good ductility and toughness, and excellent corrosion resistance. Properties are developed by work-hardening and aging. When used in work-hardened-plus-aged condition, service temperatures up to 750°F (399°C) are suggested.

CARPENTER FERRIUM S53* ALLOY

0.20 C	5.50 Ni	1.00 W	0.30 V
10.00 Cr	2.00 Mo	14.00 Co	Bal. Fe

(figures are nominal)

A corrosion resistant, ultrahigh-strength steel for structural aerospace applications. Possesses mechanical properties equal to or better than conventional ultrahigh-strength steels such as 300M and SAE 4340 with the added benefit of general corrosion resistance. Has improved resistance to stress-corrosion cracking over 300M and SAE 4340.

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▸ Alloys With Maximum Service Temperatures between 750 and 1000°F (399 and 538°C)

CONSUMET® H-46 ALLOY

0.15/0.20 C	10.00/14.00 Cr	0.20/0.40 V	0.04/0.10 N
0.50/0.80 Mn	0.30/0.60 Ni	0.20/0.60 Cb & Ta	Bal. Fe
0.20/0.60 Si	0.50/1.00 Mo		

(single figures are maximums)

Ferritic 12% chromium steel for high-strength applications, exhibiting low thermal expansion. Has been used for jet aircraft engine compressor blades and rotor discs in the 900/1200°F (482/649°) range.

CARPENTER C-276 ALLOY (UNS N10276)

Refer to Superior Corrosion Resistant Alloys on page 15.

CUSTOM AGE 625 PLUS® ALLOY (U.S. PATENT NO. 5,556,594) (UNS N07716)

0.03 C	0.010 S	59.00/63.00 Ni	1.00/1.60 Ti
0.20 Mn	0.20 Si	7.00/9.50 Mo	0.35 Al
0.015 P	19.00/22.00 Cr	2.75/4.00 Cb	Bal. Fe

(single figures are maximums)

This precipitation-hardenable, nickel-base alloy provides high levels of strength while maintaining corrosion resistance, even in applications where large-section size or intricate shape precludes warm or cold working. Offers exceptional resistance to pitting, crevice and general corrosion, as well as stress-corrosion cracking in the age-hardened (high-strength) condition. Capable of yield strength up to 260 ksi (1793 MPa) with cold work and age.

ALLOY 2 (AMS 5842) (UNS R30159)

Refer to Superior Corrosion Resistant Alloys on page 16.

▸ Alloys With Maximum Service Temperatures between 1000 and 1250°F (539 and 677°C)

PYROMET® ALLOY A-286 (AISI NO. 660) (UNS K66286)

0.08 C	13.50/16.00 Cr	1.90/2.30 Ti	0.003/0.010 B
2.00 Mn	24.00/27.00 Ni	0.10/0.50 V	Bal. Fe
1.00 Si	1.00/1.50 Mo	0.35 Al	

(single figures are maximums)

Iron-base austenitic alloy that has notched rupture strength superior to any other alloy with comparable high-temperature properties. Can be precipitation hardened and strengthened by heat treatment. Good for service at temperatures to 1300°F (704°C). Has been used for numerous jet engine applications.

PYROMET ALLOY 718 (UNS N07718)

0.10 C	0.015 S	2.80/3.30 Mo	0.001/0.006 B
0.35 Mn	17.00/21.00 Cr	4.75/5.50 Cb + Ta	0.15 Cu
0.35 Si	50.00/55.00 Ni + Co	0.65/1.15 Ti	Bal. Fe
0.015 P		0.35/0.85 Al	

(single figures are maximums)

Precipitation-hardened, nickel-base alloy designed to display exceptional alloy high-yield, tensile and creep-rupture properties up to 1300°F (704°C). Has been used for jet engine and high-speed airframe parts such as wheels, buckets, spacers, and high-temperature bolts and fasteners. Also has been used in oil and gas exploration and completion.

636 ALLOY (TYPE 422) (AISI NO. 616) (UNS S42200)

0.20/0.25 C	0.04 P	0.50/1.00 Ni	0.20/0.50 V
1.00 Mn	0.03 S	0.75/1.25 Mo	Bal. Fe
1.00 Si	11.50/13.50 Cr	0.75/1.25 W	

(single figures are maximums)

Hardenable stainless designed for service to 1200°F (649°C). Good resistance to scaling and oxidation in continuous service at temperatures to 1400°F (760°C). Has been used for compressor and steam turbine buckets and blades.

Some grades may require the purchase of a minimum heat lot quantity.

AMS 5616 ALLOY (GREEK ASCOLOY) (AISI NO. 615) (UNS S41800)

0.15/0.20 C	0.03 P	1.80/2.20 Ni	2.50/3.50 W
0.50 Mn	0.03 S	0.50 Mo	Bal. Fe
0.50 Si	12.00/14.00 Cr		

(single figures are maximums)

This martensitic alloy is designed for service at temperatures to 1200°F (649°C) in highly stressed parts. Capable of extreme deep hardening.

LAPELLOY "C" ALLOY

0.20/0.25 C	0.03 P	0.50 Ni	0.06/0.10 N
0.65 /1.00 Mn	0.03 S	2.50/3.00 Mo	Bal. Fe
0.50 Si	11.00/12.00 Cr	1.75/2.25 Cu	

(nominal analysis)

Alloy possessing good resistance to scaling and oxidation for continuous service up to 1400°F (760°C). High mechanical properties can be developed by heat treatment. Has been used for compressor wheels, turbine shafts, compressor buckets, blades and bolts.

MOLY ASCOLOY (UNS K64152)

0.08/0.15 C	0.025 P	2.00/3.00 Ni	0.01/0.05 N
0.50/0.90 Mn	0.025 S	1.50/2.00 Mo	Bal. Fe
0.35 Si	11.00/12.50 Cr	0.25/0.40 V	

(single figures are maximums)

Hardenable martensitic, easily machined stainless steel often used for steam turbine components and compressor parts in gas turbines involving service temperatures to 1200°F (649°C).

PYROMET® ALLOY 800

0.10 C	0.03 P	32.00/34.00 Ni	0.50/0.60 Ti
0.70/1.00 Mn	0.02 S	0.15/0.60 Al	Bal. Fe
0.40/0.75 Si	20.00/22.00 Cr		

(single figures are maximums)

A corrosion- and oxidation-resistant alloy with high strength that also resists carburization. It is suggested elevated temperature applications be held to temperatures below 1200°F (649°C). This alloy is not appropriate for any application requiring resistance to creep rupture.

PYROMET ALLOY CTX-3 (UNS N11907)

0.05 C	0.015 S	13.00/15.00 Co	0.25 Al
0.50 Mn	0.50 Cr	4.50/5.50 Cb + Ta	0.012 B
0.50 Si	37.00/39.00 Ni	1.25/1.75 Ti	Bal. Fe
0.015 P	0.50 Cu		

(single figures are maximums)

A low-expansion, high-strength, precipitation-hardenable superalloy. Offers significant improvement in notched stress rupture strength over Pyromet alloy CTX-1. Has been used for gas turbine engine components. This alloy requires a protective coating if exposed to atmospheric conditions above 1000°F (538°C).

PYROMET ALLOY CTX-909 (UNS N11909)

0.06 C	0.015 S	1.60 nom. Ti	0.50 Cu
0.50 Mn	0.50 Cr	4.90 nom. Cb + Ta	0.012 B
0.40 nom. Si	38.00 nom. Ni	0.15 Al	Bal. Fe
0.015 P	14.00 nom. Co		

(single figures are maximums)

A high-strength, precipitation-hardenable superalloy which exhibits a low and relatively constant coefficient of thermal expansion over a broad temperature range, high hot hardness and good thermal fatigue resistance. Offers significant improvement over Pyromet Alloys CTX-1 and CTX-3 due to its excellent combination of tensile properties and stress rupture strength to 1200°F (649°C) in the recrystallized condition combined with the use of common age hardening treatments. This alloy requires a protective coating if exposed to atmospheric conditions above 1000°F (538°C).

THERMO-SPAN® ALLOY (U.S. PATENT NO. 5,283,032)

0.05 C	0.015 S	0.80 Ti	0.50 Cu
0.50 Mn	5.50 Cr	4.80 Cb	0.01 B
0.30 Si	25.00 Ni	0.50 Al	Bal. Fe
0.015 P	29.00 Co		

(nominal analysis)

Precipitation hardenable superalloy exhibiting a low coefficient of thermal expansion over a broad temperature range, high tensile and rupture strengths, and good thermal fatigue resistance. Significant improvement in environmental resistance over CTX alloys due to chromium addition. Excellent combination of tensile properties and stress rupture strength in the recrystallized condition with the use of common solution and age hardening treatments. May be considered for use in all applications for which the current low expansion superalloys are suited, including compressor and exhaust casings, seals and other gas turbine engine components.

Some grades may require the purchase of a minimum heat lot quantity.

PYROMET® ALLOY 706 (UNS N09706)

0.06 C	0.020 P	39.00/44.00 Ni	0.40 Al
0.35 Mn	0.015 S	2.50/3.30 Cb + Ta	0.006 B
0.35 Si	14.50/17.50 Cr	1.50/2.00 Ti	0.30 Cu
			Bal. Fe

(single figures are maximums)

Precipitation-hardenable nickel-base alloy with high strength from cryogenic temperatures to about 1200°F (650°C). Has similar characteristics to those of Alloy 718 but has improved fabricability and can be processed into larger ingots and forgings than other superalloys. Has been used for a variety of applications that require high elevated-temperature strength in larger section sizes along with good fabricability.

▸ Alloys With Maximum Service Temperatures Between 1250 and 1500°F (677 and 816°C)

PYROMET® ALLOY 720

0.02 C	2.75/3.25 Mo	1.0/1.5 W	0.50 Fe
0.10 Mn	14.0/16.0 Co	0.05 Zr	Bal. Ni
0.10 Si	4.75/5.25 Ti	0.02 B	
15.00/17.00 Cr	2.25/2.75 Al		

(single figures are maximums)

Nickel-base precipitation-hardening superalloy with exceptional mechanical properties at temperatures up to 1650°F (900°C). Has been used for high-strength gas-turbine discs.

PYROMET ALLOY X-750 (AISI NO. 688) (UNS N07750)

0.08 C	0.010 S	2.25/2.70 Ti	0.05 Cu
0.30 Mn	14.0/17.0 Cr	0.40/1.00 Al	5.0/9.0 Fe
0.50 Si	70.00 Ni and Co	0.70/1.20 Cb + Ta	

(single figures are maximums)

Precipitation-hardening alloy, highly resistant to chemical corrosion and oxidation. Has been used as high-temperature structural members for jet engine parts, heat-treating fixtures and forming tools.

PYROMET ALLOY 751

0.04 C	15.00 Cr	6.75 Fe	0.05 Cu
0.70 Mn	0.007 S	2.50 Ti	Bal. Ni
0.30 Si	1.00 Cb	1.20 Al	

(nominal analysis)

High-strength, nickel-base alloy obtaining maximum high-temperature properties through age-hardening. Has been used for diesel truck and locomotive valves.

PYROMET ALLOY 80A (UNS N07080)

0.06 C	20.00 Cr	2.35 Ti	1.00 Co
0.35 Mn	0.007 S	1.25 Al	Bal. Ni
0.35 Si	0.75 Fe	0.05 Cu	

(nominal analysis)

Nickel-base alloy having excellent creep- and oxidation-resistant properties and high resistance to fatigue under critical conditions. Has been used for aircraft gas turbine engine components and diesel engine valves.

PYROMET ALLOY 31V

0.04 C	0.015 S	2.0 Mo	0.90 Cb
0.20 Mn	22.7 Cr	2.3 Ti	0.005 B
0.20 Si	57.0 Ni	1.3 Al	Bal. Fe
0.015 P			

(nominal analysis)

Sulfidation-resistant, precipitation-hardenable superalloy with an unusual combination of corrosion resistance and strength to 1500°F (816°C). Excellent resistance to hot-sulfidation attack. Has been used in truck and locomotive diesel valve service.

PYROMET ALLOY 901 (AISI NO. 681, 682) (UNS N09901)

0.10 C	11.00/14.00 Cr	2.35/3.10 Ti	0.010/0.020 B
1.00 Mn	40.00/45.00 Ni	0.50 Cu	Bal. Fe
0.60 Si	5.00/7.00 Mo	0.35 Al	

(single figures are maximums)

A chromium-nickel-iron-base superalloy combining high strength and good corrosion resistance at elevated temperatures. Has been used for components in aircraft and gas turbines, such as turbine rotors, compressor discs, hubs and shafts.

CARPENTER 286-LNI ALLOY

0.08 C	13.50/16.00 Cr	2.20/2.80 Ti	0.003/0.010 B
2.00 Mn	18.00/20.00 Ni	0.50 Al	Bal. Fe
1.00 Si	1.00 Mo	0.50 V	

(single figures are maximums)

A precipitation hardenable iron-nickel-chromium alloy that may be considered for applications requiring high-strength and good corrosion resistance at temperatures up to 1300°F (704°C). The properties are similar to those of A-286. The alloy is particularly useful in the automotive industry where good corrosion resistance and high-strength at elevated temperatures are required.

Some grades may require the purchase of a minimum heat lot quantity.

Alloys With Service Temperatures Above 1500°F (816°C)

TYPE 330 STAINLESS

0.08 C	0.03 P	18.00/19.00 Cr	0.75 Mo
1.0/2.0 Mn	0.005 S	34.50/36.00 Ni	Bal. Fe
0.75/1.25 Si			

(single figures are maximums)

A stainless steel with good corrosion resistance and ductility. It resists the absorption of carbon and nitrogen, making it an excellent candidate for furnace components. Has been used in low stress applications to temperatures as high as 2250°F (1230°C) and moderate resistance to creep 1600°F (870°C).

CARPENTER L-605 ALLOY (UNS R30605)

Refer to Superior Corrosion Resistant Alloys on page 16.

PYROMET® ALLOY 41 (AISI NO. 683) (UNS N07041)

0.06/0.12 C	18.00/20.00 Cr	3.00/3.30 Ti	5.00 Fe
0.50 Mn	9.00/10.50 Mo	1.40/1.60 Al	Bal. Ni
0.50 Si	10.00/12.00 Co	0.003/0.010 B	

(single figures are maximums)

A nickel-base, precipitation-hardening alloy that exhibits high strength in the 1200/1800°F (649/982°C) temperature range. Has been used in jet engine and high-speed airframe components.

PYROMET ALLOY 600 (UNS N06600)

0.10 C	0.50 Si	14.00/17.00 Cr	0.50 Cu
1.00 Mn	0.015 S	72.00 min. Ni	6.00/10.00 Fe

(single figures are maximums)

Non-magnetic, high-corrosion-resistant and heat-resistant nickel-base alloy. Has excellent combination of high strength, hot and cold workability, and freedom from aging or stress corrosion throughout the range from annealed to heavily cold-worked material.

PYROMET ALLOY 601

0.10 C	0.015 S	21.00/25.00 Cr	58.00/63.00 Ni
1.00 Mn	1.00 Cu	1.00/1.70 Al	Bal. Fe
0.50 Si			

(single figures are maximums)

Non-magnetic, high corrosion- and heat-resistant nickel base alloy possessing good high-temperature strength and corrosion resistance. Has been used in heat treating baskets and fixtures, radiant furnace tubes, thermocouple protection tubes, furnace muffles and retorts.

PYROMET ALLOY 625 (UNS N06625)

Refer to Superior Corrosion Resistant Alloys on page 16.

PYROMET ALLOY 680 (UNS N06002)

0.05/0.15 C	0.040 P	0.50/2.50 Co	17.00/20.00 Fe
1.00 Mn	0.030 S	8.00/10.00 Mo	Bal. Ni
1.00 Si	20.50/23.00 Cr	0.20/1.00 W	

(single figures are maximums)

Non-magnetic heat- and corrosion-resistant material which derives exceptional properties up to 2200°F (1200°C) from solid-solution strengthening. Has been used for gas turbine components and furnace and chemical processing equipment hardware.

WASPALOY [SUPER WASPALOY] (AISI NO. 658) (UNS N07001)

0.03/0.04	19.00/19.50 Cr	2.60/3.25 Ti	0.04/0.06 Zr
(0.02/0.03) C	4.10/4.35 Mo	[3.00/3.25 Ti]	0.003/0.008 B
0.10 Mn	12.00/13.00 Co	1.00/1.50 Al	2.00 Fe
0.10 Si	[13.00/14.00 Co]	[1.45/1.60 Al]	Bal. Ni
0.008 S			

(single figures are maximums)

Precipitation-hardening, nickel-base alloys that have been used for gas turbine engine parts requiring good strength and corrosion resistance to 1600°F (870°C). Carpenter Super Waspaloy has slightly higher room temperature and elevated temperature tensile strength than the standard grade.

BEARING ALLOYS

CARPENTER STAINLESS TYPE 440C (UNS S44004)

Refer to Stainless Steels–Conventionally Hardened Grades on page 10.

MICRO-MELT® 440C ALLOY (UNS S44004)

0.95/1.20 C	0.040 Ph	1.00 Si	0.75 Mo
1.00 Mn	0.030 S	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

Refer to Stainless Steels – Conventionally Hardened Grades on page 10.

Some grades may require the purchase of a minimum heat lot quantity.

MICRO-MELT® M62 ALLOY

1.30 C	0.60 Si	10.50 Mo	6.25 W
0.70 Mn	3.75 Cr	2.00 V	Bal. Fe
0.050 S			

(single figures are maximums)

A high-speed powder metal tool steel capable of reaching hardnesses in excess of HRC 67 without the use of cobalt. Provides performance similar to AISI Type M42 in terms of hot hardness and heat treatment response. Possesses good toughness and excellent abrasion resistance.

MICRO-MELT 440-XH® ALLOY (U.S. PATENT NO. 5,370,750)

Refer to Stainless Steels–Conventionally Hardened Grades on page 10.

PYROWEAR® 675 STAINLESS (U.S. PATENT NO. 5,002,729)

0.07 C	13.00 Cr	1.80 Mo	5.40 Co
0.65 Mn	2.60 Ni	0.60 V	Bal. Fe
0.40 Si			

(nominal analysis)

Carburizing stainless steel with corrosion resistance similar to Type 440C and core fracture toughness equivalent to Type 9310. The maximum use temperature is 675°F (357°C), higher than that of Pyrowear 53 alloy.

VIM-VAR 52100 (AISI TYPE E52100) (UNS G52986)

1.00 C	0.25 Si	1.40 Cr	Bal. Fe
0.30 Mn			

(nominal analysis)

High-carbon, chromium-bearing steel produced by vacuum induction melting followed by vacuum arc remelting. Has met exacting requirements of bearing manufacturers for a clean steel of uniform microstructure. Is deep-hardening and has high wear resistance.

VIM-VAR M-50 (AISI TYPE M-50) (UNS K88165)

0.80 C	0.015 P	0.10 Ni	4.50 Mo
0.25 Mn	0.015 S	1.00 V	Bal. Fe
0.25 Si	4.00 Cr		

(nominal analysis)

Produced by vacuum induction melting followed by vacuum arc remelting. M-50 has excellent resistance to softening at high service temperatures and has been widely used for bearings in aircraft engines.

VIM-VAR M-50 NIL (UNS K88165)

0.13 C	0.25 Si	3.50 Ni	4.25 Mo
0.25 Mn	0.015 S	1.25 V	Bal. Fe
0.015 P	4.00 Cr		

(nominal analysis)

A low-carbon, carburizing, bearing steel produced by vacuum induction melting followed by vacuum arc remelting. M-50 NIL has excellent resistance to softening at high surface temperatures and exhibits superior fracture toughness characteristics. Has been used for bearings in aircraft jet turbine engines.

NICKEL-COPPER ALLOYS

Carpenter nickel-copper alloys combine high strength and toughness over a wide temperature range, with excellent resistance to many corrosive environments. The alloys are readily fabricated and have found use in many fields, particularly marine applications and chemical processing.

CARPENTER NICKEL-COPPER 400

0.2 C	0.5 Si	63.0/70.0 Ni	Bal. Cu
2.0 Mn	0.015 S	2.50 Fe	

(single figures are maximums)

A nickel-copper solid solution alloy which has been used up to 800°F (427°C) in a variety of applications, including chemical processing and marine applications. Alloy can be strengthened by cold working.

HIGH STRENGTH ALLOYS

These Carpenter alloy steels offer a combination of high strength, ductility and toughness often required in applications such as engine shafting and structural components for aircraft.

NO. 882 ALLOY (AISI TYPE H11) (UNS T20811)

0.40 C	0.90 Si	0.45 V	Bal. Fe
0.35 Mn	5.00 Cr	1.35 Mo	

(nominal analysis)

A 5% chromium hot-work tool steel combining a high-level toughness and good red-hardness. It has been widely used as a structural material for critical components in aircraft missiles.

Some grades may require the purchase of a minimum heat lot quantity.

AF1410/HIGH CARBON AF1410

0.17 or 0.20 C	0.003 P	14.2/14.4 Co	2.0 Cr
0.10 Mn	0.001 S	1.0 Mo	Bal. Fe
0.10 Si	10/10.3 Ni		

(single figures are maximums)

This alloy is available only in the United States to DOD-approved/funded projects. Please contact your nearest Carpenter service center for more details.

NIMARK® ALLOY 250

0.03 C	0.01 S	0.3/0.5 Ti	0.003 B
0.10 Mn	18.0/19.0 Ni	0.05/0.15 Al	0.05 Ca
0.10 Si	7.0/8.0 Co	0.03 Zr	Bal. Fe
0.01 P	4.7/5.0 Mo		

(single figures are maximums)

Low-carbon, maraging nickel steel attaining ultrahigh tensile strength by aging at 850/950°F (454/510°C) temperatures. Readily weldable, good ductility.

NIMARK ALLOY 300

0.03 C	0.01 S	0.50/0.80 Ti	0.003 B
0.10 Mn	18.00/19.00 Ni	0.05/0.15 Al	0.05 Ca
0.10 Si	4.70/5.10 Mo	0.030 Zr	Bal. Fe
0.01 P	8.0/9.50 Co		

(single figures are maximums)

This low-carbon, nickel maraging alloy attains yield strengths over 270 ksi (1862 MPa) through simple low temperature heat treatment. Excellent notch ductility.

AERMET® 100 ALLOY (U.S. PATENT NO. 5,087,415) (UNS K92580)

0.23 C	11.10 Ni	13.40 Co	Bal. Fe
3.10 Cr	1.20 Mo		

(nominal analysis)

An iron-cobalt-nickel alloy that has been strengthened by carbon, chrome and molybdenum. Is equal in strength to 300M alloy but has increased fracture toughness and stress-corrosion cracking resistance. The improved properties of AerMet 100 alloy are expected to provide greater reliability and weight-saving advantages in aircraft landing and arresting gear components.

AERMET 310 ALLOY (U.S. PATENT NO.5,866,066)

0.25 C	11.0 Ni	15.0 Co	Bal. Fe
2.40 Cr	1.40 Mo		

(nominal analysis)

Possesses higher hardness and strength than AerMet 100 alloy while maintaining exceptional ductility and toughness. At a 310 ksi (2137 MPa) ultimate tensile strength, AerMet 310 alloy exhibits toughness values equivalent to alloys 20 ksi (138 MPa) lower in strength. May be considered as a candidate for use in components requiring high strength, high fracture toughness and exceptional resistance to stress corrosion cracking and fatigue.

AERMET 340 ALLOY

0.33 C	12.00 Ni	15.60 Co	Bal. Fe
2.25 Cr	1.85 Mo		

(single figures are nominal)

Possesses high hardness and strength while exhibiting exceptional toughness and ductility. May be considered for use in applications such as structural tubing, structural members, drive shafts, springs, connecting rods and crank shafts.

CARPENTER FERRIUM S53* ALLOY

0.20 C	5.50 Ni	1.00 W	0.30 V
10.00 Cr	2.00 Mo	14.00 Co	Bal. Fe

(figures are nominal)

Refer to Aerospace and High Temperature Alloys on page 20.

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GEAR ALLOYS

Carpenter's premium melting capabilities, including vacuum induction melting and vacuum arc remelting, provide these alloys with the properties necessary to meet the service requirements of gearing applications.

PYROWEAR® ALLOY 53 (UNS K71040)

0.10 C	1.00 Cr	3.25 Mo	0.10 V
0.35 Mn	2.00 Ni	2.00 Cu	Bal. Fe
1.00 Si			

(nominal analysis)

This specially designed carburizing alloy has useful properties at temperatures above the maximum application temperature of Type 9310 alloy.

Some grades may require the purchase of a minimum heat lot quantity.

PYROWEAR 675 STAINLESS (U.S. PATENT NO. 5,002,729)

0.07 C	13.00 Cr	1.80 Mo	5.40 Co
0.65 Mn	2.60 Ni	0.60 V	Bal. Fe
0.40 Si			

(nominal analysis)

Carburizing stainless steel with corrosion resistance similar to Type 440C and core fracture toughness equivalent to Type 9310. The maximum use temperature is 675°F (357°C), higher than that of Pyrowear Alloy 53.

VIM-VAR 9310 (AISI TYPE 9310) (UNS T51606)

0.10 C	0.30 Si	1.0 Cr	Bal. Fe
0.50 Mn	3.50 Ni	0.10 Mo	

(nominal analysis)

A chromium-nickel carburizing steel that has been used for applications requiring an extra measure of core strength in sections up to five inches thick. The steel develops high wear-resistant case characteristics when carburized and hardened. Has been used in very large parts requiring maximum strength, wear resistance and toughness. Applications have included heavy-duty gears, shafts, clutch parts, piston pins, chain rollers and bushings, wrist pins, boring bars, cutting shanks, jig bars, ratchets, power tool cams, rock drill assemblies, balls arbors, broach holders and rolls for aluminum rolling.

VALVE ALLOYS

Valve steels are materials exhibiting excellent high-temperature corrosion resistance, fatigue strength, creep strength and hot hardness. These materials have been designed to withstand the severe conditions encountered within the chambers of internal combustion engines.

21-12N VALVE STEEL (UNS K63017)

0.20 C	0.80 Si	11.50 Ni	Bal. Fe
1.25 Mn	21.00 Cr	0.20 N	

(nominal analysis)

An austenitic nitrogen-bearing, chrome-nickel alloy with excellent high-temperature strength, hardness and corrosion resistance to combustion products. Has been widely used as head material in two-piece exhaust valves.

C-XB ALLOY (UNS K65006)

0.75/0.90 C	1.75/2.60 Si	19.00/21.00 Cr	Bal. Fe
0.80 Mn	0.040 S	1.00/1.70 Ni	

(single figures are maximums)

High-silicon-chromium alloy offering high-temperature strength and good corrosion resistance to combustion products of automotive engines. Has been used for exhaust valves and valve seat inserts.

NCF 3015 ALLOY (Manufactured and sold under license from Hitachi)

0.08 C	0.010 S	30.0/33.5 Ni	0.40/0.90 Cb/Nb
0.50 Mn	0.50 Si	0.40/1.00 Mo	1.60/2.20 Al
0.015 P	13.50/15.50 Cr	2.30/2.90 Ti	Bal. Fe

(single figures are maximums)

A precipitation-hardenable, iron-nickel base alloy with mechanical properties between those of the iron-base and the more costly nickel-base alloys that have been used for engine valve applications. The alloy was designed for high strength and corrosion resistance up to 1400°F (760°C). Can be considered for engine valve applications and as a replacement for nickel-base superalloys in applications involving the need for strength at elevated temperatures.

PYROMET® ALLOY 31V

Refer to Aerospace and High Temperature Alloys on page 22.

PYROMET ALLOY 751

0.04 C	15.00 Cr	6.75 Fe	0.05 Cu
0.70 Mn	0.007 S	2.50 Ti	Bal. Ni
0.30 Si	1.00 Cb	1.20 Al	

(nominal analysis)

High-strength, nickel-base alloy obtaining maximum high-temperature properties through age-hardening. Has been used for diesel truck and locomotive valves.

PYROMET ALLOY 80A (UNS N07080)

Refer to Aerospace and High Temperature Alloys on page 22.

Some grades may require the purchase of a minimum heat lot quantity.

MAGNETIC, CONTROLLED EXPANSION AND ELECTRONIC ALLOYS

The unique, highly specialized characteristics of these alloys demand exact controls be placed on their manufacture. The quality control programs applied in the research, testing and manufacture of Carpenter electronic alloys include AC and DC magnetic testing and expansion testing to maintain consistently high standards of quality and uniformity.

► Soft Magnetic Iron Alloys

ELECTRICAL IRON

0.02 max. C	0.010 P	0.20 Cr	0.05 V
0.12 Mn	0.010 S	0.08 Ni	Bal. Fe
0.12 Si			

(nominal analysis)

Low-carbon iron with good direct current soft magnetic properties after heat treatment. Has been used in electro-mechanical relays, solenoids, magnetic pole and other flux-carrying components.

CONSUMET® ELECTRICAL IRON

0.02 max. C	0.15 max. Si	0.04/0.10 V	Bal. Fe
0.15 max. Mn			

(nominal analysis)

A double-melted, low-carbon iron manufactured under close control to minimize imperfections and nonmetallic inclusions. Has been used for machining into high-vacuum component parts having wall thickness sections as thin as 0.020" which are perpendicular to bar length. Has good DC magnetic properties after heat treatment.

VACUMET® CORE IRON

0.015 max. C	0.05 Si	0.05 Ni	Bal. Fe
0.05 Mn	0.05 Cr		

(nominal analysis)

A premium pure iron capable of providing improved soft magnetic characteristics, superior to Electrical Iron when heat-treated in the same manner as Electrical Iron.

VACUMET CONSUMET CORE IRON

0.015 max. C	0.05 Si	0.05 Ni	Bal. Fe
0.05 Mn	0.05 Cr		

(nominal analysis)

A premium commercial pure iron, double-melted under close control to have a very low degree of nonmetallic inclusions and very soft magnetic property capability after heat-treating as suggested.

► Soft Magnetic Silicon-Iron Alloys

SILICON CORE IRON "A"

0.04 max. C	0.18 P	1.0 Si	Bal. Fe
0.15 Mn			

(nominal analysis)

A magnetic core alloy suggested for applications requiring a higher electrical resistivity than Electrical Iron. The alloy exhibits high initial permeability, and low hysteresis loss in AC and DC circuits.

SILICON CORE IRON "A-FM"

0.04 max. C	1.0 Si	0.18 P	Bal. Fe
0.15 Mn			

(nominal analysis)

Exhibits machining characteristics superior to Silicon Core Iron "A". Up to 40% improvement in machinability has been reported on automatic screw machines with this free-machining alloy.

SILICON CORE IRON "B"

0.03 C	0.15 Mn	2.5 Si	Bal. Fe

(nominal analysis)

Magnetic core alloy with fine-grained, uniform quality and a higher electrical resistivity than Silicon Core Iron "A". Has been widely used in making solenoid switches, pole pieces, relays and similar products.

SILICON CORE IRON "B-FM"

0.03 C	2.5 Si	0.12 P	Bal. Fe
0.40 Mn			

(nominal analysis)

Improved machining characteristics over "B" grade are being obtained by using this modified free-machining alloy with no sacrifice in magnetic properties.

Some grades may require the purchase of a minimum heat lot quantity.

SILICON CORE IRON "B2"

0.02 C	2.0 Si	0.12 P	Bal. Fe
0.30 Mn			

(nominal analysis)

Characteristics are very similar to Silicon Core Iron B-FM except after final treatment, parts have an improved degree of ductility because of the low silicon content. Silicon Core Iron B2 is a free-machining grade.

SILICON CORE IRON "C"

0.03 C	0.15 Mn	4.0 Si	Bal. Fe

(nominal analysis)

For applications requiring maximum electrical resistivity and minimum hysteresis loss in AC and DC circuits. Has been used for producing solenoid switches, relays, pole pieces and cores.

Soft Magnetic Chromium-Iron (Ferritic Stainless) Alloys

CARPENTER STAINLESS TYPE 430FR SOLENOID QUALITY

0.065 C	0.24/0.40 S	17.25/18.25 Cr	0.50 Mo
0.80 Mn	1.00/1.50 Si	0.60 Ni	Bal. Fe
0.03 P			

(single figures are maximums)

Has been used for solenoid valve magnetic core components that must combat corrosion from atmosphere, fresh water and corrosive environments. This grade has a higher electrical resistivity than 430F, which reduces eddy current losses of material.

CHROME CORE® 8 / [CHROME CORE 8-FM] ALLOYS (U.S. PATENT NO. 4,994,122)

0.03 C	0.03 S	0.30/0.70 Si	0.20/0.50 Mo
0.20/0.70 Mn	[0.20/0.40 S]	7.5/8.5 Cr	Bal. Fe
0.030 P			

(single figures are maximums)

A family of controlled chemistry, ferritic chromium-iron alloys that may be considered for use in magnetic components where corrosion resistance superior to that of pure iron, low carbon steel and silicon-iron alloys is desired without the substantial decrease in saturation induction associated with the 18% Cr ferritic stainless steels. Applications could include electromechanical devices requiring some degree of corrosion resistance. Each chrome level is available in both a standard and a free-machining grade.

CHROME CORE 12-FM ALLOY (U.S. PATENT NO. 5,091,024)

0.03 C	0.03 S	0.30/0.70 Si	0.20/0.50 Mo
0.20/0.70 Mn	[0.20/0.40 S]	11.5/12.5 Cr	Bal. Fe
0.030 P			

(single figures are maximums)

Refer to Chrome Core 8 and 8-FM above.

CHROME CORE 13-FM ALLOY

0.03 C	0.030 P	0.70/1.80 Si	0.20/0.50 Mo
0.20/0.70 Mn	0.03 S	12.50/13.50 Cr	Bal. Fe
[0.50/1.20 Mn]	[0.20/0.40 S]		

(single figures are maximums)

Refer to Chrome Core 8 and 8-FM above.

CHROME CORE 13-XP ALLOY (U.S. PATENT PENDING)

0.03 C	0.200/0.400 S	12.50/13.50 Cr	0.50/1.00 V
0.50 Mn	1.20/1.80 Si	0.50/1.00 Mo	Bal. Fe
0.030 Ph			

(single figures are maximums)

A controlled chemistry, free machining, ferritic 13% chromium alloy that is a candidate for use in magnetic components where corrosion resistance superior to pure iron, low carbon steel and silicon-iron alloys is desired. Exhibits comparable salt spray corrosion resistance when compared to the 18% Cr ferritic stainless steels without the substantial decrease in saturation induction.

CHROME CORE 18-FM ALLOY (U.S. PATENT NO. 5,601,664)

0.015 C	0.020 P	0.20 Ni	0.25 Cb
0.40 Mn	0.30 S	1.75 Mo	Bal. Fe
0.90 Si	17.50 Cr		

(nominal analysis)

A soft magnetic ferritic material designed for operation in more corrosive environments than those tolerated by 18% Cr-Fe Type 430 stainless. Has corrosion resistance superior to that of Type 430 FR stainless with generally similar magnetic properties.

CHROME CORE 29 ALLOY (U.S. PATENT NO. 6,616,125)

0.02 C	0.4 Si	0.004 S max.	Bal. Fe
0.4 Mn	28.5 Cr		

(nominal analysis)

A soft magnetic, superior corrosion-resistant alloy for use in electromechanical parts exposed to corrosive environments such as encountered in semiconductor manufacturing.

Some grades may require the purchase of a minimum heat lot quantity.

Soft Magnetic Nickel-Iron Alloys

HIGH PERMEABILITY "36" ALLOY (UNS K93603)

0.02 C	0.25 Si	36 Ni	Bal. Fe
0.4 Mn			

(nominal analysis)

Vacuum-melted grade similar to Carpenter Invar "36"® alloy possessing good magnetic permeability and high electrical resistivity. Has been used in magnetic shielding and high frequency transformer cores.

CARPENTER HIGH PERMEABILITY "45" ALLOY (UNS K94490)

0.02 C	0.25 Si	45 Ni	Bal. Fe
0.4 Mn			

(nominal analysis)

A 45% nickel-iron alloy capable of exhibiting a high initial and a maximum permeability slightly lower than Carpenter High Permeability "49"® alloy. Has been used predominantly in the telecommunications industry.

CARPENTER HIGH PERMEABILITY "49"® ALLOY (UNS K94840)

0.02 C	0.35 Si	48.0 Ni	Bal. Fe
0.50 Mn			

(nominal analysis)

A 48% nickel-iron alloy with high initial and maximum permeability and low core loss after suggested heat treatment. Has been used in laminated cores for instrument transformers, magnetic shields, solenoid cores and various sensitive magnetic core components. Unannealed strip items 0.020" thick or less are available as Transformer (oriented) and Rotor (unoriented) grades.

HIGH PERMEABILITY "49" FM ALLOY

0.02 C	0.35 Si	48.0 Ni	Bal. Fe
0.50 Mn	0.1 Se		

(nominal analysis)

A free-machining, 48% nickel-iron alloy having lower magnetic permeability than Carpenter High Permeability "49" alloy but having much improved machinability.

HIGH PERMEABILITY "55" ALLOY

0.02 C	0.25 Si	56 Ni	Bal. Fe
0.4 Mn			

High-permeability alloy designed for heat treatment in a magnetic field. It has been used for high accuracy current transformers and choke coils. Available only as thin strip and foil.

HIPERNOM® ALLOY

0.02 C	0.35 Si	4.20 Mo	Bal. Fe
0.50 Mn	80.0 Ni		

(single figures are nominal)

This soft magnetic alloy develops extremely high permeabilities with minimum hysteresis loss. Has been used primarily in shielding applications. Can be fabricated by roll forming, spinning, deep drawing and other conventional sheet metal operations.

HYMU "77" ALLOY (UNS N14076)

0.02 C	0.30 Si	2.5 Cr	Bal. Fe
0.50 Mn	77 Ni	4.75 Cu	

A high-permeability, soft magnetic alloy that has been used for certain magnetic shielding applications and having slightly improved cold-formability as compared with Carpenter HyMu "80"® alloy.

HYMU "77" PLUS ALLOY

0.02 C	0.20 Si	4.2 Mo	Bal. Fe
0.50 Mn	77.0 Ni	4.4 Cu	

(nominal analysis)

Very high permeability alloy used in the production of GFCI cores. Cores made from this alloy require aging (baking) at 480-490°C in order to achieve the highest magnetic permeability.

CARPENTER HYMU "80"® ALLOY (UNS N14080)

0.02 C	0.35 Si	4.2 Mo	Bal. Fe
0.50 Mn	80.0 Ni		

(nominal analysis)

An 80% nickel-iron-molybdenum alloy with extremely high initial and maximum permeability and minimum hysteresis loss. Has been used primarily for transformer cores, tape-wound toroids, shielding and laminations operating at very low magnetic field strengths.

HYMU "80" MARK II ALLOY (UNS N14080)

0.02 C	0.30 Si	4.6 Mo	Bal. Fe
0.50 Mn	80.0 Ni		

(nominal analysis)

A very high permeability alloy used in the production of transformer laminations and tape toroids. Alloy is designed to respond best to cooling rates of about 167°C/hr. Very high permeability can also be obtained by aging (baking) at about 520°C.

Some grades may require the purchase of a minimum heat lot quantity.

CARPENTER HYMU "800" ALLOY (UNS N14080)

0.01 C	0.15 Si	5.0 Mo	Bal. Fe
0.50 Mn	80.0 Ni		

(nominal analysis)

A very high permeability alloy used in the production of transformer laminations and tape toroids. Requires lower cooling rates and baking temperatures than HyMu "80" Mark II to develop the highest permeabilities.

HYMU "800" – 5.2 MO ALLOY (UNS N14080)

0.01 C	0.15 Si	5.2 Mo	Bal. Fe
0.50 Mn	80.0 Ni		

A very high permeability alloy used in the production of transformer laminations and tape toroids. Requires lower cooling rates and baking temperatures than HyMu "800" to develop the highest permeabilities.

HY-RA "49"® ALLOY (UNS K94840)

0.02 C	0.30 Si	48.0 Ni	Bal. Fe
0.30 Mn			

(nominal analysis)

A specially processed alloy supplied in strip form only. Capable of exhibiting square loop magnetic behavior after suggested heat treatment.

CARPENTER TEMPERATURE COMPENSATOR "30"® ALLOY (TYPES 2 & 4)

0.12 C	0.25 Si	30.0 Ni	Bal. Fe
0.60 Mn			

(nominal analysis)

Two types of temperature-compensating alloys having different permeability versus temperature characteristics. Have been used primarily as "shunts" in watt-hour meters, speedometers, tachometers, voltage regulators and similar instruments.

TEMPERATURE COMPENSATOR "31" ALLOY

0.06 C	0.25 Si	31.0 Ni	Bal. Fe
0.60 Mn			

(nominal analysis)

A temperature compensator alloy containing nominal nickel content of 31.00%, balance Fe, having magnetic flux density versus temperature characteristics in between Type 2 and Type 1.

TEMPERATURE COMPENSATOR "32" ALLOY (TYPE 1)

0.12 C	0.25 Si	32.5 Ni	Bal. Fe
0.60 Mn			

(nominal analysis)

Type 1 has been used when compensation is required at higher temperatures than Types 2 and 4 as in the "shunt" for automobile voltage regulators located close to engines and other devices.

▸ Soft Magnetic Cobalt-Iron Alloys

HIPERCO® 15 ALLOY

0.01 C	0.30 Si	15.0 Co	Bal. Fe.
2.70 Mn	0.60 Cr		

(nominal analysis)

A low cobalt-content, soft magnetic alloy with higher magnetic saturation than either iron or silicon iron. The alloy also possesses relatively high electrical resistivity. May be considered for use in automotive applications requiring high magnetic saturation such as diesel fuel injector components.

HIPERCO 27 ALLOY (UNS K92650)

0.01 C	0.25 Si	0.60 Ni	Bal. Fe
0.25 Mn	0.60 Cr	27 Co	

(nominal analysis)

A ductile-high-magnetic saturation alloy which has been used in magnetic flux-carrying members, magnetic pole caps and laminations for aircraft motors and generators.

HIPERCO 50 ALLOY (UNS R30005)

0.01 C	0.05 Si	1.9 V	Bal. Fe
0.05 Mn	48.75 Co	0.05 Nb	

(nominal analysis)

A high-magnetic-saturation alloy which has been used primarily in laminations for aircraft motors and generators. This alloy has higher mechanical strength than Hiperco 50A alloy and better magnetic characteristics than Hiperco 27 alloy.

Some grades may require the purchase of a minimum heat lot quantity.

HIPERCO 50A ALLOY (UNS R30005)

0.004 C	0.05 Si	2.0 V	Bal. Fe
0.05 Mn	48.75 Co		

(nominal analysis)

A high-magnetic-saturation alloy that has been used for transformer laminations and tape toroids. Has slightly better magnetic properties than Hiperco 50 alloy. Available in bar larger than 0.500" round, strip, and wire less than 0.250" round.

HIPERCO 50B ALLOY

0.01 C	0.25 Si	0.60 Ni	2.75 V
0.25 Mn	0.60 Cr	48.3 Co	Bal. Fe

(nominal analysis)

A high-magnetic-saturation alloy supplied in bar or wire form less than 0.500" round. This alloy has been used as fine wire in dry reed switches for the telecommunication field.

HIPERCO 50 HS ALLOY (U.S. PATENT NO. 5,501,747) (UNS R30005)

0.01 C	0.05 Si	1.9 V	Bal. Fe
0.05 Mn	48.75 Co	0.3 Nb	

(nominal analysis)

A high-magnetic-saturation alloy which possesses a unique combination of high yield strength and moderate core loss. Capable of producing a higher yield strength than conventional Hiperco 50 alloy. It has been used primarily in laminations for high-speed generators and magnetic bearings.

▸ Semi-Hard and Hard Magnetic Alloys

CARPENTER CHROMIUM MAGNET STEEL 73

1.0 C	0.25 Si	3.5 Cr	Bal. Fe
0.30 Mn			

(nominal analysis)

A semi-hard, permanent magnet steel that requires a quench and temper heat treatment to produce its hard magnetic characteristics. Applications have included hysteresis motor laminations and magnets for automotive speedometers.

CARPENTER P6 ALLOY

6.00 Ni	45.00 Co	4.80 V	Bal. Fe

(nominal analysis)

A ductile, semi-hard magnetic alloy that has been used in laminations for hysteresis motors. Alloy exhibits highest efficiency (loss per unit magnetic field strength) of any known material.

CHROMINDUR II (registered trademark of AT&T)

28 Cr	10.5 Co	Bal. Fe	

(nominal analysis)

This hard magnetic alloy (coercivity typically 300 Oe or 24 kA/m) is ductile until heat treated. Due to the high chromium content, the alloy also exhibits good corrosion resistance. It has been used in telephone receiver magnets and magnetic couplings.

MAGNEDUR® 20-4 ALLOY (U.S. PATENT NO. 5,685,921)

0.01 C	0.15 Si	4.00 Mo	Bal. Fe
0.30 Mn	20.0 Ni		

(nominal analysis)

A cobalt-free alloy with semi-hard magnetic properties. It is malleable and ductile, and has lent itself to the manufacture of strip, foil and wire. Although it has been used in theft detection tags, it could be considered as a candidate for applications in instruments and hysteresis motors.

VICALLOY I ALLOY

0.03 C	0.20 Si	10 V	Bal. Fe
0.04 Mn	52.0 Co		

(nominal analysis)

A precipitation hardening, ductile permanent magnet alloy capable of being processed into strip, bar and wire products prior to heat treatment for electromechanical device applications.

▸ Controlled Expansion and Glass Sealing Alloys

485 ALLOY

0.01 C	0.15 Si	6.0 Cr	Bal. Fe
0.20 Mn	0.15 Al	47 Ni	

(nominal analysis)

A low-expansion nickel-chromium-iron alloy that has primarily been used to make anode buttons for cathode ray tubes.

Some grades may require the purchase of a minimum heat lot quantity.

GLASS SEALING "27" ALLOY (UNS K92801)

0.05 C	0.40 Si	0.50 max. Ni	Bal. Fe
0.60 Mn	28 Cr		

(nominal analysis)

Ductile chromium-iron alloy that has been used for strong glass-to-metal seals in electronic and vacuum tubes and incandescent and fluorescent lamps. It exhibits no phase transformation up to 2100°F (1150°C).

GLASS SEALING "42" ALLOY (UNS K94100)

0.05 max. C	0.25 Si	41 Ni	Bal. Fe
0.40 Mn			

(nominal analysis)

Has been used for integrated circuit lead frames and some selected glass-metal sealing applications.

GLASS SEALING "42" GAS-FREE ALLOY

0.010 C	0.2 Si	0.4 Ti	Bal. Fe
0.50 Mn	41.0 Ni		

(nominal analysis)

Has been used for automotive and industrial lamps and terminals for enameled resistors and, without prior thermal treatment, in making bubble-free glass-metal seals.

GLASS SEALING "42-6" ALLOY (UNS K94760)

0.07 max. C	0.25 Si	5.75 Cr	Bal. Fe
0.50 Mn	42.5 Ni		

(nominal analysis)

Has been used for sealing to Corning 0120 glass. A special thermal treatment develops a tightly adherent oxide beneficial to obtaining hermetic seals.

GLASS SEALING "46"GAS-FREE ALLOY

0.03 C	0.25 Si	0.40 Ti	Bal. Fe
0.50 Mn	46 Ni		

(nominal analysis)

Has been used for terminal bands in enameled resistors and for enameling without degasification.

GLASS SEALING "51" GAS-FREE ALLOY

0.005 C	0.10 Si	51 Ni	Bal. Fe
0.25 Mn			

(nominal analysis)

Has been used for contact blades in dry reed switches.

GLASS SEALING "52" ALLOY (UNS N14052)

0.01 max. C	0.20 Si	50.5 Ni	Bal. Fe
0.30 Mn			

(nominal analysis)

Has been used for sealing to soft glasses such as in the lead wire for mercury switches and semiconductor devices.

HIGH EXPANSION "18-11" ALLOY

0.10 C	0.30 Si	18.0 Ni	Bal. Fe
0.45 Mn	11.25 Cr		

(nominal analysis)

A high-expansion alloy used in thermostat metal production. Conforms to ASTM B753 – Alloy T-18.

HIGH EXPANSION "19-2" ALLOY (UNS K92100)

0.55 C	0.20 Si	19 Ni	Bal. Fe
1.00 Mn	2 Cr		

(nominal analysis)

Has been used as the high-expansion component in thermostat bimetal applications. Conforms to ASTM B753 – Alloy T-19.

Some grades may require the purchase of a minimum heat lot quantity.

HIGH EXPANSION "19-7" ALLOY

0.10 C	0.25 Si	19 Ni	Bal. Fe
0.80 Mn	7.2 Cr		

(nominal analysis)

A high-expansion alloy used in thermostat metal production.

HIGH EXPANSION 20NI-6MN ALLOY

0.05 C	6.2 Mn	20.2 Ni	Bal. Fe

(nominal analysis)

A high-expansion alloy used in thermostat metal production.

CARPENTER HIGH EXPANSION 22-3 ALLOY (UNS K92510)

0.10 C	0.25 Si	22 Ni	Bal. Fe
0.50 Mn	3.1 Cr		

(nominal analysis)

A high-expansion alloy that has been used as the high-expansion component in thermostat bimetal applications. Conforms to ASTM B753 – Alloy T-22.

HIGH EXPANSION "25-8" ALLOY (UNS K92350)

0.03 C	0.80 Si	25.0 Ni	Bal. Fe
0.75 Mn	8.50 Cr		

(nominal analysis)

A high-expansion alloy that has been used in thermostat metal production. Conforms to ASTM B753 – Alloy T-25.

HIGH EXPANSION "72" ALLOY (UNS M27200)

0.02 C	10 Ni	18 Cu	Bal. Fe
72 Mn			

(nominal analysis)

A nonferrous alloy that has been used as the high-expansion component in thermostat bimetal applications. Conforms to ASTM B753 – Alloy T-10.

CARPENTER INVAR "36"® ALLOY (UNS K93601 AND UNS K93603)

0.02 C	0.20 Si	36.0 Ni	Bal. Fe
0.35 Mn			

(nominal analysis)

A 36% nickel-iron alloy with a rate of thermal expansion approximately one-tenth that of carbon steel at temperatures up to 400°F (204°C). Has been used in applications such as radio and electronic devices where dimensional changes due to temperature must be minimal, as well as in support and structural members in precision optical laser mechanical measuring and positioning devices and for thermostat metals.

FREE-CUT INVAR "36"® ALLOY (UNS K93602 AND UNS K93050)

0.05 C	0.35 Si	0.20 Co	Bal. Fe
0.90 Mn	36.0 Ni	0.20 Se	

(nominal analysis)

Free-machining alloy used for machined parts in which dimensional changes due to temperature variations must be minimized. It has been used in radio and electronic devices and aircraft controls.

LOW EXPANSION "38-7" ALLOY

0.10 C	0.20 Si	38.0 Ni	Bal. Fe
0.40 Mn	7.0 Cr		

(nominal analysis)

A low-expansion alloy used for the production of thermostat metal.

LOW EXPANSION "39" ALLOY (UNS K94000)

0.05 C	0.25 Si	39.00 Ni	Bal. Fe
0.40 Mn			

(nominal analysis)

A special controlled-expansion alloy designed originally to match the thermal expansion of certain hard glasses up to 392°F (200°C). Has been used for tunable capacitors and as low-expansion element in thermostat bimetal products.

CARPENTER LOW EXPANSION "42"® ALLOY (UNS K94200)

0.50 max. C	0.2 Si	41.0 Ni	Bal. Fe
0.40 Mn			

(nominal analysis)

This nickel-iron alloy has a virtually constant low rate of thermal expansion at temperatures up to about 650°F (343°C). Has been used in thermostats and thermoswitches, as well as in thermostat bimetal applications as the low-expansion element.

Some grades may require the purchase of a minimum heat lot quantity.

LOW EXPANSION "42"® DUMET CORE ROD (UNS K94101)

0.10 C	0.20 Si	42.0 Ni	Bal. Fe
1.0 Mn			

(nominal analysis)

A low expansion Ni-Fe alloy used for making Dumet wire for electrical lighting and electronics.

LOW EXPANSION 43-PH ALLOY

0.03 C	0.50 Si	42.5 Ni	2.50 Ti
0.50 Mn	5.25 Cr	0.50 Al	Bal. Fe

(nominal analysis)

Low Expansion 43-PH is an age-hardenable, ferromagnetic, austenitic alloy. Its constant modulus of elasticity, inherent high-strength, good formability, adjustable elastic coefficient and low mechanical hysteresis have been factors in its consideration for use in a wide variety of applications in precision devices where the ambient temperature mechanical property variations must be held to low limits.

KOVAR® ALLOY (ALSO KNOWN AS RODAR ALLOY) (UNS K94610 AND K94630)

0.02 max. C	0.20 Si	17 Co	Bal. Fe
0.30 Mn	29 Ni		

(nominal analysis)

A low-expansion alloy which has been widely used for making hermetic seals with the harder Pyrex glass and ceramic materials such as in power tubes, microwave tubes, transistors and diodes, as well as integrated circuits.

LOW EXPANSION "45" ALLOY (UNS K94500)

0.05 C	0.25 Si	45.0 Ni	Bal. Fe
0.4 Mn			

(nominal analysis)

Has a relatively constant rate of thermal expansion to about 800°F (538°C). It has been used in thermostats, and its thermal expansion approximates that of some alumina ceramics.

LOW EXPANSION "49" ALLOY

0.03 C	0.25 Si	48.0 Ni	Bal. Fe
0.40 Mn			

(nominal analysis)

Has been used for glass sealing of fiber optics.

LOW EXPANSION "50" ALLOY (UNS K95000)

0.015 C	0.20 Si	50.2 Ni	Bal. Fe
0.20 Mn			

(nominal analysis)

Has been used for the production of thermostat metal and conforms to ASTM B752 – Alloy T-50.

SUPER INVAR "32-5" ALLOY (UNS K93500)

0.02C	0.25 Si	5.5 Co	Bal. Fe
0.40 Mn	32.0 Ni		

(nominal analysis)

Super-Invar "32-5" is an iron-nickel-cobalt alloy which exhibits approximately one half of the thermal expansion of Carpenter Invar "36"® alloy in the vicinity of room temperature. This alloy has been used as structural components or bases and supports for optical and laser instruments.

RESISTANCE ALLOYS

These alloys have been used as resistance elements to control or measure electrical current. Applications have included wire-wound resistors, rheostats, potentiometers and shunts.

CB CUPRON

54.5 Cu	44 Ni	1.5 Mn

(nominal analysis)

Standard Cu-Ni precision resistance alloy conforming to ASTM B267, Class VA. The TCR of CB Cupron is approximately +/- 40 ppm in the range from -67/221°F (- 55/105°C). The room temperature electrical resistivity is about 300 ohms-cir-mil/ft.

CBX CUPRON® ALLOY

53 Cu	44 Ni	3 Mn

(nominal analysis)

Similar to the standard CB Cupron alloy but superior uniformity of TCR from the hot to cold regions. The TCR of CBX Cupron is virtually always positive in the cold range. CBX Cupron is always gas free and with its resistivity of 310 ohms-cir-mil/ft, it offers higher ohms per pound wire than standard CB Cupron. Meets ASTM B267 Class VA specification.

Some grades may require the purchase of a minimum heat lot quantity.

EVANOHM® ALLOY R

75 Ni	20 Cr	2.5 Al	2.5 Cu

(nominal analysis)

Has been used extensively in fine sizes for precision wound resistors. Has a high tensile strength in fine sizes, a high resistance to corrosion and is non-magnetic. Resistivity: 800 ohms – c mil/ft. Also available in strip form as well as wire and ribbon.

EVANOHM ALLOY S

72 Ni 20 Cr	3 Al	4 Mn	1 Si

(nominal analysis)

It has been used in fine wire precision resistors. Has extremely low TCR with less than 1 ppm difference between hot and cold ranges. Has a high tensile strength, excellent corrosion resistance and is non-magnetic. Resistivity: 825 ohms – c mil/ft. Available in both wire and ribbon product forms.

180 ALLOY

77 Cu	23 Ni		

(nominal analysis)

A copper-nickel alloy with resistivities between copper and Cupron alloy. Has been used where lower resistance is required. Resistivity is 180 ohms – c mil/ft.

MANGANIN ALLOY

12 Mn	0.8 Fe	Bal. Cu	

(nominal analysis)

Manganin Alloy is a nonferrous low TCR alloy used in precision resistors operating at room temperature. Resistivity is 250 ohms – c mil/ft.

MANGANIN 13

9.7 Mn	4.6 Ni	Bal. Cu	

(nominal analysis)

Manganin 13 is a nonferrous low TCR alloy used in precision resistors operating at room temperature. The alloy has found wide use for electrical current metering shunts. Resistivity is 220 ohms – c mil/ft.

MANGANIN 130

84 Cu	12 Mn	4 Ni	

(nominal analysis)

Has been used for precision-built electrical apparatus such as wheat-stone bridges, decade boxes, voltage dividers, potentiometers and resistance standards. Resistivity: 290 ohms – c mil/ft.

NO. 1-JR® ALLOY (TYPES 1 AND 2)

Type 1:	Type 2:
0.15 C	0.15 C
12.0/14.0 Cr	12.0/14.0 Cr
4 Al (nom.)	3.5 Al (nom.)
0.7 Ti	0.7 Ti
Bal. Fe	Bal. Fe

(single figures are maximums, except aluminum, which is nominal)

Oxidation-resistant steel offering an excellent combination of electrical resistance and scale resistance. Resistivity in ohms – cir mil/ft at 68°F is: Type 1, 720; Type 2, 680.

HEATING ELEMENT ALLOYS

These are nickel-chromium, nickel-chromium-iron and iron-chromium alloys that have been used for elements in high-temperature heating applications such as industrial furnaces, process heating, space heating, clothes dryer, hot water heaters and other home appliances.

ALCHROME ALLOY 875 (UNS K92500)

22 Cr	5.5 Al	Bal. Fe	

(nominal analysis)

Has been used extensively as heating elements in industrial furnaces and electrical kilns at temperatures up to 2550°F (1399°C). Has less hot strength than Tophet alloys but much higher melting point. Meets ASTM B603 Class I specification.

Some grades may require the purchase of a minimum heat lot quantity.

TOPHET® ALLOY 30 (UNS N06008)

70 Ni	30 Cr		

(nominal analysis)

Superior oxidation resistance promotes longer life at temperatures up to 2300°F (1260°C). May be considered over other Tophet alloys for industrial furnaces with exothermic, hydrogen, air and dissociated ammonia atmospheres.

TOPHET ALLOY A (UNS N06003)

80 Ni	20 Cr		

(nominal analysis)

Has been widely used at temperatures up to 2150°F (1177°C). High corrosion resistance to most acids and alkaline solutions. Has been used for chemical industry hardware as well as electric furnace and appliance heating elements. Also available in strip form as well as wire and ribbon.

TOPHET ALLOY C (UNS N06004)

60 Ni	16 Cr	Bal. Fe	

(nominal analysis)

Has heat resistance up to 1850°F (1010°C). Considered by many the most suitable element alloy for appliances where high quality is essential but where operating temperatures do not require the higher heat-resisting properties of Tophet Alloys A or 30. Also available in strip form as well as wire and ribbon.

THERMOCOUPLE ALLOYS

19 ALLOY

0.8 Co	Bal. Ni		

(nominal analysis)

Negative thermoelement in nickel-moly/nickel thermocouples. Has been used in hydrogen, dissociated ammonia and vacuum furnaces to 2500°F (1371°C).

20 ALLOY

18.0 Mo	Bal. Ni		

(nominal analysis)

Positive thermoelement in nickel-moly/nickel thermocouples.

CUPRON® ALLOY

55 Cu	45 Ni		

(nominal analysis)

Standard negative thermoelement used with copper to produce the ISA Type T curve, with iron to produce the Type J curve, and with Tophet alloy to produce the Type E curve.

NIAL® ALLOY (UNS N02016)

95 Ni	Bal. Al		

(nominal analysis)

Standard negative thermoelement for Type K thermocouples. Magnetic.

NICROSIL ALLOY

14.4 Cr	1.4 Si	0.10 Mg	Bal. Ni

(nominal analysis)

Standard Type N positive thermoelement developed to produce a thermocouple more stable than the standard Type K.

NISIL ALLOY

4.2 Si	0.10 Mg	Bal. Ni	

(nominal analysis)

Standard Type N negative thermoelement developed to produce a thermocouple more stable than the standard Type K.

PCLW-BPX ALLOY

4.0 Mn	Bal. Cu		

(nominal analysis)

Copper-base positive extension wire used with copper as the negative leg for compensating extension wires for Type B thermocouples.

Some grades may require the purchase of a minimum heat lot quantity.

PCLW-SNX ALLOY

1.0 Ni	Bal. Cu		

(nominal analysis)

Copper-base negative extension wire used instead of platinum as a compensating leg in Type S or R thermocouples.

THERMOCOUPLE IRON

99 Fe			

Extremely low residuals
(nominal analysis)

Engineered especially for thermocouple applications. Thermocouple Iron is vacuum melted to produce extremely low levels of residuals. Exacting process controls from melting through final processing result in a very tight EMF value, statistically constant from heat-to-heat. Thermocouple Iron is the positive leg and is combined with CA Cupron to make the type J thermocouple.

TOPHEL® ALLOY (UNS N06010)

90 Ni	10 Cr		

(nominal analysis)

Positive thermoelement for Types K and E thermocouples. Has excellent oxidation resistance and ElectroMotive Force stability. Non-magnetic.

HIGH-NICKEL ALLOYS

CARPENTER CATHODE NI-W ALLOY

96 Ni	4 W		

Low-Residual-Alloy Content
(nominal analysis)

This high-purity vacuum melted alloy has been used for the active cathode element in cathode ray electron gun applications.

CARPENTER NICKEL 200 ALLOY (UNS N02200)

99.5 nom. Ni + Co	0.35 Mn	0.25 Fe	0.01 S
0.07 C	0.25 Si	0.15 Cu	

(single figures are maximums)

A commercially pure nickel alloy possessing good corrosion resistance and relatively low electrical resistivity. Has been used in a wide variety of applications including food handling equipment, magnetically actuated parts, sonar devices, and electrical and electronic leads. Meets ASTM B160 specification requirements.

CARPENTER NICKEL 201 ALLOY (UNS N02201)

99.5 nom. Ni + Co	0.35 Mn	0.25 Fe	0.01 S
0.02 C	0.25 Si	0.15 Cu	

(single figures are maximums)

A low-carbon variety of Nickel alloy 200 possessing low annealed hardness and a very low work-hardening rate desirable for cold forming operations. This alloy exhibits creep resistance superior to that of Nickel Alloy 200 above 600°F (315°C) and has been used in electronics applications up to 1200°F (649°C).

CARPENTER NICKEL 205 ALLOY (UNS N02205)

99.5 nom. Ni + Co	0.15 Si	0.15 Cu	0.01/0.05 Ti
0.07 nom. C	0.20 Fe	0.01/0.08 Mg	0.008 S
0.35 Mn			

(single figures are maximums)

Wrought nickel alloy possessing an excellent combination of mechanical, electrical and corrosion resistant properties. Has been used in various electronic components. Meets ASTM F9 specification requirements.

NI-4AL ALLOY (UNS N03301)

93.0 Ni	0.30 Mn	4.60 Al	0.60 Ti
0.20 C	0.40 Si		

(nominal analysis)

Wrought, age-hardenable alloy possessing the corrosion resistance of Nickel 200 coupled with greater strength and hardness. High electrical conductivity and good thermal conductivity. Has been used under stress conditions for which the fatigue strength of Nickel 200 is inadequate. A candidate for use in springs, clips, signal flashers, diaphragms, extrusion components for plastics, bearings, as well as pump and valve parts.

Some grades may require the purchase of a minimum heat lot quantity.

BORATED STAINLESS STEELS

These alloys are sold by Carpenter Powder Products, a business unit of Carpenter Technology Corporation.

MICRO-MELT® NEUTROSORB PLUS® ALLOYS (U.S. PATENT NO. 5,017,437) (ASTM A887 GRADE "A" ALLOYS) (UNS 530460-67)

0.08 C	0.030 S	12.00/15.00 Ni	0.10 N
2.00 Mn	0.75 Si	Up to 2.25 B	Bal. Fe
0.045 P	18.00/20.00 Cr		

(single figures are maximums)

A family of 18% chromium austenitic stainless steels balanced with increased nickel versus Type 304 and a boron addition (up to 2.5%) which imparts a high thermal neutron absorption cross-section. ASTM A887 Grade "A" alloys display superior ductility, impact and fracture toughness to their Grade "B" counterparts. Alloys have been used in the nuclear power generation industry.

MICRO-MELT® NEUTROSORB ALLOYS (ASTM A887 GRADE "B" ALLOYS) (UNS 530460-67)

0.08 C	0.030 S	12.00/15.00 Ni	0.10 N
2.00 Mn	0.75 Si	Up to 2.25 B	Bal. Fe
0.045 P	18.00/20.00 Cr		

(single figures are maximums)

A family of 18% chromium austenitic stainless steels balanced with increased nickel versus T304 and a boron addition (up to 2.5%) which imparts a high thermal neutron absorption cross-section. This family of ASTM A887 Grade "B" alloys displays the same refined boride microstructure and boride uniformity present in the Micro-Melt NeutroSorb PLUS family of alloys. The Micro-Melt NeutroSorb family of alloys has higher ductility, impact strength and fracture toughness compared to their ASTM A887 Grade "B" counterparts produced by cast/wrought processsing and lower ductility, impact strength and fracture toughness compared to their Micro-Melt NeutroSorb Plus ASTM Grade "A" counterparts.

TOOL AND DIE STEELS

Each of these Carpenter Powder Products tool and die steels is produced to provide a specific combination of mechanical properties, strength characteristics and fabrication qualities.

▸ Micro-Melt® High Speed Steels

MICRO-MELT 23 ALLOY (AISI M3) (UNS T11323)

1.30 C max.	5.00 Mo	6.30 W	0.35 Si
4.20 Cr	3.10 V	0.30 Mn	Bal. Fe

(nominal analysis)

A general-purpose powder high speed tool steel possessing an excellent combination of wear resistance, toughness and strength. Offers low distortion in heat treat and good grindability. Typical working hardness range is HRC 62-66. May be considered for a variety of applications including cold working applications and tools of complicated design.

MICRO-MELT 60 ALLOY

2.30 C	6.50 V	10.50 Co	0.35 Si
4.00 Cr	6.50 W	0.30 Mn	Bal. Fe
7.00 Mo			

(nominal analysis)

A high alloy content high speed powder metal tool steel capable of reaching a hardness of up to HRC 69.5. Has an excellent combination of wear resistance, hot hardness and toughness. May be considered for many tooling applications, including cold working applications due to its combination of excellent abrasion resistance and high compressive strength.

MICRO-MELT HS30 ALLOY

1.27 C	0.03 S	5.00 Mo	8.50 Co
0.30 Mn	0.55 Si	3.10 V	Bal. Fe
0.03 P	4.20 Cr	6.25 W	

(nominal analysis)

An 8.50% cobalt, high hardenability tungsten-molybdenum high speed steel possessing excellent hot hardness combined with good wear resistance and toughness. Has been used for cutting tools for difficult-to-machine materials and high cutting speeds.

MICRO-MELT M3 CLASS 2 ALLOY (AISI TYPE M3T2) (UNS T11323)

1.25 C	6.0 Mo	6.25 W	0.40 Si
0.07 S	3.0 V	0.30 Mn	Bal. Fe
4.0 Cr			

(nominal analysis)

A tungsten/molybdenum powder high-speed tool steel which has superior wear resistance for difficult cutting operations.

MICRO-MELT M4 ALLOY (AISI TYPE M4) (UNS T11304)

1.45 C	0.06 S	4.50 Mo	5.50 W
0.30 Mn	4.50 Cr	4.00 V	Bal. Fe
0.30 Si			

(nominal analysis)

A molybdenum/tungsten-bearing powder high-speed tool steel with high carbon and vanadium contents. This grade provides very high wear resistance along with high strength.

Some grades may require the purchase of a minimum heat lot quantity.

MICRO-MELT® M42 ALLOY (AISI TYPE M42) (UNS T11342)

1.10 C	9.50 Mo	0.30 Mn	8.25 Co
0.006 S	1.15 V	0.60 Si	Bal. Fe
3.75 Cr	1.50 W		

(nominal analysis)

A super-high-speed tool steel possessing a hardness capability of Rockwell C 68/70. The alloy has been used for cutting tools for the toughest machining operations.

MICRO-MELT M48 ALLOY (AISI M48) (UNS T11348)

1.55 C	0.03 S	5.25 Mo	9.00 Co
0.20 Mn	0.40 Si	3.10 V	Bal. Fe
0.03 P	4.00 Cr	10.00 W	

(nominal analysis)

Superior high speed steel exhibiting abrasion resistance equal to T15 and red hardness superior to T15 and M42. Heat treatable to HRC 70. Consider for use in cutting tools where the ASTM M40 series are inadequate.

MICRO-MELT M62 ALLOY (AISI M62) (UNS T11362)

1.30 C	10.50 Mo	6.25 W	0.25 Si
0.050 S	2.00 V	0.30 Mn	Bal. Fe
3.75 Cr			

(nominal analysis)

A high speed powder metal tool steel capable of reaching hardnesses in excess of HRC 67 without the use of cobalt. Provides performance similar to AISI Type M42 in terms of hot hardness and heat treatment response, in addition to good toughness and excellent abrasion resistance.

MICRO-MELT MAXAMET® ALLOY (U.S. PATENT NO. 6,482,354)

2.15 C	6.00 V	10.00 Co	0.60 Si
0.03 S	13.00 W	0.70 Mn	Bal. Fe
4.75 Cr			

(In addition, the alloy can be produced with increased sulfur levels up to 0.30%, for tools requiring improved machinability).

(nominal analysis)

A high alloy content, super hard powder, high speed steel with properties intermediate between conventional high speed steels and cemented carbide. Consider for use in applications where conventional tool steels do not hold up. The alloying additions provide excellent wear resistance due to a high carbide volume, and good toughness at high hardness levels.

MICRO-MELT T15 ALLOY (AISI TYPE T15) (UNS T12015)

1.60 C	5.0 V	5.0 Co	0.35 Si
0.06 S	12.25 W	0.30 Mn	Bal. Fe
4.25 Cr			

(nominal analysis)

A high-carbon tungsten/cobalt vanadium powder high-speed tool steel having excellent abrasion resistance and red hardness.

MICRO-MELT T15 PLUS ALLOY

1.60 C	4.80 Cr	8.00 Co	10.50 W
0.030 S	2.00 Mo	5.00 V	Bal. Fe

(nominal analysis)

A high alloy-content, high-speed powder metal tool steel with improved hardness capability and wear resistance compared to standard M-series high speed steels.

▸ High Speed Steels

STAR-MAX® ALLOY (AISI TYPE M1) (UNS T11301)

0.81 C	0.30 Si	8.50 Mo	1.50 W
0.30 Mn	4.00 Cr	1.10 V	Bal. Fe

(nominal analysis)

A general-purpose, molybdenum-bearing ESR (ElectroSlag Remelted) quality high speed steel. Provides unusual toughness. Has been used for form cutters, lathe tools, planers, punches, reamers and taps.

SPEED STAR® (AISI TYPE M2) (UNS T11302)

0.82 C	0.25 Si	5.00 Mo	1.80 V
0.30 Mn	4.25 Cr	6.25 W	Bal. Fe

(nominal analysis)

Fine-grained molybdenum/tungsten high-speed steel that machines more easily than conventional 18-4-1 alloys, and is relatively lower in cost. Has been used for tools such as lathes, planers, drills, broaches, gear cutters and milling cutters.

Some grades may require the purchase of a minimum heat lot quantity.

CARPENTER FOUR STAR ALLOY (AISI TYPE M4) (UNS T11304)

1.30 C	0.30 Si	4.50 Mo	5.50 W
0.30 Mn	4.50 Cr	4.00 V	Bal. Fe

(nominal analysis)

Very high wear resistance and high strength are offered by this high speed tool steel. It has a high carbon and vanadium content.

SEVEN STAR® ALLOY (AISI TYPE M7) (UNS T13307)

1.00 C	0.25 Si	8.75 Mo	1.75 W
0.25 Mn	4.00 Cr	2.00 V	Bal. Fe

(nominal analysis)

Higher carbon and vanadium contents than M1 result in improved cutting efficiency without reducing the toughness of the ESR-quality high speed steel.

CARPENTER SUPERSTAR® ALLOY (AISI TYPE M42) (UNS T11342)

1.08 C	3.75 Cr	1.15 V	8.00 Co
0.25 Mn	9.50 Mo	1.50 W	Bal. Fe
0.25 Si			

(nominal analysis)

Molybdenum-type high-speed steel with high carbon and cobalt content giving good success when machining high-hardness and difficult-to-machine materials.

▸ Ultrahigh Combined Strength and Toughness Tooling Alloy

AERMET®-FOR-TOOLING ALLOY (U.S. PATENT NOS. 5,087,415 AND 5,268,044) (UNS K92580)

0.23 C	11.10 Ni	13.40 Co	Bal. Fe
3.00 Cr	1.20 Mo		

(nominal analysis)

A double-vacuum melted iron-cobalt-nickel alloy possessing high hardness and strength combined with exceptional ductility and toughness. Designed for components that require a combination of HRC 53/55 hardness with the highest toughness available.

▸ Micro-Melt® Cold Work Tool Steels

MICRO-MELT® 440-XH® ALLOY (U.S. PATENT NO. 5,370,750)

1.60 C	0.85 Mo	0.55 Mn	0.35 Ni
16.00 Cr	0.45 V	0.40 Si	Bal. Fe

(nominal analysis)

An air-hardening, high carbon, high chromium, corrosion resistant alloy. It can be described as either a high hardness Type 440C stainless steel or a corrosion resistant D2 tool steel. May be considered for many types of tooling applications where a combination of good hot hardness, toughness and abrasion resistance is required.

MICRO-MELT A11-LVC ALLOY

Equivalent in hardness, wear resistance and heat treating response to CPM 9V alloy.
CPM and 9V are registered trademarks of Crucible Materials Corporation.

1.70/1.85 C	0.75/1.10 Si	1.10/1.50 Mo	0.03 S
0.35/0.60 Mn	4.75/5.75 Cr	8.25/9.50 V	Bal. Fe

(single figures are maximums)

A high-vanadium, powder metal cold work tool steel with wear resistance superior to most other tool steels, but slightly lower than Micro-Melt A11 Alloy.

MICRO-MELT A11 ALLOY (AISI A11)

Equivalent in hardness, wear resistance and heat treating response to CPM 10V alloy.
CPM and 10V are registered trademarks of Crucible Materials Corporation.

2.40/2.50 C	0.75/1.10 Si	1.10/1.50 Mo	0.05/0.09 S
0.35/0.60 Mn	4.75/5.75 Cr	9.25/10.25 V	Bal. Fe

(single figures are maximums)

A high-vanadium, powder metal cold work tool steel with wear resistance superior to most other tool steels, and possessing good strength and toughness characteristics.

Some grades may require the purchase of a minimum heat lot quantity.

MICRO-MELT CD#1 ALLOY

0.70 C	8.25 Cr	1.40 Mo	0.09 N
0.40 Mn	1.50 Ni	1.00 V	Bal. Fe
1.00 Si			

(nominal analysis)

A shock resistant cold work die steel possessing an excellent combination of toughness and wear resistance. Has a fine carbide distribution, which when combined with a low sulfur content, results in excellent polishability of dies or tools manufactured from the alloy. May be considered for many types of cold work tooling applications where a combination of good toughness and wear resistance is required. May also be considered for coining applications due to excellent polishability.

MICRO-MELT PD#1 ALLOY

1.10 C	1.20 Si	1.60 Mo	1.10 W
0.25 Mn	7.75 Cr	2.40 V	Bal. Fe

(nominal analysis)

An air hardening cold work die steel possessing wear resistance superior to that of conventional grades such as AISI D2, while still maintaining excellent toughness. Has the compressive strength required for resistance to deformation in tooling applications. Potential applications may include punches, rotary shears, blanking dies, chipper knives, slitter knives and thread rolling dies.

▸ Micro-Melt® Corrosion and Wear Resistant Cold Work Tool Steels

MICRO-MELT® 440C ALLOY (UNS S44004)

0.95/1.20 C	0.040 Ph	1.00 Si	0.75 Mo
1.00 Mn	0.030 S	16.00/18.00 Cr	Bal. Fe

(single figures are maximums)

Refer to Stainless Steels – Conventionally Hardened Grades on page 10.

MICRO-MELT 440-XH® ALLOY (U.S. PATENT NO. 5,370,750)

1.60 C	0.85 Mo	0.55 Mn	0.35 Ni
16.00 Cr	0.45 V	0.40 Si	Bal. Fe

(nominal analysis)

An air-hardening, high carbon, high chromium, corrosion resistant alloy. It can be described as either a high hardness Type 440C stainless steel or a corrosion resistant D2 tool steel. May be considered for many types of tooling applications where a combination of good hot hardness, toughness and abrasion resistance is required.

MICRO-MELT 420-CW ALLOY

2.25 C	0.030 S (Max.)	12.80 Cr	9.25 V
0.50 Mn (Max.)	0.90 Si	1.30 Mo	Bal. Fe

(figures are nominal except where noted)

A corrosion-resistant, high vanadium wear-resistant tool steel produced using Carpenter's Micro-Melt powder process. Comparable in wear resistance to Micro-Melt A11-LVC alloy and comparable in toughness to Micro-Melt A11 alloy. May be considered for those applications where 440C and D2 tool steels do not have adequate wear resistance or for applications where A11-LVC, A11, D2 or other tool steels do not have adequate corrosion resistance.

MICRO-MELT 20-4 ALLOY

1.90 C	0.60 Si	1.00 Mo	4.00 V
0.35 Mn	20.00 Cr	0.65 W	Bal. Fe

(figures are nominal)

Highly wear and corrosion resistant, air hardening, martensitic cold-work stainless tool steel produced using Carpenter's Micro-Melt powder metallurgy process. Uniform microstructure, fine carbide distribution, and high chromium content are responsible for an excellent combination of wear resistance, toughness, polishability and corrosion resistance.

▸ Cold Work Tool Steels

NO. 484 ALLOY (AISI TYPE A2) (UNS T30102)

1.00 C	0.30 Si	1.10 Mo	Bal. Fe
0.80 Mn	5.25 Cr	0.20 V	

(nominal analysis)

Air-hardening steel capable of hardening throughout in heavy sections. Good balance between hardness and toughness. Has been used for large blanking dies, long punches, rolls and coining dies.

Available as DeCarb-Free (DCF).

Some grades may require the purchase of a minimum heat lot quantity.

VEGA ALLOY (AISI TYPE A6) (UNS T30106)

0.70 C	0.30 Si	1.35 Mo	Bal. Fe
2.00 Mn	1.00 Cr		

(nominal analysis)

This die steel combines the deep-hardening and minimum size-change characteristics of air-hardening steels with the simplicity of low-temperature heat treatment possible in many oil-hard steels.

Available as DeCarb-Free (DCF).

CARPENTER A-8 ALLOY (AISI TYPE A8) (UNS T30108)

0.55 C	0.90 Si	5.0 Cr	0.10 V
0.30 Mn	1.3 W	1.30 Mo	Bal. Fe

(nominal analysis)

A medium-carbon, air-hardening tool steel that has been used for punches, pneumatic tools, shear blades, forming dies and blanking dies.

NO. 610 ALLOY (AISI TYPE D2) (UNS T30402)

1.50 C	0.30 Si	0.80 Mo	Bal. Fe
0.50 Mn	12.00 Cr	0.90 V	

(nominal analysis)

An air-hardening, high-carbon, high-chromium steel. Extremely high wear-resistant properties. Very deep hardening.

Available as DeCarb-Free (DCF).

SOLAR® ALLOY (AISI TYPE S2) (UNS T41902)

0.50 C	1.00 Si	0.50 Mo	Bal. Fe
0.40 Mn			

(nominal analysis)

An extremely tough water-hardening alloy. Has been used in applications where no other tool steel holds up. Sizes under 3/4" (19 mm) round will harden through.

CARPENTER S7 ALLOY (AISI TYPE S7) (UNS T41907)

0.50 C	0.30 Si	1.40 Mo	Bal. Fe
0.70 Mn	3.25 Cr		

(nominal analysis)

This air-hardening tool steel with high impact and shock resistance and good resistance to softening at moderately high temperatures is an excellent general-purpose steel. Has been used for many hot-work and cold-work applications.

Available as DeCarb-Free (DCF).

R.D.S.® ALLOY (AISI TYPE L6) (UNS T61206)

0.70 C	0.25 Si	1.75 Ni	Bal. Fe
0.35 Mn	1.00 Cr		

(nominal analysis)

An oil-hardening die steel combining extreme toughness with very little size change when heat-treated. Has been used for hobs, collets, blanking dies, punches, etc.

Available as DeCarb-Free (DCF).

440-XH® ALLOY (U.S. PATENT NO. 5,370,750)

1.60 C	0.40 Si	0.35 Ni	0.45 V
0.50 Mn	16.00 Cr	0.80 Mo	Bal. Fe

(nominal analysis)

An air hardening, high-carbon, high-chromium, corrosion-resistant alloy that can be described as either a high-hardness Type 440C stainless steel or a corrosion-resistant D2 tool steel. Possesses corrosion resistance equivalent to Type 440C stainless but can attain a maximum hardness of 64 HRC, approaching that of D2 tool steel.

CARPENTER O1 ALLOY (AISI TYPE O1) (UNS T31501)

0.90 C	0.50 Cr	0.50 W	Bal. Fe
1.20 Mn	0.20 V		

(nominal analysis)

An oil-hardening die steel safe to harden in intricate sections. A good general-purpose tool and die steel.

▸ Hot Work Die Steels

EXTENDO-DIE® HOT WORK DIE STEEL

0.45 C	1.0 Si	1.9 Mo	Bal. Fe
0.50 Mn	6.0 Cr	0.8 V	

(nominal analysis)

Extendo-Die is a premium-quality, ESR-melted, hot work die steel that has been used in mandrels and large die sections for extrusion of materials such as aluminum. The alloy has also found application for dies, inserts and cores in the die casting of aluminum alloys.

Some grades may require the purchase of a minimum heat lot quantity.

NO. 882 ALLOY (AISI TYPE H11) (UNS T20811)

0.40 C	0.90 Si	0.45 V	Bal. Fe
0.35 Mn	5.00 Cr	1.35 Mo	

(nominal analysis)

A 5% chromium hot-work tool steel combining a high-level toughness and good red-hardness. It has been widely used as a structural material for critical components in aircraft missiles.

NO. 883 ALLOY (AISI TYPE H13) (UNS T20813)

0.41 C	1.00 Si	1.40 Mo	Bal. Fe
0.35 Mn	5.35 Cr	0.90 V	

(nominal analysis)

Designed particularly for applications requiring extreme toughness combined with red-hardness. Has been used for tools subject to heavy hammer blows.

PYROTOOL® ALLOY 7 (UNS N07718)

0.05 C	52.50 Ni and Co	5.25 Co + Ta	0.60 Al
19.00 Cr	3.00 Mo	1.00 Ti	Bal. Fe

(nominal analysis)

An austenitic, precipitation-hardening, nickel-base alloy with high tensile and yield properties. Has been used for high-temperature tooling, forging dies, rams and similar applications.

PYROTOOL ALLOY A (UNS K66286)

0.04 C	0.50 Si	25.00 Ni	2.20 Ti
1.20 Mn	14.50 Cr	1.50 Mo	Bal. Fe

(nominal analysis)

High strength and good ductility at temperatures to 1200°F (649°C) are outstanding properties of this austenitic, precipitation-hardening, iron-base alloy.

PYROTOOL ALLOY W (UNS N07001)

0.05 C	19.50 Cr	3.10 Ti	1.00 Fe
0.20 Mn	4.25 Mo	1.20 Al	Bal. Ni
0.20 Si	13.00 Co		

(nominal analysis)

Austenitic, hardenable, nickel-base alloy with high strength and hardness up to 1500°F (816°C). Has been used for dummy blocks, rings, holders, mandrels.

▸ Mold Steels

STAINLESS TYPE 420 (AISI TYPE 420) (UNS S42000)

0.33 C	0.50 Si	13.50 Cr	Bal. Fe
0.40 Mn			

(nominal analysis)

Has been used for long-run molding jobs. Has provided good protection against corrosive hazards due to machine shutdowns and storage between runs, plastic compounds and humid climates.

CARPENTER NO. 158® PLASTIC MOLD STEEL (AISI TYPE P6) (UNS T51606)

0.10 C	0.30 Si	3.50 Ni	Bal. Fe
0.50 Mn	1.50 Cr		

(nominal analysis)

Case-hardening mold steel with exceptionally high strength. Electric furnace melted to provide unvarying lot-to-lot uniformity.

CARPENTER

ALLOYS	Page No.	AISI Type	UNS	ASTM	AMS	QQS
STAINLESS STEELS						
STANDARD GRADES						
Carpenter Stainless Type 302	4	302	S30200	A193, A240, A276, A313, A314, A320, A479, A492, A493, A580	5516, 5636, 5637, 5639, 5647, 5688	QQ-S-763
Carpenter Stainless Type 304	4	304	S30400	A193, A240, A276, A313, A314, A320, A479, A492, A493, A580	5513, 5639, 5688, 5647, 5697	QQ-S-763
Carpenter Stainless Type 304L	4	304L	S30403	A193, A240, A314, A276, A320, A479, A493, A580	5647, 5639	QQ-S-763
Carpenter Stainless Type 316	4	316	S31600	A193, A240, A276, A313, A314, A320, A479, A492, A493, A580	5648	QQ-S-763
Carpenter Stainless Type 316L	4	316L	S31600	A193, A240, A276, A314, A320, A479, A493, A580	5507, 5648, 5653	QQ-S-763
Carpenter Stainless Type 321	4	321	S32100	A193, A240, A276, A314, A320, A479, A580	5510, 5645, 5689	QQ-S-763
Carpenter Stainless Type 347	4	347	S34700	A193, A240, A276, A314, A320, A479, A580	5512, 5646, 5654, 5674	QQ-S-763
Carpenter Stainless Type 410	4	410	S41000	A193, A240, A276, A314, A479, A493, A580	5504, 5505, 5613, 5776	QQ-S-763
Carpenter Stainless Type 430	5	430	S43000	A276, A314, A479, A493, A580	5503, 5627	QQ-S-763
SUPER-CLEAN QUALITY (SCQ) GRADES						
304-SCQ™	5			A479		QQ-S-763
316L-SCQ®	5			A479		QQ-S-763
MACHINING GRADES						
Project 70+® Type 303	5		S30300	A314, A320, A581, A582	5640	QQ-S-764
Project 70+ Type 304/304L Stainless	5		S30400/S30403	A193, A240, A276, A313, A492, A493, A479, A580	5639, 5647	QQ-S-763
Project 70+ Type 316/316L Stainless	5		S31600/S31603	A193, A240, A276, A314, A320, A479, A493, A580	5648, 5653	QQ-S-763
Project 70+ Type 416 Stainless	6	416	S41600	A314, A581, A582	5610	QQ-S-764
Project 70+ Custom 630 Stainless	6	17-4	S17400	A564, A693, A705, F899	5643	
Project 70+ 15Cr-5Ni Stainless	6	XM-12	S15500	A564, A705, F899	5659	
302HQ-FM® Stainless	6		S30431			
Carpenter Stainless Type 303 Se	6	303 SE	S30323	A314, A320, A581, A582	5516, 5640, 5641	QQ-S-764
Stainless Type 309	6		S30900	A240, A276, A314, A479, A580	5650	QQ-S-763
Carpenter StainlessType 321	6		S32100	A193, A240, A276, A314, A320, A4719, A580	5510, 5645, 5689	QQ-S-763
Carpenter Stainless Type 347	6		S34700	A193, A240, A276, A314, A320, A479, A580	5512, 5646, 5654, 5674	QQ-S-763
Carpenter Stainless Type 416	7	#5 416	S41600	A314, A581, A582	5610	QQ-S-764
Carpenter Stainless Type 416 BQ	7		S41600	A314, A581, A582	5610	QQ-S-764
No. 5-F Stainless	7		S41600	A582		
Type 420F Stainless	7	420F	S42020	A582	5620	QQ-S-764
Type 430F Stainless	7		S43020	A314, A581, A582, A838		
Types 440F-Se Stainless	7		S44020	A582	5632	QQ-S-764
HEADING GRADES						
Carpenter Type 204-Cu Stainless	7		S20430	A313		
302HQ-FM® Stainless	7		S30431			
Carpenter 302HQ-SFQ Stainless	8		S30430	A493		
Carpenter Stainless Type 304	8		S30400	A193, A276, A320, A493, A479	5639	QQ-S-763
Carpenter Stainless Type 305	8		S30500	A193, A314, A320, A580	5685, 5686	QQ-S-763
Custom Flo 302HQ Stainless	8		S30430	A276, A493		
Carpenter Stainless No. 10 (Type 384)	8	384	S38400	A493		
Carpenter Stainless Type 410	8		S41000	A276, A479, A493, A580, F899	5613	QQ-S-763

STAINLESS STEELS Continued

ALLOYS	Page No.	AISI Type	UNS	ASTM	AMS	QQS
HEADING GRADES Continued						
Carpenter Stainless Type 430	8		S43000	A240, A276, A314, A479, A493, A580	5627	QQ-S-763
TrimRite® Stainless	8		S42010	A276. A493		
Trinamet® Stainless	8					
Type 409Cb Stainless	8		S40940	A493, A580, A959		
HEAT-RESISTING GRADES						
Type 309 Stainless	9		S30900	A276, A314, A479, A580		QQ-S-763
Type 310 Stainless	9		S31000	A276, A314, A479, A580		QQ-S-763
Type 330 Stainless	9			B511, B536	5716	
Type 446 Stainless	9			A176, A276, A314, A580		QQ-S-763
HIGH STRENGTH GRADES						
Conventionally-Hardened Grades						
Carpenter Stainless Type 410	9		S41000	A276, A479, A493, A580, F899	5613	QQ-S-763
Carpenter Stainless Type 416	9		S41600	A582	5610	QQ-S-764
Carpenter Stainless Type 416BQ	9		S41600	A582	5610	QQ-S-764
Carpenter Stainless Type 420	9		S42000	A276, A314, A580	5621	QQ-S-763
Carpenter Stainless Type 420F	10		S42020	A582	5620	QQ-S-764
Carpenter Stainless Type 431	10		S43100	A276, A314, A479, A580	5628	
TrimRite® Stainless	10		S42010	A276, A493		
Trinamet® Stainless	10					
Carpenter Stainless Type 440A	10		S44002	A276, A314, A580, F899	5631	QQ-S-763
Carpenter Stainless Type 440B	10		S44003	A276, A314, A580, F899		QQ-S-763
Carpenter Stainless Type 440C	10		S44004	A276, A314, A493, A580, A756	5630	QQ-S-763
Micro-Melt® 440C Alloy	10		S44004			
Micro-Melt 440-XH® Alloy	10					
Type 440F-Se Stainless	11		S44020	A582	5632	QQ-S-764
Carburizing Grades						
Pyrowear® Alloy 53	11		K71040		6308	
Pyrowear 675 Stainless	11		S42670		5930	
VIM-VAR 9310	11	9310	T51606	A646	6260, 6265	
VIM-VAR M-50 NIL	11		K88165		6278	
Nitrogen-Strengthened Grades						
Carpenter Stainless Type 201 Modified	11					
Carpenter Type 204-Cu Stainless	11					
Carpenter 18Cr-2Ni-12Mn Stainless	11	XM-28	S24100	A276, A314, A580		
Carpenter 21Cr-6Ni-9Mn Stainless	11	XM-11	S21904	A276, A314, A412, A479, A580	5595, 5656	
Carpenter 22Cr-13Ni-5Mn Stainless	11		S20910	A240, A276, F1314, A412, A479, A580	5764	
SeaFast® 50 Stainless	11		S20910	A276, A314, A412, A479, A580	5764	
25Cr-20Ni-6Mo Stainless	12		N08926			
7-Mo PLUS Stainless	12		S32950	A240, A479, A789, A790		
Gall-Tough® Stainless	12		S20161	A240, A276, A314, A479, A580	5931	
Gall-Tough PLUS Stainless	12		S21800/S20162	A276, A479, A580	5848	
15-15LC® Modified Stainless	12					
15-15HS® Stainless	12					
15-15HS® Max Stainless	12					
SCF 19® Alloy	13					
Precipitation-Hardenable Grades						
Carpenter 15Cr-5Ni Stainless	13	XM-12	S15500	A564, A705, F899	5659, 5862	
Carpenter 15-7PH Stainless	13		S15700			
Custom 450® Stainless	13	XM-25	S45000	A564, A693, A959	5763, 5773, 5863	
Custom 455® Stainless	13	XM-16	S45500	A564	5617, 5860	
Custom 465® Stainless	13		S46500	A564	5936	
Custom 475® Stainless	13					
Carpenter 275 Stainless	13					
Carpenter Stainless Custom 630	14		S17700	A313	5528, 5678	
Carpenter Stainless Custom 631	14		S17700	A313	5528, 5678	

CARPENTER

ALLOYS	Page No.	AISI Type	UNS	ASTM	AMS	QQS
STAINLESS STEELS Continued						
HIGH STRENGTH GRADES Continued						
Carpenter 13-8 Stainless	14	XM-13	S13800	A564, A693, A705	5629	
Alloy A-286	14	660	S66286	A453, A638	5525, 5731, 5732, 5734-5737, 5895	
Pyromet® Alloy 350	14	633	S35000		5548, 5745	
Pyromet Alloy 355	14	634	S35500	A564	5743, 5744	
SUPERIOR CORROSION RESISTANT ALLOYS						
Carpenter Alloy 925	14					
20Cb-3® Stainless	15		N08020	B462, B463, B464, B473, B729		
20Mo-6 HS Stainless	15		N08036			
22Cr-13Ni-5Mn Stainless	15		S20910	A240, A276, A412, A479, A580	5764	
SeaFast® 50 Stainless	15		S20910	A276, A314, A412, A479, A580	5764	
25Ni-20Cr-6Mo Stainless	15		N08926			
Carpenter Alloy C-276	15		N10276	B574		
Custom Age 625 PLUS® Alloy	15		N07716	B805	5854	
7-Mo PLUS® Stainless	15		S32950	A240, A479		
Duplex Alloy 255	16		S32550	A240, A276, A479		
Carpenter L-605 Alloy	16		R30605	F90	5537, 5759	
MP35N Alloy	16		R30035	F562, F688	5758, 5844, 5845	
Pyromet® Alloy 625	16		N06625	B446, B564	5599, 5666, 5837	
Pyromet Alloy 718	16		N07718	B637, B670	5596, 5662-5664	
Carpenter Nickel-Copper 400	16		N04400	B164, B564	4544	
SCF 19® Alloy	16					
Alloy 2 (AMS 5842)	16		R30159		5841, 5842, 5843	
Micro-Melt® CCW Alloy	16					
MEDICAL ALLOYS						
BioDur® 108 Alloy	17		S29108	F2229		
BioDur Type 316LS Stainless	17		S31673	F138, F139		
BioDur 22Cr-13Ni-5Mn Stainless	17			F1314		
BioDur 734 Stainless	17					
TrimRite® Stainless	17		S42010	A276		
Custom 450® Stainless	17	XM-25	S45000	A564, A693, A705, F899	5763, 5773, 5859, 5863	
Custom 455® Stainless	18	XM-16	S45500	A313, A564, A693, A705, F899	5617, 5860	
Custom 465® Stainless	18		S46500	A564		
Custom 475® Stainless	18					
Micro-Melt® BioDur®	18					
Custom 470 FM Alloy	18					
Custom 630 Stainless	18	XM-7	S17400	A564, A693, A705, F593, F594, F899	5604, 5622, 5643	
BioDur Carpenter CCM® Alloy	18		R31537	F75, F799, F1537		
Micro-Melt® BioDur Carpenter CCM Alloy	18			F75, F799, F1537		
BioDur CCM PLUS® Alloy	18		R31538	F75, F799, F1537		
REINFORCING BAR ALLOYS						
EnduraMet® 32 Stainless	19					
EnduraMet 2205 Stainless	19		S31803	A955		
EnduraMet 316LN Stainless	19		S31653	A314, A580, A955		
EnduraMet 33 Stainless	19			A314, A58		

ALLOYS	Page No.	AISI Type	UNS	ASTM	AMS	QQS
AEROSPACE AND HIGH TEMPERATURE ALLOYS						
ALLOYS WITH MAXIMUM SERVICE TEMPERATURES TO 750°F (399°C)						
AerMet® 100 Alloy	19		K92580		6478, 6532	
AerMet 310 Alloy	19					
AF1410/High Carbon AF1410	19					6527
MP35N Alloy	20					
Carpenter Ferrium S53 Alloy	20				5922	
ALLOYS WITH MAXIMUM SERVICE TEMPERATURES BETWEEN 750 AND 1000°F (399 AND 539°C)						
Consumet® H-46	20					
Carpenter C-276 Alloy	20		N10276	B574, B575	5530	
Custom Age 625 PLUS® Alloy	20		N07716	B805	5854	
Alloy 2 (AMS 5842)	20		R30159		5841, 5842, 5843	
ALLOYS WITH MAXIMUM SERVICE TEMPERATURES BETWEEN 1000 AND 1250°F (539 AND 677°C)						
Pyromet® Alloy A-286	20	660	S66286	A453, A638	5525, 5731, 5732,	
Pyromet Alloy 718	20		N07718			
636 Alloy	20	616	S42200	A565	A5655	
AMS 5616 Alloy	21	615	S41800	A565	5616, 5508	
Lapelloy "C" Alloy	21					
Moly Ascoloy	21		K64152	A565	5719	
Pyromet Alloy 800	21		N08800	B408, B564	5766	
Pyromet Alloy CTX-3	21		N11907			
Pyromet Alloy CTX-909	21		N11909		5844, 5893	
Thermo-Span® Alloy	21					
Pyromet Alloy 706	22		N09706	5701, 5702, 5703		
ALLOYS WITH MAXIMUM SERVICE TEMPERATURES BETWEEN 1250 AND 1500°F (677 AND 816°C)						
Pyromet Alloy 720	22					
Pyromet Alloy X-750	22	668	N07750		5667, 5568-5671	
Pyromet Alloy 751	22					
Pyromet Alloy 80A	22		N07080	B637		
Pyromet Alloy 31V	22		N07031	B637		
Pyromet Alloy 901	22	681, 682	N09901		5660, 5661	
Carpenter 286-LNi Alloy	22					
ALLOYS WITH SERVICE TEMPERATURES ABOVE 1500°F (816°C)						
Type 330 Stainless	23		N08330	B511, B536	5716	
Carpenter L-605 Alloy	23		R30605	F90	5759, 5537	
Pyromet Alloy 41	23	683	N07041		5712, 5713, 5800	
Pyromet Alloy 600	23		N06600	B564	5540, 5665, 5687	
Pyromet Alloy 601	23				5870	
Pyromet Alloy 625	23		N06625	B446	5536, 5754, 5798	
Pyromet Alloy 680	23		N06002	B572	5536, 5754, 5798	
Waspaloy	23	685	N07001	B637	5704, 5706-5709,	
BEARING ALLOYS						
Carpenter Stainless Type 440C	23		S44004	A276, A314, A493, A580, A756, F899	5618, 5630, 5880	QQ-S-763
Micro-Melt® 440C Alloy	23	S44004				
Micro-Melt M62 Alloy	24					
Micro-Melt 440-XH® Alloy	24					
Pyrowear® 675 Stainless	24				5930	
VIM-VAR 52100	24	E52100	G52986	A295, A535	6440, 6444	QQ-S-624C
VIM-VAR M-50	24	M-50	K88165		6490, 6491	
VIM-VAR M-50 NIL	24		K88165		6278	
NICKEL-COPPER ALLOYS						
Carpenter Nickel-Copper 400	24		N04400	B164	4675	QQ-N-281

ALLOYS	Page No.	AISI Type	UNS	ASTM	AMS	QQS
HIGH STRENGTH ALLOYS						
No. 882 Alloy	24	H11	T20811	A681	6437, 6485, 6487, 6488	
AF1410/High Carbon AF1410	25				6527	
NiMark® Alloy 250	25				6512, 6520	
NiMark Alloy 300	25				6514	
AerMet® 100 Alloy	25		K92580		6478, 6532	
AerMet 310 Alloy	25					
AerMet 340 Alloy	25					
Carpenter Ferrium S53 Alloy	25				5922	
GEAR ALLOYS						
Pyrowear® Alloy 53	25		K71040		6308	
Pyrowear 675 Stainless	26		S42670		5930	
VIM-VAR 9310	26	9310	T51606	A646	6260, 6265	
VALVE ALLOYS						
21-12N Valve Steel	26		S63017			
C-XB Alloy	26		S65006		5710	
NCF 3015 Alloy	26					
Pyromet® Alloy 31V	26					
Pyromet Alloy 751	26					
Pyromet Alloy 80A	26		N07080	B637		
MAGNETIC, CONTROLLED EXPANSION AND ELECTRONIC ALLOYS						
SOFT MAGNETIC IRON ALLOYS						
Electrical Iron	27			A848		
Consumet® Electrical Iron	27			A848		
Vacumet® Core Iron	27			A848		
Vacumet Consumet Core Iron	27					
MAGNETIC SILICON-IRON ALLOYS						
Silicon Core Iron "A"	27			A867		
Silicon Core Iron "A -FM"	27			A867		
Silicon Core Iron "B"	27			A867		
Silicon Core Iron "B-FM"	27			A867		
Silicon Core Iron "B2"	28			A867		
Silicon Core Iron "C"	28			A867		
SOFT MAGNETIC CHROMIUM-IRON (FERRITIC STAINLESS) ALLOYS						
Carpenter Stainless Type 430FR Solenoid Quality	28			A838		
Chrome Core® 8 Alloys	28					
Chrome Core 12-FM Alloy	28					
Chrome Core 13-FM Alloy	28					
Chrome Core 13-XP Alloy	28					
Chrome Core 18-FM Stainless	28					
Chrome Core 29 Alloy	28					
SOFT MAGNETIC NICKEL-IRON ALLOYS						
High Permeability "36" Alloy	29		K93603			
Carpenter High Permeability "45" Alloy	29	K94490	A753			
Carpenter High Permeability "49"® Alloy	29		K94840	A753		
High Permeability "49" FM Alloy	29					
High Permeability "55" Alloy	29					
Hipernom® Alloy	29		N14080	A753	7701, 7702	
HyMu "77" Alloy	29		N14076	A753	7701, 7702	
HyMu "77" Plus Alloy	29				7701, 7702	

MAGNETIC, CONTROLLED EXPANSION AND ELECTRONIC ALLOYS Continued

RESISTANCE ALLOYS

HEATING ELEMENT ALLOYS

THERMOCOUPLE ALLOYS

HIGH-NICKEL ALLOYS

BORATED STAINLESS STEELS*

*Sold by Carpenter Powder Products, a business unit of Carpenter Technology Corporation.

TOOL AND DIE STEELS

MICRO-MELT® HIGH SPEED STEELS

TOOL AND DIE STEELS Continued

APPENDIX A-CORROSION CONTROL

All metals and alloys are susceptible to corrosion in some environments and, therefore, no single metal or alloy is suitable for all applications. For example, gold, which historically is known for its excellent resistance to the atmosphere, will corrode if exposed to mercury at ambient temperature. On the other hand, iron is relatively inert to mercury but corrodes readily in the atmosphere.

Fortunately, one or more materials will perform satisfactorily in a given environment. The stainless steels are versatile in that they are resistant to corrosion in a wide range of environments.

The Problem of Corrosion

Selecting a material with inadequate corrosion resistance for a particular application can be a costly mistake. Direct and indirect economic losses which can result from corrosion include expenses due to:

1. Replacement of corroded equipment.
2. Overdesign to allow for corrosion.
3. Shutdown of equipment because of a corrosion failure.
4. Loss of a product, such as a container that corroded through.
5. Contamination of a product.
6. Loss of efficiency. For example, corrosion product lowers heat transfer rate in heat exchangers.

Some of these indirect losses, such as loss due to shutdown of equipment, can cost many times more than the difference between buying a material that would have performed satisfactorily and one that did not. Be sure to consider potential indirect losses due to corrosion when making a material selection.

Corrosion can also constitute a significant safety hazard, for example, in containers for toxic products (poisonous gases, etc.) and critical parts in transportation media.

The Special Case of Stainless Steel

The fundamental resistance of stainless steel to corrosion occurs because of its ability to form a protective coating on its surface. This coating is a passive film which is resistant to further oxidation or other forms of chemical attack. This passive film may be monomolecular in thickness, usually invisible, but generally protective in oxidizing environments such as air and nitric acid. The passive film will, however, tend to lose its protectiveness in reducing environments such as hydrochloric acid. Whether an environment is oxidizing or reducing is not always a function of its oxygen content. For example, different aqueous solutions can oxidize the surface of a metal to different degrees independent of their oxygen content. Also, the oxidizing power of the given solution may change with concentration, temperature and impurity content.

Chromium is the most important element in maintaining the passive film. With free chromium (not present as carbides or other compounds) in excess of about 11%, steels do not typically form red rust, and so they are called “stainless.” Increasing the chromium content of the stainless steel invariably broadens the range of environments which are sufficiently oxidizing to maintain a passive film. Alloying additions of nickel and molybdenum also expand the range of passivity.

Fundamental to most types of corrosion to which stainless steels are subject is that halogen salts, primarily chlorides, easily penetrate the passive film and allow corrosive attack to occur. Chlorides are abundant in nature and are used extensively for de-icing, cooking, etc. Chlorides are soluble, active ions and the basis for good electrolytes—good conditions for chemical attack or corrosion.

More information about controlling corrosion in a variety of alloys is available in Carpenter’s Alloys for Corrosive Environments booklet. Visit www.cartech.com and select Product Literature to request a copy.

Types of Corrosion

Corrosion can be divided into two basic types:

1. **General Corrosion** in which the metal corrodes at a uniform rate over the entire surface; and
2. **Localized Corrosion** in which only a small area of the metal surface is affected but the rate of corrosion in this small area is relatively high. These types of localized corrosion are discussed in detail in Carpenter’s booklet, “Alloys for Corrosive Environments.”
    a. Intergranular Corrosion
    b. Pitting Corrosion
    c. Crevice Corrosion
    d. Galvanic Corrosion
    e. Stress-Corrosion Cracking

Corrosion Testing

Selection of appropriate corrosion tests requires consideration of the potential forms of corrosion, details of the service environment and the material composition and fabrication. Some of the factors affecting corrosion are presented above.

Corrosion evaluation methods can be divided into simulated service and accelerated tests. In a simulated service test, both environment and material condition are similar to that in service. Long-term exposures can be required for a proper evaluation. Accelerated tests are designed to detect the susceptibility of a material to one or more forms of corrosion in a relatively short period of time.

Intergranular Corrosion. The standard tests for intergranular attack are generally viewed as accelerated techniques and often are used to verify that the material received a good anneal. The ASTM standards are listed in *Table 1*. Each ASTM designation is applicable to different alloys or material conditions: A 262 for austenitic stainless steels, A 763 for ferritic stainless steels and G 28 for wrought, nickel-rich, chromium-bearing alloys.

Pitting and Crevice Corrosion. ASTM G 48 describes accelerated tests for pitting and crevice corrosion in ferric chloride or ferric chloride-hydrochloric acid. Samples (with or without crevices) may be exposed at one constant temperature and evaluated by weight loss and appearance. Alternatively, the critical temperature for attack may be determined by exposing several sets of specimens at increasing temperatures and recording the temperature at which attack occurs. Critical pitting temperature can also be determined electrochemically using ASTM G 150.

Cracking. The boiling magnesium chloride test of ASTM G36 has been used extensively to evaluate resistance to stress-corrosion cracking at elevated temperature, but this test is much more severe than most service environments. An alternative environment, which may be more useful to predict service experience, is found in ASTM G 123 and consists of boiling 25% NaCl acidified to pH 1.5 with phosphoric acid.

Cracking that occurs at lower temperatures can be studied using the salt spray test of ASTM B117 at 95°F (35°C). If hydrogen sulfide is present, sulfide-stress-cracking resistance can be evaluated using NACE TM0177 which involves exposing stressed samples to an acidified H_2S environment.

Cracking is possible in other than chloride environments. For example, sensitized Type 304 can be cracked in polythionic acid,produced when hydrogen sulfide and sulfur dioxide are bubbled through water. The evaluation test is found in ASTM G 35.

Several methods are available to externally stress samples for exposure to corrosive environments. Sample configurations include U-bends (ASTM G 30), bent beams (ASTM G 39), C-rings (ASTM G 38) and tensile samples (ASTM G 49). C-rings and tensile samples can be notched to change the stress state and increase the likelihood that failure will occur in a predetermined area. Some notched samples can be fatigue pre-cracked to study crack propagation. Examples of such specimens are wedge open load, compact tension, cantilever beam and double cantilever beam. In addition, slow strain rate tests, which evaluate stress corrosion resistance by slowly pulling a specimen to failure in a corrosive environment, are found in ASTM G 129.

Test samples for the evaluation of weldments are described in ASTM G 58. These include samples using the residual stresses from welding as well as externally stressed or pre-cracked specimens.

Corrosion in Atmospheres. Three tests have been widely used for stainless steels. All are performed in controlled-atmosphere chambers. The mildest, 100% humidity at 95°F, simulates storage or use in many damp environments. The 5% salt spray (sodium chloride) of ASTM B 117 is more aggressive and has been used to simulate exposure to road salt or marine environments. The Copper-Accelerated Acetic Acid-Salt Spray test (ASTM B 368) is an even more severe test in which 5% sodium chloride with a copper II chloride addition is acidified using acetic acid. This test and the Salt Spray test are not suggested for all grades of stainless steels.

Table 1 – ASTM Intergranular Corrosion Tests

ALLOY SYSTEMS	ASTM STANDARD	TEST MEDIA	TEST DURATION
Austenitic stainless steels	A 262-A A 262-B A 262-C A 262-E	Oxalic acid etch Ferric sulfate-sulfuric acid Nitric acid (Huey test) Copper sulfate - 16% sulfuric acid (copper contact)	Etch test 120 hours 240 hours 24 hours
Wrought nickel-rich, chromium-bearing alloys	G 28-A G 28-B	Ferric sulfate - sulfuric acid Mixed acid-oxidating salt	24/120 hours 24 hours
Ferritic stainless steels	A 763-W A 763-X A 763-Y A 763-Z	Oxalic acid etch Ferric sulfate - sulfuric acid Copper sulfate - 50% sulfuric acid Copper sulfate - 16% sulfuric acid (copper contact)	Etch test 24/120 hours 96/120 hours 24 hours

Importance of Cleaning and Passivating

The corrosion-resisting qualities of stainless steels are inherent in the metal itself. However, contamination of the surface by adhering dirt or scale can have a deleterious effect. For this reason, surfaces must be free of scale, lubricants, foreign particles and coatings applied for drawing and heading. After fabrication of parts, cleaning and/or passivation should be considered.

Passivation maximizes the inherent corrosion resistance of stainless steel. Perhaps the best test to confirm that passivation has been effective is a 24-hour exposure to 100% humidity at 95°F. For more information on cleaning and passivation, turn to page 63.

APPENDIX B-MAGNETIC PROPERTIES OF STAINLESS STEELS

The magnetic behavior of stainless steels varies considerably, ranging from paramagnetic (non-magnetic) in fully austenitic grades to hard or permanent magnetic behavior in the hardened martensitic grades. Stainless steels have not found widespread use solely as magnetic materials since their magnetic capability is almost always inferior to conventional magnetic materials. However, there are circumstances and applications where the magnetic or non-magnetic behavior can significantly influence fabrication and use of these alloys.

Austenitic (non-magnetic) Stainless Steels

All austenitic stainless steels are paramagnetic (non-magnetic) in the fully austenitic condition as occurs in well-annealed alloys. The DC magnetic permeabilities range from 1.003 to 1.005 when measured at magnetizing forces of 200 oersteds (16k A/m). The permeability increases with cold work due to deformation-induced martensite, a ferromagnetic phase. For certain grades such as Types 302 and 304, the increase in magnetic permeability can be appreciable, resulting in these grades being weakly ferromagnetic in the heavily cold-worked condition. The susceptibility of a particular grade to becoming ferromagnetic when heavily cold worked depends on the stability of the austenite, which, in turn, depends on chemical composition and homogeneity. This is described in the article "Stability of Austenite in Stainless Steels" by C. B. Post and W. S. Eberly, published in "Transactions of the American Society for Metals," volume 39, (1947), pages 868 to 890.

The effect of cold work on magnetic permeability is illustrated for several austenitic stainless steels in *Figure 1*. The relationship between ultimate tensile strength and magnetic permeability is shown in *Figure 2*. The rise in permeability correlates well with the increase in tensile strength or work-hardening behavior, which is another measure of austenite stability. The differing performance between grades is a reflection of their composition. In particular, nickel increases austenite stability, thereby decreasing the work-hardening rate and the rate of increase of magnetic permeability. Consequently, the higher nickel grades, such as Carpenter Stainless No. 10 (Type 384), exhibit lower magnetic permeabilities than the lower nickel grades such as Project 70+® Type 304/304L when cold worked in equivalent amounts. The high-manganese, high-nitrogen alloys, such as Carpenter 18Cr-2Ni-12Mn, are also noted for maintaining low permeability after heavy deformation.

The magnetic permeabilities achievable in austenitic stainless steels are very low compared with conventional magnetic materials such as silicon-iron alloys. Therefore, their non-magnetic behavior is more of a concern. Certain uses such as housings and components for magnetic detection equipment used for security, measuring and control purposes require that the steel be non-magnetic. That is because the presence of even weakly ferromagnetic parts can adversely affect performance. Unless the austenitic stainless steel parts are used in the annealed condition and are not subjected to deformation during use, a higher nickel grade would be a prudent choice assuming it offered the appropriate corrosion resistance and strength.

For a given grade, the magnetic permeability can vary significantly depending on the chemistry and degree of cold work of the steel. Often a particular lot of an "unstable" grade such as Type 304 can perform satisfactorily. If the magnetic permeability of an austenitic stainless steel is of particular concern, it can be measured by relatively simple means as described in ASTM Standard Method A342.

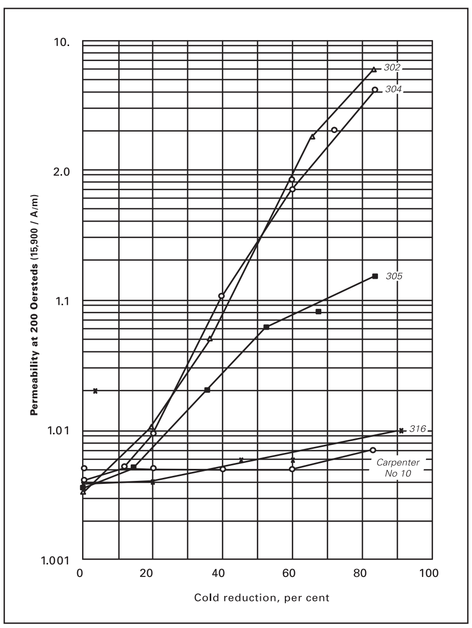


Figure 1: When cold working is employed, some normally non-magnetic austenitic steels become substantially ferromagnetic.

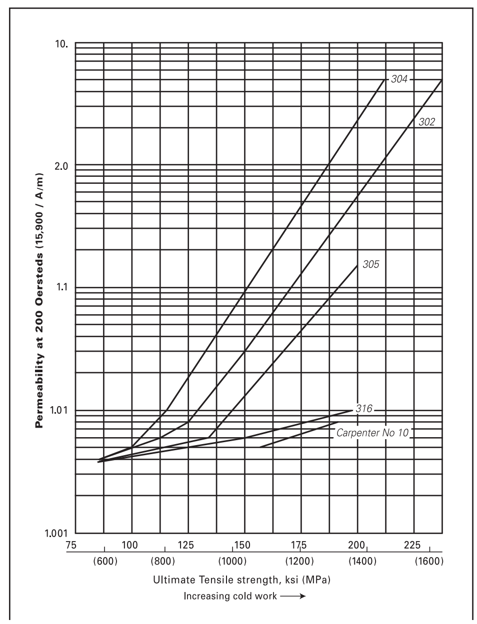


Figure 2: Magnetic permeability of austenitic alloys subjected to cold working can also be expressed as a function of tensile strength.

Ferritic Stainless Steels

Ferritic stainless steels are ferromagnetic and have been used as soft magnetic components such as solenoid cores and pole pieces. Although their magnetic properties are not generally as good as conventional soft magnetic alloys, they are successfully used for magnetic components which must withstand corrosive environments. As such, they offer a cost-effective alternative to plated iron and silicon-iron components. In addition, the relatively high electrical resistivity of ferritic stainless steels has resulted in superior AC performance.

Soft magnetic properties, i.e., high magnetic permeability, low coercive force (H_c) and low residual induction (B_r), depend strongly on alloy chemistry, particularly impurities such as carbon, sulfur and nonmetallic inclusions and stresses due to cold working. Magnetic permeability decreases and the coercive force increases. That is, the behavior is less magnetically soft, with increasing amounts of impurities and stress. As a result, well-annealed, high-purity alloys yield optimum magnetic performance. Carpenter produces two grades of ferritic stainless steel, Carpenter Stainless Type 430F Solenoid Quality and Carpenter Stainless Type 430FR Solenoid Quality, for consideration in soft magnetic alloy applications. These two grades are melted and processed for consistent magnetic properties while offering corrosion resistance similar to that of Type 430F.

Even if a ferritic stainless steel is not being used as a magnetic component, its magnetic behavior can be of significance to fabrication and use. Annealed ferritic stainless steels exhibit soft magnetic behavior, which means they do not have the ability to attract other magnetic objects when removed from an externally applied magnetic field. Cold working, however, increases the coercive force (H_C) of these steels changing their behavior from that of a soft magnet to that of a weak permanent magnet. If parts of cold worked ferritic stainless steel are exposed to a strong magnetic field such as occurs in magnetic particle inspection, the parts can be permanently magnetized and, therefore, able to attract other ferromagnetic objects. Apart from possibly causing handling problems, the parts would be able to attract bits of iron or steel which will, if not removed, impair corrosion resistance. It is therefore prudent to either electrically or thermally demagnetize such parts if they have been subjected to a strong magnetic field during fabrication. Magnetic properties of some ferritic stainless steels are listed in *Table 1*.

Martensitic and Precipitation Hardenable Stainless Steel

All martensitic and most precipitation hardenable stainless steels are ferromagnetic. Due to the stresses induced by the hardening transformation, these grades exhibit permanent magnetic properties if magnetized in the hardened condition. For a given grade, the coercive force tends to increase with increasing hardness, rendering these alloys more difficult to demagnetize. Although not used as permanent magnets to any significant extent, the previously mentioned potential difficulties of hardened ferritic stainless steels also apply to these steels. Magnetic properties of some martensitic steels are also shown in *Table 1*.

Table 1 – Magnetic Properties of Some Ferritic and Martensitic Stainless Steels

GRADE	CONDITION	ROCKWELL HARDNESS	MAXIMUM RELATIVE PERMEABILITY	ROCKWELL	
				OERSTEDS	A/M
Type 410 (Martensitic)	A H	B 85 C 41	750 95	6 36	480 2900
Type 416 (Martensitic)	A H	B 85 C 41	750 95	6 36	480 2900
Type 420 (Martensitic)	A H	B 90 C 50	950 40	10 45	800 3600
Type 430F Solenoid Quality (Ferritic)	A	B 78	1800	2	160
Type 430FR Solenoid Quality (Ferritic)	A	B 82	1800	2	160
Type 440B (Martensitic)	H	C 55	62	64	5100
Type 446 (Ferritic)	A	B 85	1000	2	360

Above data determined on round bars 0.375" (9.53 mm) to 0.625" (15.88 mm) per ASTM A 341-Fahy permeameter.
A—fully annealed H—heat treated for maximum hardness

APPENDIX C-FABRICATING CARPENTER STAINLESS STEELS

This section will share general knowledge of the methods of fabrication. We will discuss relative workability of selected alloys; forging; blanking, punching, shearing and perforating; annealing and heat treating; cleaning and passivating; tumbling and ball burnishing; machining and abrasive wheel grinding; heading; drawing, forming and spinning; soldering and brazing; welding; and galling prevention of Carpenter stainless steels.

The following industry associations and technical societies are good resources for additional information:

American Iron and Steel Institute
www.aist.org

ASM International
www.asminternational.org

ASTM International
www.astm.org

American Welding Society, Inc.
www.aws.org

Forging Industry Association
www.forging.org

Industrial Fasteners Institute
www.industrial-fasteners.org

National Association of Corrosion Engineers
www.nace.org

Precision Machined Products Association
www.pmpa.org

Wire Association International
www.wirenet.org

Relative Workability of Selectaloy Stainless Steels - Annealed Condition

E-Excellent F-Fair NR-Not Recommended
G-Good P-Poor

CARPENTER STAINLESS STEEL	BALL BURNISHING (TUMBLING)	BLANKING	BRAZING (SEE NOTE NO. 1)	BUFFING (SEE NOTE NO. 2)	COINING (COLD)	DEEP DRAWING AND STAMPING	ELECTROLYTIC POLISHING	EMBOSSING	ETCHING
Project 70+® Type 304/304L)	E	G	G	E	G	G	E	G	Aqua Regia
Project 70+ Type 316/316L	E	G	G	E	G	G	E	G	Aqua Regia
20Cb-3® Stainless	E	G	G	E	G	G	E	G	Aqua Regia
Type 430	E	G	G	E	E	G	E	G	50-50 Hydro-chloric
Type 409Cb	E	G	G	E	E	G	E	G	50-50 Hydro-chloric
Type 410	E	G	G	E	G	F	E	G	50-50 Hydro-chloric
Type 420	E	G	G	E	G	P	G if hardened otherwise F	G	50-50 Hydro-chloric
Type 431	E	G	G	E	G	F	G	F	50-50 Hydro-chloric
Type 440C	E	G	F	E	F	NR	G if hardened	P	50-50 Hydro-chloric
Custom 450® Stainless	—	G	E to G	E	G to F	P to F	P to E	—	Special*
Custom 455® Stainless	—	G	F	E	F to G	P to F	G to E	—	Special*

FORGING HOT	FORGING COLD	FORMING	GRINDING (EASE)	GRINDING (IS IT MAGNETIC?)	HEADING HOT	HEADING COLD	HOBBING	MACHINABILITY % OF 1212 (SEE NOTE NO. 3)	PUNCHING (PERFORATING) (SEE NOTE NO. 4)
G	G	E	F	No	G	F	P	62	Yes
G	G	E	F	No	G	F	P	57	Yes
G	G	G	F	No	G	G	P	42	Yes
G	G	G	F	Yes	G	E	G	57	Yes
G	G	G	F	Yes	G	E	G	57	Yes
G	G	G	F	Yes	G	E	G	57	Yes
G	Slight	F	F	Yes	G	F	G	52	Yes
G	G	F	F	Yes	G	G	G	49	Yes
G	P	P	G	Yes	G	F	F	39	Yes
E	F	G	G	Yes	E	G	F	43	Yes
E	F	G	G	Yes	E	G	F	40	Yes

Note 1 - Brazing: Caution should be used in brazing or hard soldering stainless steels. See fabricating instructions.
Note 2 - Polishing: While the finish obtained on free-machining grades is good, there is a slight tendency to "pin feather drag."
Note 3 - Machining: For more complete information on machining, refer to the booklet "Guide to Machining Carpenter Specialty Alloys."
Note 4 - Punching (perforating): Generally, the free-machining grades and the ferritic/martensitic steels perforate very well. The austenitic grades tend to drag on the break. On all types, stepped punches are desirable.

Terms: Excellent, good, fair, etc., are relative among the several stainless steels. Grades marked "excellent" represent the best conditions. "Good" means that this operation presents no difficulties important enough to interfere with the selection of that particular steel, if its other properties are desirable. "Slight" means that the steel will stand a certain amount of such working but not as much as steels rated "good."

*50 ml Dist. H_2O, 50 ml Ethyl Alcohol, 50 ml Methyl Alcohol, 50 ml HCl (37-38%), 2.5 ml H NO_3, 1 gm cupric chloride, 3.5 gm ferric chloride.

Relative Workability of Selectaloy Stainless Steels—Annealed Condition (Continued)

E-Excellent F-Fair NR-Not Recommended
G-Good P-Poor

CARPENTER STAINLESS STEEL	PRESS BRAKE FORMING	POLISHING SETUP WHEELS (SEE NOTE NO. 2)	RIVETING (COLD)	ROLL FORMING	ROLL THREADING	SHEARING (COLD) (SEE NOTE NO. 5)	SAWING (SEE NOTE NO. 6)	SLITTING
Project 70+® Type 304/304L	G	E	F	E	G	G	F	G
Project 70+ Type 316/316L	G	E	F	E	G	G	F	G
20Cb-3® Stainless	G	E	G	E	G	G	F	G
Type 430	G	E	E	E	E	G	F	G
Type 409Cb	G	E	E	E	E	G	F	G
Type 410	G	E	G	G	E	G	G	G
Type 420	F	E	F	F	F	F	F	F
Type 431	E	E	G	F	G	G	G	G
Type 440C	P	E	F	P	F	F	F	Not made as sheet or strip
Custom 450® Stainless	F	G	G	G	G	G	F	G
Custom 455® Stainless	F	G	G	G	G	G	F	G

SOLDERING SOFT	SOLDERING HARD (SEE NOTE NO. 7)	SURFACE HARDENING (SEE NOTE NO. 8)	SPINNING (SEE NOTE NO. 9)	SWAGING	UPSETTING (HOT)	UPSETTING (COLD)	WELDING (FUSION AND RESISTANCE) (SEE NOTE NO. 10)	IN ALL HOT WORKING OPERATIONS, LOOK OUT FOR…
G	G	G	G	G	G	F	E	Intergranular corrosion—anneal afterward.
G	G	G	G	G	G	F	E	Intergranular corrosion—anneal afterward.
G	G	G	G	G	G	G	G	Intergranular corrosion—anneal afterward.
G	G	G	G	G	G	E	F	Grain Growth
G	G	G	G	G	G	E	F	Grain Growth
G	G	G	G	G	G	G	G	Air Hardening
G	G	G	P	F	G	F	F	Air Hardening
G	F	G	F	G	G	G	F	Air Hardening
F	F	G	NR	Slight	G	F	NR	Air Hardening
—	G	G	—	G	E	F	G	None
—	F	G	—	G	E	F	F	Grain Growth

Note 5 - Shearing (cold): On all stainless, reduce the speed of the press to about 75% of normal, use shear angle, when possible, on punch or shear blade to relieve high pressures.

Note 6 - Sawing: Band saws for use with stainless have 14 teeth per inch, running at about 110 feet per minute—hacksaws, 6 to 10 teeth per inch and 60 strokes per minute. If band saws are used with over 15 and up to 18 teeth per inch, cut speed to 100 feet per minute.

Note 7 - Hard Soldering: If temperatures above 1400°F (760°C) are involved, the martensitic grades will harden and must be tempered subsequently.

Note 8 - Surface Hardening: Very high surface hardness can be obtained to a depth of .004 to .018" (0.10-0.45 mm) by nitriding. This will reduce corrosion resistance to some extent.

Note 9 - Spinning: Carpenter Stainless Type 304 is the best in the austenitic group. The martensitic/ferrite/age hardening steels do not work-harden as rapidly as the austenitic steels.

Note 10 - Welding: See fabrication instructions on page 73 for more complete information.

FORGING CARPENTER STAINLESS STEELS

In all metalworking operations stainless steel can be easily worked when the characteristics of these alloys are understood. Stainless steels have good inherent forgeability, but there are important differences from the carbon and low-alloy steels.

Most importantly, stainless steels are much stronger at forging temperatures and thus require greater force or more blows under a hammer than is required for leaner alloys. The high temperature alloys are even harder and more resistant to flow in forging operations.

All stainless steels have much lower thermal conductivity than ordinary steel—thus the heat penetrates the steel more slowly. The best results are obtained in a muffle or semimuffle type of furnace with pyrometer control. Keep open flames away from the steel.

As shown in the chart on page 61, the forging temperature depends upon the type of steel—austenitic, martensitic, ferritic, duplex or precipitation hardenable, with a few special cases. There is no simple rule to follow for thermal handling on either heating or cooling. The suggested forging temperatures should be attained by heating in furnaces held at those temperatures (all temperatures are furnace temperatures, not die temperatures). The furnace must not be run excessively hot and the steel withdrawn "on the fly" as it rushes up to the forging heat. This gives a wash heat on the surface and a cold center.

Hold the heating furnace steady at the proper forging temperature and no hotter; allow the steel to soak out a little before withdrawing, and it will flow readily under the dies. In order not to slow down the forging operation and still run the furnace at a "slow" heat, more bars or billets can usually be heated at one time.

Most grades are subject to rapid grain growth at the forging heat. If all parts of the steel are thoroughly forged after heating, the grain structure will be refined again. If some parts of the forging get little reduction under the hammer, care must be exercised to limit grain growth by avoiding a long soak at temperature.

Surface preparation of forging bars and billets is generally more critical for stainless steels for several reasons. One example is the aircraft industry, which demands close tolerances for weight economy. This allows little or nothing for removing defects from finished parts. Any forging job will cost less if no defects must be removed because of poorly prepared stock.

Lastly, stainless steels require special heat treatments after forging to obtain best corrosion resistance and mechanical properties. (See the chart.) Briefly, the austenitic, ferritic and duplex grades should be annealed for optimum corrosion resistance; the martensitic grades are air-hardening and require slow cooling after forging plus subsequent annealing to prevent cracking; and the precipitation hardenable grades require a solution anneal for optimum aging response.

Carpenter practices have been perfected for developing stainless steels that have optimum forgeability as opposed to, say, optimum machinability. The factors that contribute to good inherent forgeability in Carpenter stainless steel are as follows:

1. Controlled melting process for sounder centers, cleaner metal and less center segregation.
2. Balanced analysis for better metal flow, reduced hot shortness, and less in-process preparations.
3. Rare earth additions to highly alloyed austenitic grades such as 20Cb-3® stainless for reduced hot shortness and better yields.

Every metal fabricator who hot-works steels and alloys knows how important it is to determine the best temperature range for forging each grade. The more narrow the forging range, the more critical the problem becomes.

Many tests used to predict hot-working temperature ranges are helpful in that they offer a rough measure of forgeability over a given range, but they do not give specific values. This has forced forgers to rely on approximate temperatures which, in many cases, are not the best ones for the material being worked.

Hot tensile ductility is often used to determine the forging temperature range for a given alloy. Evaluation is performed using a Gleeble thermomechanical testing unit. The main feature of the unit is the ability to reproduce any desired thermal cycle on a test specimen via resistive heating.

Whereas inherent forging quality is melted into stainless steels, there is another equally important aspect to Carpenter forging quality: mechanical forgeability. This includes factors that contribute to soundness:

1. Disc inspection and sonic inspection of in-process billets and finished forging billets.
2. Adequate surface preparation both on in-process billets for manufacturing forging bars and also final surface preparation of forging bars and billets
3. Quality control upset forging tests conducted on critical forging bar items.

Ask your Carpenter representative for additional information on Carpenter stainless steels for the forging industry. Technical information on hundreds of Carpenter alloys, as well as dozens of technical articles, is available free on Carpenter's technical information database at www.cartech.com.

GRADE	DO NOT FORGE *BELOW*		DO NOT FORGE *ABOVE*		SPECIAL INSTRUCTIONS
	°F	°C	°F	°C	
Type 302	1700	927	2300	1260	
Type 304	1700	927	2300	1260	
Type 304L	1700	927	2300	1260	
NeutroSorb PLUS® alloy	1800	982	2200	1204	
	Forging temperature varies with Boron Content.				
Type 303	1700	927	2300	1260	Slow preheat is *not* necessary.
Type 303Se	1700	927	2300	1260	Cool forgings in air.
Type 305	1700	927	2300	1260	Anneal after forging to restore corrosion resistance.
Type 309	1800	982	2250	1232	
Type 309S	1800	982	2250	1232	
Type 310	1800	982	2250	1232	
Type 310S	1800	982	2250	1232	
Type 384	1700	927	2250	1232	
Type 316	1700	927	2300	1260	
Type 316L	1700	927	2300	1260	
Type 317	1700	927	2300	1260	
Type 321	1700	927	2300	1260	
Type 347	1700	927	2250	1232	
20Cb-3® stainless	1800	982	2250	1232	
Type 410	1650	899	2200	1204	Slow preheat is *not* necessary.
Type 414	1650	899	2200	1204	Cool forgings in air. Do not quench.
Type 416	1700	927	2250	1232	Anneal after forging to avoid cracking; cool to room temperature before annealing.
Type 420	1650	899	2200	1204	Slow preheat is necessary.
Type 420F	1650	899	2200	1204	Cool forgings very slowly. Furnace cooling preferred. Anneal after forging to avoid cracking; cool to room temperature before annealing.
Type 431	1650	899	2200	1204	Slow preheat is *not* necessary. Cool forgings slowly. Anneal after forging to avoid cracking; cool to room temperature before annealing.
Type 440A	1700	927	2200	1204	Slow preheat is necessary.
Type 440B	1700	927	2150	1177	Cool forgings very slowly. Furnace cooling preferred.
Type 440C	1700	927	2100	1149	Anneal after forging to avoid cracking;
Type 440F	1700	927	2100	1149	cool to room temperature before annealing.
Pyromet® Alloy 355	1700	927	2100	1149	Slow preheat is *not* necessary. Air cool, equalize and overtemper.
Custom 455® stainless	1650	899	2300	1260	Slow preheat is *not* necessary.
Custom 450® stainless	1650	899	2300	1260	Cool forgings in air and anneal.
Custom 630 (17Cr-4Ni)	1850	1010	2200	1204	
Type 409Cb	1500	816	2050	1121	Slow preheat is necessary.
Type 430	1500	816	2050	1121	Cool forgings in air.
Type 430F	1500	816	2100	1149	When reheating, use lower forging temperature and finish cold as possible for optimum grain refinement.
7-Mo® stainless	1700	927	2000	1093	Anneal after forging to restore corrosion resistance.
7-Mo PLUS stainless	2150	1177	2375	1302	Slow preheat is *not* necessary. Cool forgings in air. Anneal after forging to restore corrosion resistance.

BLANKING, PUNCHING, SHEARING AND PERFORATING CARPENTER STAINLESS STEELS

The following four properties should help you successfully blank punch, shear and perforate stainless steels:

1. All stainless steels have higher tensile and shear strengths than mild steel even when dead soft annealed. This tells us that the press must have adequate power. The constant uniform pressure provided by hydraulic presses makes them desirable for these operations. On some jobs, slower speeds and higher pressures than are normal for mild steel will work better with stainless steels. This property also indicates that tools must be rugged and strong because they will wear faster. Tool steels that provide maximum wear resistance and good toughness, such as Carpenter's Hampden®, No. 610 (D2), Micro-Melt® A11*, and Micro-Melt A11-LVC tool steels, have displayed excellent results on long-run jobs.
2. All stainless steels excepting the free-machining types have a tendency to gall, or pick-up on the tools. This involves the tolerances in fitting punches and dies. Tool clearances for the straight chrome grades will approach that for ordinary steels. Galling and tool pick-up can be reduced or eliminated by properly mating the tools. A practice frequently followed is to allow very little clearance between the punch and die, then if it is too close, relieve the punch until the correct tolerance is obtained for the job. Evidence of too little clearance is the early tendency for the punch to gall or pick-up. Too much clearance will result in excessive burrs and a drawing action along the edge of the cut.
3. The austenitic chrome-nickel stainless steels, as annealed, are tough and gummy. There will be less breakout on these particular types. They will break more uniformly, however, if the alloys can be used at a slightly higher hardness. The straight chrome types will have a more normal breakout.
4. The austenitic chrome-nickel stainless steels work harden more rapidly but are more ductile than ordinary soft steels. This is not true of the straight chrome steels, which work harden at about the same rates as mild steel but are only about 80% as ductile.

This property indicates difficulty in shaving on the chrome-nickel types. The sheared edges are work hardened to such an extent that it is difficult to pick up a light cut. For shaving these grades, a more generous second cut must be taken to get under the hardened skin. This difficulty does not exist in the straight chrome types.

When shearing annealed stainless steel, increase the pressure or use heavier equipment than that required for mild steel. As a guide, the shear strength of annealed stainless is generally estimated at 75,000 to 100,000 psi (517 to 690 MPa) as compared to 50,000 to 70,000 psi (345 to 483 MPa) for mild steel and medium carbon steels. An increase in press capacity from 30% to 50% is usually ample for most jobs. In cold-worked or -hardened conditions, stainless develops very high mechanical properties and requires correspondingly greater pressures to shear.

Break-through varies with the type of stainless. The straight chrome types of the 400 Series work much the same as ordinary steels, while the chrome-nickel steels of the 300 Series show very little break-through. Therefore, on the 300 stainless steels, keep the blades very sharp and the adjustment close to avoid dragging. For example, when cutting 19 or 20 gauge stock, a clearance of 0.001/0.002" (0.025/0.051 mm) is usually suggested.

In perforating, follow the same practice used in blanking or punching by employing slow speeds, sharp tools and sufficient power. When the perforating punches are small, drawing compounds are useful.

For punching or drilling small holes, with the straight chrome steels (400 Series), it is not always economical to perforate when the diameter of the hole is less than the thickness of the metal. With chrome-nickel steels (300 Series), the minimum hole diameter should be 1-1/2 or 2 times the metal thickness.

Clean blanking, punching and shearing can only be expected in stainless steels that are uniformly annealed at the mill. All Carpenter stainless strip steels are continuously annealed in specially designed furnaces to promote uniformity from one end of the coil to the other.

ANNEALING AND HEAT TREATING CARPENTER STAINLESS STEELS

Most consumers of stainless steel will not find it necessary to anneal or heat treat the parts they are fabricating. Most stainless products are furnished either as-annealed or as-heat treated from the mill, and further heat treatments are not usually necessary. The primary exceptions are where forging is done, where there is severe cold working done requiring subsequent annealing operations, or when martensitic or precipitation-hardening alloys must be hardened.

All forging operations should be followed by an annealing treatment, even in cases where subsequent heat treating for hardening is required. Annealing and heat treating procedures, temperatures, etc., can be found in the appropriate alloy data.

A Note on Heat Treating Atmospheres

It is possible to heat treat (anneal or harden) in the following environments:

1. Open atmospheres ranging from pure air to the normal products of combustion.
2. Special controlled atmospheres, some designed for heat treating carbon steels and those especially designed for stainless steels.
3. Vacuum.
4. Liquid salt baths ranging from neutral to carburizing or nitriding.

It is best to thoroughly clean all work to remove oil, grease, and other surface contamination prior to annealing or heat treating; failure to do so may cause carburization, difficult-to-remove scale, or other problems.

* Micro-Melt A11 tool steel is equivalent in hardness, wear resistance and heat treating response to CPM 10V alloy. CPM and 10V are registered trademarks of Crucible Materials Corporation.

Open annealing is generally preferred since carburization is minimized and the type of scale produced is easily removed by simple procedures. However, when it is necessary to heat treat close to or at finished dimensions, either special atmospheres or salt baths are required to prevent the formation of scale and surface contamination. In most cases, atmospheres rich in hydrogen with extremely low moisture content are the best atmospheres for annealing stainless steels. Heat treating cleaned stainless steel parts in a dry hydrogen atmosphere will result in parts that appear to be as bright as they were prior to heat treatment. However, the problem of contamination in such atmospheres cannot be overlooked and good control is necessary. A properly maintained salt bath will also yield satisfactory results.

Vacuum annealing has the advantage of not exposing the heat-treated surface to any contamination whatsoever. It eliminates potential dangers from explosion. Also, some of the hardenable stainless steels can become contaminated with gases such as nitrogen and hydrogen. As is the case with bright atmospheres, a drawback is the inherently slower cooling rate with vacuum as opposed to liquid quenching media.

Caution: Atmospheres designed primarily for carbon and alloy steels generally carburize and oxidize stainless steels. Improperly purged salt baths may also either oxidize or carburize stainless. Pack hardening or pack annealing is definitely not recommended for stainless steel because damaging carburization cannot be avoided.

When hardening the martensitic stainless steels, a fairly good rule is to soak work at least 20 minutes at heat after being certain the entire charge is up to the heat treating temperature. Water quenching is to be avoided since it will not make the steel any harder than oil quenching and it also promotes cracking. Although these steels can be both air and oil hardened, oil quenching is generally recommended because it promotes maximum mechanical properties. Because of the slower cooling rates involved, bright hardening will generally result in the loss of a few points Rockwell C hardness compared with that which can be obtained by oil quenching.

Stainless steels can be surface hardened by both carburizing and nitriding, but corrosion resistance will be decreased. In some cases, corrosion resistance can be compromised when surface hardening is required.

CLEANING AND PASSIVATING CARPENTER STAINLESS STEELS

Cleaning Processes

Practically all finishing operations require that fabricated stainless parts be subjected to some type of cleaning operation. These include painting, enameling, electroplating, metallizing, buffing and polishing. It is generally necessary to clean after welding, brazing and machining operations. Heat treating often requires cleaning both before and after that operation.

The specific method of cleaning to be employed depends primarily upon the surface contamination present. However, there are other considerations such as design, subsequent operations, cleaning equipment required, shop operating conditions, production volume, cost and some special precautions.

The following methods can be used to clean stainless steels depending upon the surface contamination:

- Soak alkali cleaning
- Soak emulsion cleaning
- Soak acid cleaning
- Machine cleaning
- Electrocleaning
- Barrel cleaning, tumbling
- Steam cleaning
- Petroleum spirit cleaning
- Vapor degreasing
- Acid pickling
- Electrolytic pickling
- Salt bath cleaning, descaling
- Blast cleaning
- Brushing

Scale or Foreign Contamination

Cleaning operations can generally be divided into two categories: (1) methods for removing foreign contamination such as lubricants, paints, shop dust, polishing compounds, etc., and (2) methods for removing surface oxide or scale resulting from forging, heat treating, welding, etc.

The principles and methods used for removing foreign contamination from stainless steel are similar to the methods used for other metals. Space does not permit a description of all the metal cleaning methods. However, this section does describe some of the methods used for removing scale and oxide. Carpenter has developed most of this information in its own mill through experience with descaling and pickling processes.

Excellent information has been published by the A.S.T.M. as shown in Standard Recommended Practice for Cleaning and Descaling Stainless Steel Parts, Equipment, and Systems, Designation A-380. Topics covered in detailed include descaling, pickling and passivating processes.

Descaling

Both mechanical cleaning and molten salt baths can be used for removing heavy scale from stainless steel.

Mechanical cleaning methods include dry blasting with cast iron grits, metal shot, cut wire or sand. Wet blasting will provide a better finish but is applicable mainly to small parts or when a light scale is to be removed. Brushing and tumbling might also be included as mechanical descaling methods.

Salt bath descaling methods have been found most advantageous for removing scale from large production lots of stainless steel. These methods involve molten salts operated at temperatures ranging from approximately 700° to 900°F (371° to 482°C). The sodium hydride caustic soda process is quite versatile; scale is removed by a reducing process so that base metal is not removed. Alternatively, the Hooker and Kolene processes oxidize the scale to a form in which it is more easily removed by acid pickling.

Acid Pickling

Most descaling methods must be followed by acid pickling for the complete removal of surface oxide. Perhaps the most versatile acid bath for removing scale from all types of stainless steel is a solution containing 10% by volume sulfuric acid, with or without an inhibitor, operated at approximately 150° to 180°F (66° to 82°C). Following a descaling treatment, this sulfuric acid pickling bath will effectively remove scale from most stainless steels, although it will react somewhat slowly with the austenitic stainless grades. A 50% by volume solution of hydrochloric acid (all acids are mixed with water), with or without an inhibitor, operated at 150° to 160°F (66° to 71°C), will clean all stainless grades considerably faster, although closer control is required.

Sometimes a two-bath operation is used with the austenitic stainless grades. Either the sulfuric or hydrochloric acid pickling solutions are followed by a bath consisting of approximately 10% by volume nitric acid and 2% by volume hydrofluoric acid, operated up to 120°F (49°C). The nitric-hydrofluoric pickle bath is used to remove the last traces of scale retained after sulfuric acid pickling processes.

After descaling and between each pickling tank, a water rinse is always used. This may be in the form of a water blast to remove traces of scale and prevent contamination from one bath to the other.

Nearly all pickling operations impart a dark “smutty” surface on stainless steel, which can be removed in a cold 20% by volume nitric acid bath. This final pickling process both brightens and passivates the stainless steel surface.

Acid Brittleness

Pickling can cause “hydrogen brittleness” or “acid brittleness” because of hydrogen absorption. Some hard and highly stressed parts are susceptible enough to suffer cracking during the pickling process. While hard but not highly stressed parts will seldom crack in the acid bath, they may crack in service when subjected to stress. Consequently, steels should not be “overpickled.” Hardened articles should receive a stress-relieving temper before pickling and “bake” after pickling. The baking process consists of heating the part to about 300° to 400°F (149° to 204°C) for several hours to remove hydrogen and restore ductility.

Examples of pickling techniques most likely to cause cracking are hot hydrochloric acid and electrolytic techniques, which liberate large amounts of hydrogen. When employing these methods, high-strength grades such as Type 420 or the 440 series and the precipitation hardenable martensitics should not be exposed for long periods.

Passivating

The non-rusting properties of stainless steels are attributable to a very thin, invisible oxide film that completely covers the surfaces of the parts and prevents corrosion from taking place. Theoretically, a freshly machined, polished or pickled part will acquire this film rather quickly from the atmosphere. In practice, however, such fabricated parts may be contaminated with small particles of foreign matter, which must be removed to impart full stainless properties. As an example, a slight amount of material worn off the cutting tools may be transferred to the stainless parts during machining. Under certain conditions, a thin coating of rust may appear on the part. This is corrosion of the tool steel and not the parent metal.

The primary purpose of a passivating treatment is to remove surface contamination, usually iron, so that the optimum corrosion resistance of the stainless steel will be maintained. Passivation is not a scale removal treatment.

Basic procedure in passivating consists of cleaning the work with a commercial degreaser or cleanser, immersing it in a solution containing nitric acid, rinsing and drying it. The importance of cleaning prior to acid bath immersion cannot be over-emphasized. In some instances, this step is omitted, assuming the acid bath will give the necessary cleanness. Cleaning should not be skipped because the acid might not remove all of the residual cutting fluid, resulting in possible chemical reactions with the residual cutting fluid known as “flash attack.” These unwanted reactions may cause serious deterioration of the surfaces that passivation is designed to protect.

After degreasing and thorough water rinsing, passivation of the stainless steels should take place according to the following table:

Passivating Stainless Steels

GRADES	PASSIVATION
- Chrome-Nickel Grades (300 Series) - Grades with 17% Chromium or more (except 440 Series)	20% by vol. nitric acid at 120/140°F (49/60°C) for 30 minutes.
- Straight Chromium grades (12-14% Chromium) - High Carbon–High-Chromium Grades (440 Series) - Precipitation Hardening Stainless	20% by vol. nitric acid + 3 oz. per gallon (22 g/liter) sodium dichromate at 120/140°F (49/60°C) for 30 minutes **OR** 50% by vol. nitric acid at 120/140°F (49/60°C) for 30 minutes.

The addition of sodium dichromate or use of 50% nitric acid solution increases the “passivating potential” of the bath so that undesirable local attack is less likely.

The free-machining grades differ from the regular grades of stainless steels because they contain a large number of nonmetallic inclusions throughout their microstructures which create microscopic discontinuities in the machined part surfaces. Even normally efficient water rinses can leave residual acid in these discontinuities after passivation. This acid can then attack the surface of the part unless it is neutralized or removed. Work in Carpenter’s research and development laboratory has shown that the following passivating procedure for free-machining grades will produce resistance to subsequent superficial rusting. This procedure is known as the Alkaline-Acid-Alkaline, or A-A-A, passivation method.

PASSIVATION FOR FREE-MACHINING STAINLESS STEELS (including AISI Types 420F, 430F, Type 203, Project 70+® Type 303, and Project 70+ Type 416)
1. 5% by wt. sodium hydroxide at 160/180°F (71/82°C) for 30 minutes. 2. Water rinse. 3. 20% by vol. nitric acid + 3 oz. per gal. (22 g/liter) sodium dichromate at 120/140°F (49/60°C) for 30 minutes. 4. Water rinse. 5. 5% by wt. sodium hydroxide at 160/180°F (71/82°C) for 30 minutes. 6. Water rinse.

Other Important Considerations

Maintain an effective passivating solution to prevent localized attack. Tap water is usually adequate for diluting the acid, although high chloride contents (greater than several hundred ppm) could be deleterious in a borderline situation. Nitric acid concentration should be checked periodically using a simple titration procedure, which can be provided upon request.

When high production rates cause a heavy flow of material through a passivating bath, it is probably best to maintain a definite schedule for replacing the bath to avoid a significant decrease in the “passivating potential,” which can result in corrosive attack of the work piece. You should also use a control sample of the same composition as the material to be passivated to test the bath. If the sample is attacked, it is time to change the bath before additional parts are passivated.

The temperature of the bath should be within the specified temperature range. A room temperature bath has a lower “passivating potential” than a warm bath and is, therefore, more likely to cause local attack.

It is good practice to passivate only one grade of stainless steel at a time. Not only can mix-ups be prevented but you can avoid galvanic reactions.

Parts that were improperly heat-treated may lead to attack in a passivating bath. Furthermore, high-carbon, high-chromium grades must be hardened to render them corrosion resistant. Stainless steel parts that have been carburized or nitrided should never be passivated. These surface treatments lower the corrosion resistance of stainless steel, thus opening the way to attack in the passivating tank.

TUMBLING AND BALL BURNISHING CARPENTER STAINLESS STEELS

Small stainless stampings can be given a fairly good finish and color in a tumbling barrel. Remember these points:

1. Be sure the parts are thoroughly cleaned before they are charged into the barrel. During fabrication, the parts are covered with a lubricant which must be removed before tumbling. The best cleaning solution will depend upon the type of lubricant to be removed.

    (a) If a water-soluble lubricant, use alkali washing solution.

    (b) If an oil-base lubricant, chemical degreasing will be required.

    After the cleaning operation is completed, parts should not be exposed to shop dust and dirt.

2. Most important is the type and condition of the water used for charging the barrel in normal operation and for rinsing the finished burnished pieces. The formation of insoluble hard water curd from the soap always occurs if no attention is given to "water hardness." All hard water should be reduced to soft water before charging the barrel. This is quickly done by finding out from your water supplier the number of grains of hardness per gallon you have in your water. The water can then be softened by adding one ounce of trisodium phosphate per one grain of hardness per 100 gallons of water. This procedure will also prevent a coating of insoluble lime soap from forming on the surface of the burnishing balls. Avoid this coating, because once this deposit is present, no alkaline cleaning or rinsing in kerosene will remove it. Balls coated like this do not impart bright, clean luster finishes on the work.

3. Absolute cleanliness is important. In every step of the job, no "hangover" material should be left in the barrel or clinging in the load.

    For successful operation, wash the barrel and the balls before each loading. This requires roughly 30 minutes' spinning of the barrel, one-third full of water with one pound of soda ash, and one ounce of cyanide. Include the balls required for a normal load of work and discard the solution after the balls and barrel have been cleaned.

4. No. 1 burnishing balls should be used. Some manufacturers sell an especially good ball, particularly recommended for stainless steel. It pays to use them. On some parts with sharp angles or deep ridges, it may be desirable to use specially shaped burnishing materials, such as "jacks," "cones," "ovals," etc.

5. Never use cheap yellow soap. Only good white soap or soap flakes will be satisfactory.

6. On some pieces, due to size and shape, the speed of the barrel can control the type of finish. For example, small lock parts can be successfully run at 20 rpm. Some parts might be run as high as 27/32 rpm but, in general, the higher speeds do not give quite as good a finish as the slower speeds.

MACHINING AND ABRASIVE WHEEL GRINDING OF CARPENTER STAINLESS STEELS

Machining

These three characteristics of stainless steel exert the most influence on machinability:

1. Relatively high mechanical properties (including yield strength)
2. High work-hardening rate
3. Ductility

These factors explain the material's tendency to form a built-up edge during machining. For example, the chips removed in machining exert high pressures on the nose of the tool and therefore tend to weld fast, producing what machinists call a "bug." This causes the tool to run hot, slows down the job and interferes seriously with the finish.

The austenitic stainless steels (300 Series) are not only troublesome because of "bugging" and chip disposal, but they work harden so that the tool, in passing over the work, will harden the surface and thus interfere with the next cut. The only remedy for this is to reduce the speed, increase the cut somewhat, if possible, and keep cutting. The tool must not be allowed to dwell on the work.

The best mechanical method for chip control is to grind the tools with a fairly steep top rake or lip angle. Tools with a 5° to 10° angle will generate less heat and be freer and cleaner cutting. Generous chip curlers or chip breakers are also a decided advantage. It is also helpful to stone the top of the tool smooth as an aid to skidding the chips. For general-purpose drilling, twist drill makers produce a drill for drilling stainless steel. It has a shorter flute and overall length than regular drills and is therefore heavier and stronger. As sold from stock, this type of drill is generally pointed with an included angle of 140°.

Where close tolerance and fine finish are necessary, consider using a shave tool with a light cut and fast speed. This tool should be sharply ground and stoned. Running at high speed while taking a light cut (0.002/0.008" or 0.05/0.20 mm) produces an excellent finish and holds to extremely close tolerance.

Sulfur-based cutting fluids have been recognized for years for their ability to cool and prevent seizing. As a result, properly blended sulfur-base fluids have become the standard cutting fluids for machining all types of stainless steels. Here is a handy rule-of-thumb to use regarding the mixture: If the chips are welding to the tool, keep adding sulfur-based oil. If tools are failing by rapid abrasion, add more paraffin-base oil.

The real answer to machinability came with Carpenter's development of free-machining stainless steel. Both sulfur and selenium have been successfully added to stainless alloys to secure free-cutting properties. Carpenter Stainless Type 416 was the first free-machining stainless steel. Later, Carpenter used selenium in the manufacture of Carpenter Stainless Type 303 Se.

Since the 1970s, Carpenter has developed and improved upon a line of enhanced machinability stainless machining bar grades. The most recent enhancement is the Project 70+® stainless family. Users of Project 70+ machining bar have reported faster machining speeds, improved finishes and extended tool life. Access hundreds of alloy datasheets, including machining data, by visiting Carpenter's technical information database at www.cartech.com.

More detailed information about machining Carpenter alloys is available in the booklet, "Guide to Machining Carpenter Specialty Alloys." Request a booklet in the Product Literature section of www.cartech.com.

Abrasive Wheel Grinding

Precision grinding is required on jobs in which you desire excellent surface finish, exceptionally close dimensions and geometric accuracy, or when heat-treated parts are too difficult to machine.

For this work, the grinding wheel is the heart of the job. Wheels for precision grinding may contain either aluminum oxide or silicon abrasives, which may be bonded by shellac, rubber, silicate, resinoid, etc. Avoid the use of grinding wheels containing iron oxide. Contamination of the stainless surface with iron oxide will cause rapid corrosion and rust pitting. Selection of the right wheel for a job can often be made from experience on previous work. On a new job, it is best to consult a wheel manufacturer for guidance in your selection.

The method of holding or supporting the work will vary with the type of machine used and job to be done. On special jobs, various types of work holders, chucks or collets are available or may be designed and produced in your own tool room.

Whether cylindrical, universal, surface, internal, centerless, thread or special grinders, grinding machines should be massive. Distortion and vibration cause many poor grinding jobs.

In general, the most efficient grinding speeds are in the range 5500/9000 surface feet per minute. The optimum speed within this range will depend upon the grade of stainless, type of grind, rigidity of the machine and wheel selection.

The 300 Series austenitic stainless grades, being gummy, should be ground with a wheel having a porous bond to avoid early loading of the wheel. The straight chrome steels in the 400 Series can be ground with a harder wheel. It is seldom necessary to start with less than 60- to 70-grit wheels for the roughing cut. This should be followed with an 80- to 100- grit wheel having a soft or porous bond to provide faster cutting and prevent burning.

Note: When changing wheels from one size grit to another, it is important that the work be cleaned and all "wild" grit be removed. When the coarse grains are carried along to the finer grit wheels, deep scoring or scratching may occur.

Troubleshooting grinding problems

1. Traverse marking: Check the edges of your grinding wheel. They may be too sharp and should be slightly rounded off to avoid a "dragging edge." Such marking may also be caused by excessive spindle spring or too high a speed on finishing cuts. Lastly, traverse may be too fast for the work speed. This leaves a pattern on the work that can be corrected by slightly decreasing the traverse speed.
2. Loading or Glazing: The wheel may be too hard or not dressed often enough. Dressing may be too fine or dresser too dull.
3. Work "Out-of-Parallel": This condition is usually caused by mechanical faults such as "sloppy ways," improper setting of tailstock, or center not concentric with the work piece. Check accuracy of the dressing operation. If wheel is dressed off-center, it will not conform with surface of work part. After first cut is made, check for straightness, taper or chatter marks. Proper adjustments in setup at start of job will reduce rejects and save time in the long run.
4. Lubrication: Practically all grinding is done with water-base coolants because of their ability to dissipate heat rapidly and thus prevent spoiled work due to overheating. Exception: On thread grinding that requires a highly finished and smooth surface, sulfur-base oils—either straight or cut back with paraffin oil—may be used.

   Lubrication serves to reduce friction between work and wheel, and cuts down the resistance of the metal to the abrasive. Further, it washes away the chips and abrasive particles that might otherwise score the surface and spoil the part. A steady flow of coolant retards loading of the wheel and prevents impregnation of particles into the metal.

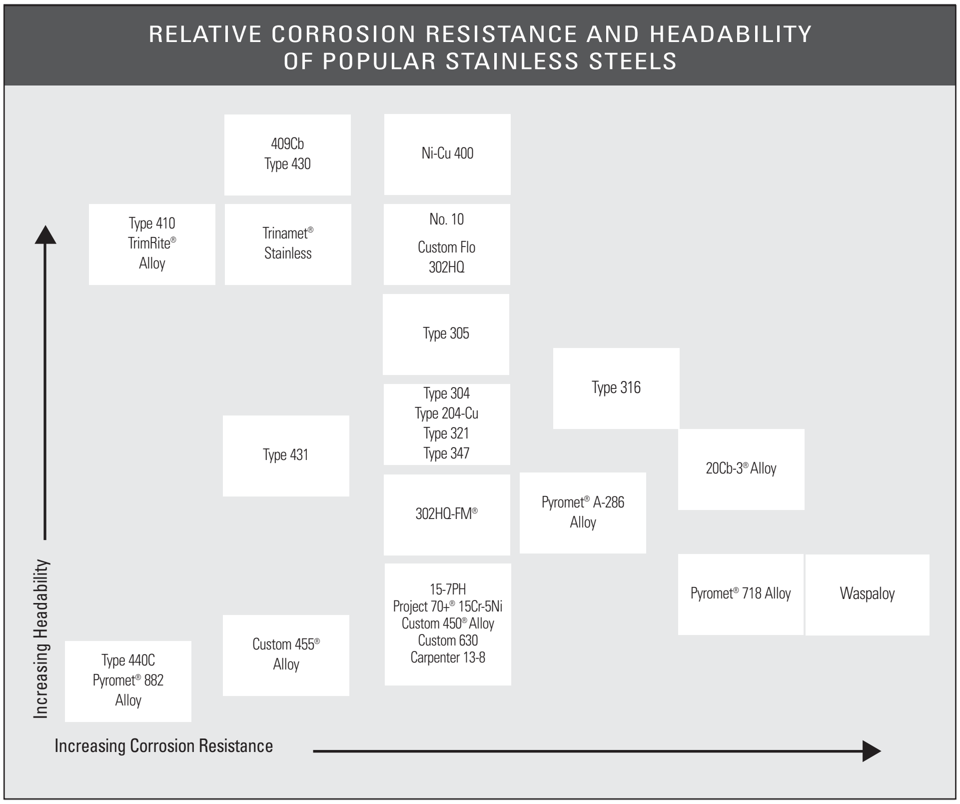
   Avoid highly alkalized lubricants, as they may deteriorate the wheel bonds. This condition can be safeguarded against to some degree by increasing the percentage of water in the mixture. This condition should be checked carefully, as premature decision may put the fault with the steel or wheels while the real problem lies elsewhere.

COLD HEADING, WARM HEADING AND HOT HEADING CARPENTER STAINLESS STEELS

Cold Heading

Stainless steels continue to be used in the manufacture of cold-headed parts. This group of alloys provides several benefits, including corrosion resistance and high strength at room and elevated temperatures. Most stainless steels can be cold headed. Carpenter has played an important role in the development and production of stainless steel cold-heading wire.

Comparison of Cold Headability: The diagram below presents a simple comparison of cold headability and corrosion resistance of the popular cold-headed grades of stainless steel.



The relative headability of martensitic stainless steels such as Type 410 and ferritic stainless steels such as Type 430 is affected primarily by carbon content and yield strength. Type 410 and Type 430 are relatively easy to cold head and are comparable to low carbon alloy steels. Martensitic stainless steels can be hardened by heat treatment but ferritic stainless steels cannot. Both types will harden slightly by cold working. Both are widely used for fasteners.

The relative headability of the austenitic stainless steels is affected primarily by composition. That is, those higher in nickel, and in some cases copper, generally exhibit lower work-hardening rates because of the more stable austenitic structure. Stainless Type 305 was the original stainless grade developed for improved cold headability. The 12% nickel content accounts for this. Carpenter also produces Carpenter No. 10 (Type 384) and Carpenter 302HQ stainless, both of which exhibit low work-hardening rates and excellent cold headability for austenitic stainless steels. Typical austenitic stainless steels cannot be hardened by heat treatment; however, cold working will increase hardness. Carpenter 302HQ stainless has been used extensively to produce Phillips and other recessed-head fasteners.

Product Forms

Carpenter manufactures three basic wire product forms in addition to specially finished wire or rod for special applications. The three basic forms include:

1. Annealed and Cold Drawn to Finish Heading Wire
2. Cold Drawn and Annealed at Finish Heading Wire
3. Hot Rolled and Annealed at Finish Rod

Annealed and Cold Drawn to Finish Heading Wire is raw material in the finished condition. It is available in all sizes up to about 1.00" (25.4 mm) in diameter. Refer to *Table 1* for specific size tolerances. Wire in this condition offers substantial surface integrity and the widest range of mill coatings. This product typically does not require additional sizing prior to entering the header.

Table 1 – Standard Size Tolerances Cold Drawn Heading Wire

SIZE RANGE	TOLERANCE
Up to 0.312" diameter	±0.001"
> 0.312" - 0.499" diameter	±0.0015"
≥ 0.500" diameter	±0.002"

Note: Half-standard tolerances may be ordered.

Table 2 – lists typical ultimate tensile strength maximums for annealed and cold-drawn wire for sizes greater than 0.100" diameter.

	TYPICAL ULTIMATE TENSILE STRENGTH	
Alloy	**ksi**	**MPa**
No. 10	85	586
Type 302HQ, Batch Annealed	83	572
Type 302HQ, Strand Annealed	96	662
Type 305	93	641
Type 316HQ	93	641
Type 316	83	572
Type 304	95	655
Type 410	90	621
Type 430	86	593
Type 431	115	793

Cold Drawn and Annealed at Finish Heading Wire is supplied cold reduced, annealed and coated. It offers the lowest mechanical properties and is suitable for redraw or heading. This product should be sized prior to entering the header. Cold drawn, annealed product is available in all sizes up to about 1.00" (25.4 mm) in diameter. Tolerances are double those available on annealed and cold drawn wire.

STARR® wire (Stainless, Annealed, Ready for Redraw) is a modification of the basic cold drawn and annealed at finish form. Its manufacturing sequence typically includes additional operations to enhance surface quality. It is available in only a few stainless grades and is typically supplied with a cross sectional area about 5 percent over the cross sectional area of the finish drawn product. Typical maximum ultimate tensile strengths for annealed at finish wire are shown in *Table 3*.

Table 3 – Typical Ultimate Tensile Strength Maximums - Annealed at Finish Wire in Diameters >0.100"

	TYPICAL ULTIMATE TENSILE STRENGTH	
Alloy	**ksi**	**MPa**
No. 10	78	538
Type 302HQ, Batch Annealed	75	517
Type 302HQ, Strand Annealed	88	607
Type 305	83	572
Type 316HQ	76	524
Type 316	85	586
Type 304	85	586
Type 410	82	565
Type 430	75	517
Type 431	105	724

Hot Rolled and Annealed at Finish Rod is the least finished condition and must be sized prior to entering the header. It is supplied annealed, descaled and coated. Of the three wire forms, rod has the roughest surface and the widest tolerances. Rod is available in a size range from about 7/32" to 1-1/4" diameter. Tolerances may be as great as ±0.010" with a maximum of 0.015" out-of-round in the larger diameters. See *Table 4*.

Table 4 – Standard Rod Tolerances

SIZE RANGE	TOLERANCE
0.221" - 0.4375"	±0.006"
0.453" - 0.625"	±0.007"
0.641" - 0.875"	±0.008"
0.891" - 1.000"	±0.009"
>1.000" - 1.250"	±0.010"

To reduce wire inventories and the number of wire sizes purchased, some headers draw wire or rod in front of the header with obvious savings.

While rod is the lowest cost wire stock, this may not be an advantage. Many fabricators report that rod necessitates the addition of more in-house capabilities. When redrawing rod, scrap losses may increase and present overall quality control problems that often negate initial raw material savings.

The best alternative for most headers is the use of wire that has been annealed and cold drawn to finish.

Coatings

Choice of the proper coating is influenced by the specific application; however, there are general considerations. The type of coating required depends on the alloy being formed, the degree of cold work needed, the temperature generated by the heading process, and the complexity of the part being formed. Additional factors influencing coating selection include availability and cost, compatibility with other mill coatings or fabricator lubricants, and the ease of coating removal from the finished parts.

For many years the most effective coating for stainless steel heading wire has been an electrolytically plated copper layer plus lime and soap drawn on during the final light draft made in finishing the wire. Today, however, coatings such as Carpenter's Ecolube® II coating may be used to eliminate the problems associated with disposal of cleaning acids containing metal ions. A key point to remember is that Carpenter, as a producer of stainless heading wire and rod and a variety of coatings, is totally equipped to help customers with coatings selection, as well as all other aspects of cold heading operations.

Coating classes are determined by selecting a coating option designated by a letter and a drawing option designated by a number. This is typically referred to as Carpenter's Alpha-Numeric Coating Classification System. The coating and drawing options are as follows:

(MUST CHOOSE ONE COATING OPTION AND ONE DRAWING OPTION)	
Coating Options (Alpha)	**Drawing Options (Numeric)**
A - Uncoated B - Lime C - Precoat F - Ecolube® II coating H - Copper + Lime K - Copper L - Copper + Precoat N - Copper + Moly Overcoat O - Copper + Ecolube II P - Special R - KnightCote™ wire coating S - Copper + KnightCote wire coating	1 - Undrawn (Annealed at Finish) 2 - Drawn in Soap 3 - Drawn in Grease 4 - Drawn in Molybdenum Disulfide - Bearing Soap 5 - Drawn Without Soap or Grease (Only coatings F, N, O, S)

Warm Heading

Warm heading is a modified form of cold heading performed at 200° to 800°F (93° to 427°C), which is below the recrystallization or transformation temperature of the metal being formed. Ductility is improved without changing the microstructure. Warm heading allows working difficult-to-form materials, requires less deformation pressure, reduces tooling loads by as much as 50 percent compared to cold forming, and generally prolongs tool life.

Warm heading is especially applicable to parts of unusual shape and forming high strength alloys that are resistant to heat and corrosion. Usually alloys that work harden rapidly can be upset without cracking. The method generally works well for making high strength bolts.

With warm heading, the wire is usually heated before it enters the feed rolls, or, when possible, between the feed rolls and the header machine frame. The most commonly used methods of heating are:

1. Resistance heating - A contact stand is installed between the wire reel and the feed rolls. A low-voltage, high-amperage circuit is then connected to the contact stand and the feed rolls. The electricalresistance of the metal itself serves to produce the heat.
2. Gas heating - A series of burners is mounted on an adjustable stand and the wire passes over them. Variations include use of a tube, surrounded by a series of ring burners, which is mounted on an adjustable stand, heating the wire as it passes through the tube.
3. Induction heating - An induction coil is installed in front of the feed rolls, and the wire is passed through the coil.

Close control of wire temperature is important since erratic heating may cause uneven flow, and may result in uncontrolled head dimensions. If the wire is over-heated, for instance, the material will tend to blob instead of flow. Also, the lubricity of the wire coating may be destroyed, and smearing may occur at the cutoff station. Close temperature control, on the other hand, improves plasticity and headability by reducing both the strength and work hardening of the material being formed. Consequently, less forming pressure is required to fill the cavity of the die or hammer, with a resulting improvement in sharper corners and shoulders and, in some cases, elimination of stress cracking.

Surprisingly good warm heading results for the stainless steels are achieved in the temperature range between 350° and 450°F (177° to 232°C). Temperatures over 600°F (316°C) should generally be avoided.

Hot Heading

Hot heading or upset forging can be done on conventional heading equipment similar to cold heading machinery or on forging machines. Hot heading is generally performed on the larger diameters which cannot be obtained in coils. The same general principles applying to conventional forging should be utilized.

DRAWING, FORMING, AND SPINNING CARPENTER STAINLESS STEELS

The production of stainless parts by cold forming is as common today as that for ordinary steels and nonferrous metals. In drawing, roll forming, spinning, etc., operators who have handled many stainless jobs prefer its consistent uniformity as compared with other metals. Because stainless steel is a high-strength material, it can be handled routinely on a profitable mass-production basis.

Anyone who has formed metals knows that differences exist between them, whether aluminum, brass, carbon steel or stainless steels. In the cold forming of stainless steels, these facts are worth knowing:

Drawing

The Press: The shear strength of annealed stainless steel is generally estimated at 75,000 to 100,000 psi (517 to 690 MPa), which is about 50 to 75 percent stronger than mild steel. Hence, more press power is required, or the job must be transferred to a heavier press. A more economical solution would be to take advantage of the high strength of stainless by changing to a lighter gauge material. If this can be done, the parts can often be formed on the same size press and with the same power used for mild steels. Regardless of press considerations, each stainless job should be figured on the basis of required mechanical properties to determine the lightest gauge stock necessary for the job.

Speeds and Clearances: It is natural to want to use the fastest possible speeds commensurate with production of the maximum number of quality parts. On some jobs, normal press speeds may be desirable; on others, slightly slower speeds may produce less downtime, fewer rejects and get the job out faster. “Stretching” of the metal must always be avoided.

On “shallow draws” with straight chrome steels of the 400 Series, press speeds and die clearances will be about the same as for mild steels. Deep draws and heavy gauges may require slower speeds. If the job is new and speeds cannot be estimated from past experience, a safe starting speed is 35 to 40 feet per minute.

A characteristic property of the chrome-nickel stainless steels is their rapid rate of cold work hardening. On deep drawn or severe forming jobs, parts must be annealed in process so that the operation can be continued. This increases production costs, is troublesome, and slows down the job.

The solution to this problem came with the development of Carpenter Stainless Type 305. This grade shows such a small rate of cold work hardening that it is now practical to run many jobs on automatic transfer presses. With Type 305, savings can often be made in production by reducing process annealing, using considerably faster press speeds, and reducing the number of presses and man-hours required when using the regular 18-8 grades.

Where regular 18-8 grades (Types 302, 304, etc.) are preferred, deeper draws can be made in one operation if slower press speeds are used and the radii on the draw ring are increased. Why? Because slower press speeds and a more generous radius on the draw ring work harden the metal more moderately and allow it to be pulled into the die without stretch or fracture.

To prevent wrinkling and buckling, use heavier pad pressure with thicker rubbers, heavier springs, or more air pressure in your air cushions.

Dies and Tools: The blanking, piercing and punching of stainless steels require the use of good tool steels that have nongalling characteristics. Carpenter K-W (F2) should be considered for tools that are not too intricate. If the design or shape of the tool prohibits the use of a water-hardening tool steel, consider Hampden® (D3) tool steel or No. 610 (D2) tool steel with a nitrided case. Other alloys to consider are powder tool steels, such as Carpenter Micro-Melt® A11 or A11-LVC tool steel.

Hard bronze, showing about 340/360 Brinell, is an excellent material for draw rings. Centrifugal castings are to be preferred where possible. If hard bronze is not available, No. 610 (D2) tool steel with a nitrided surface may be considered.

Make allowance for greater “spring back” in dies when fabricating stainless steel. Generally, a slightly larger radius on draw rings is recommended to avoid stretching the metal. This allows it to flow more freely into the die and tends to cut down work hardening. The dies or draw rings should be polished and stoned and kept smooth at all times. Use a fine stone rather than a wheel in “finish stoning” the draw rings. The small amount of extra work involved is well repaid with longer die life and smoother stampings.

Lubricants: Because of their high strength, stainless steels exert more pressure on the tools and develop more heat. Unless proper lubricants are used, the film will break down and stretching and galling will result. Improper lubrication will gall or score the tools rapidly. A constant film must stay on the metal while drawing. White lead and linseed oil mixed to the consistency of 600W oil is reasonably satisfactory. So is a 50:50 mixture of lithopone and water-free soluble oil. Both of these are a little difficult to wash off, especially if left lying around. The lead compounds, being insoluble, will load up the cleaning tanks. For making a few experimental pieces, castor oil is usually easy to procure and is a good lubricant. For very light draws, lithopone and kerosene or soap solutions may be all that are needed.

Forming

Brakes: The same bending and forming equipment that is used for mild steel can be used on stainless steels. In hand or power brakes, more power is required than for mild steel. The dies should be polished and free from imperfections. If the press brake operation is essentially drawing, lubricants are necessary, and the same ones used for drawing are satisfactory. Greater allowance must be made for “spring back” in the tool design.

Rolls: Roll forming of stainless strip into channel, molding and trim is a commonplace operation today. Stainless, possessing greater strength, will work differently from cold-rolled steel, so when long runs are required be sure the rolls are made from materials that will prove adequate for your production requirements. Good examples of this are the high-production jobs like auto body and fender trim. For jobs like these, Carpenter Hampden or No. 610 die steels for the male rolls, and hard cast bronze for the female rolls should be considered.

More leverage is required in spinning stainless than with mild steel or copper. The speeds used are also slower. In general, stainless steels of the 400 Series can be spun at 60/70% of the speed used for mild steel. Most of the steels in the 300 Series should be spun somewhat slower because of their faster work-hardening properties. Exceptions are Carpenter Stainless Type 305 and No. 10, which work harden more slowly, and therefore can be worked faster and longer before process annealing may be necessary. Many shops find it good practice to leave 1/2" of unworked metal on the rim to prevent cracking and splitting.

Lubricants are very important in spinning. Lubricants that are too heavy will not stay on the blank and will accumulate under the tool. If too thin, they will not properly lubricate. Soap suspensions and hydraulic greases are useful. Proprietary compounds, prepared especially for spinning, are available and will produce good results.

When intermediate annealing is necessary, always clean the parts thoroughly, removing all traces of lubricants and other foreign matter before placing them in the furnace.

SOLDERING AND BRAZING CARPENTER STAINLESS STEELS

Soldering and brazing differ only in the temperatures used to melt the alloy being used to join the material being soldered or brazed. The material being joined is not melted by these joining processes.

Soft Soldering: Soft soldering of stainless steel is not much of a problem when the requirements of the job are understood.The biggest problem is breaking through the passive film with a flux so that the solder will wet the stainless.

Soft solders are weak compared with stainless steel. Consequently, if strength is required, the edges should first be riveted or spot-welded, then soldered for a tight seal.

Stainless steel must be perfectly clean before soldering is attempted. Cleaning can be accomplished by pickling with acid or with mechanical polishing. Do not expect the flux to do the cleaning.

Stainless steel is resistant to the corrosive attack of most soldering fluxes, and unless the flux etches the surface, it will not function. On smooth surfaced parts, such as cold rolled strip, it will be difficult to get the flux to spread and completely cover the surface. Therefore, the soldering area should first be roughened by acid etching (50:50 muriatic acid and water) or mechanical polishing. This rough surface will take the flux quickly and the solder will flow evenly.

Use fluxes prepared especially for soldering stainless steel. Apply the flux with a brush to the area to be soldered and rub until the surface is wet. All flux must be properly and completely removed after soldering to avoid continued corrosion. Be sure to remove all splattered flux with soap and water.

Stainless steels are slower to absorb heat, and it is, therefore, necessary to use a larger and heavier iron. The iron need not be hotter, but it should be bigger and possess more heat capacity. That way, the iron will heat a sufficient area to allow the solder to flow freely. “Tinning” the joint will also assist in making the solder flow more evenly. Keep moving as fast as the solder fills the joint.

Ordinary half-and-half solder applied from the top of a well-tinned copper is satisfactory but for brighter, stronger joints, use 67 percent tin and 33 percent lead dairy solder. In general, the higher the lead content, the more quickly the joint will darken on exposure to air.

Hard Soldering or Brazing: This process is also called silver soldering and is applicable to all types of stainless steels. The temperature range in which this process is applied is typically from 1150 to 1500°F (621 to 816°C), although brazing may be performed at temperatures up to above 2000°F (1093°C), depending on the composition of the brazing material. The straight chromium martensitic steels will air harden if heated above 1450°F (788°C). Exercise care to limit the heating of ferritic steels to the minimum required for flow of the solder in order to avoid grain growth and embrittlement in these grades. The chrome-nickel austenitic steels are necessarily heated in the carbide precipitation range, which may affect their corrosion resistance.

Lap-type joints are used in silver brazing. Joint clearances should be between 0.002" and 0.005" (0.051 to 0.127 mm) for best distribution of filler metal in the joint by capillary attraction. Silver brazing alloys for stainless steel contain from about 50 percent to 75 percent silver. The best color match is obtained with the alloys containing higher percentages of silver. A flux is generally required to make a satisfactory joint. However, for certain processes, particularly the straight silver-copper filler metals, if brazing is done in a vacuum or in inert atmosphere, flux may not be needed.

The bi-metallic nature of the joint makes it very difficult to predict the corrosion resistance of silver-brazed joints in stainless steel. Give consideration to crevice corrosion whenever the fluid contains small amounts of chlorine compounds. Cleaning of the flux after brazing is essential to prevent corrosion failure. The most common method of cleaning flux is with a hot water rinse of long enough duration to dissolve all the flux.

NOTE: American Welding Society Specification AWS A5.8 for Brazing Filler Metal prescribes requirements for filler metals that are added when making a braze.

WELDING OF STAINLESS STEELS

The main methods of welding stainless steels are arc welding and resistance welding. Other techniques include electron beam welding, laser welding and solid state welding such as friction welding. Oxyacetylene welding is not recommended due to the possibility of carbon pickup. Depending on the technique, arc welding may be done autogenously or with filler metal; the other methods are primarily done without filler metal.

Protection from Atmosphere

Because of the propensity to form refractory chromium oxide at elevated temperatures, the welding process must be protected from the atmosphere. As will be discussed in the following sections, this can be accomplished with an inert shielding gas, a vacuum, or a slag cover. The gas shielded (and vacuum) processes produce higher quality welds from the standpoint that the welds are less susceptible to contamination from oxygen, nitrogen and carbon. In general, stainless steels containing significant quantities of highly reactive elements, such as Ti or Al, are welded with the gas-shielded processes.

For further information on welding processes, excellent sources are AWS Welding Handbook and ASM Handbook, 10th ed., Vol. 6, Welding, Brazing and Soldering.

Preweld Cleaning

To provide high quality welds, pay special attention to cleaning prior to welding. This includes removal of all cutting fluids, oils, paints, oxide, etc. In addition, eliminate sources of moisture because water can introduce porosity or hydrogen. Because the gas-shielded processes do not use a flux, precleaning is particularly important with these processes. Do not use copper or lead tools, such as mallets for aligning pieces, prior to welding due to the possibility of transferring metal to the weld area. Transfer of metal could lead to liquid-metal embrittlement. (Due to the lack of metal transfer, the proper use of copper chill bars and clamping fixtures does not pose a problem.)

Besides lead, other low-melting-point metals to be avoided include cadmium, zinc and tin, which may be present in protective coatings. If grinding is necessary prior to welding, aluminum oxide wheels should be used rather than silicon carbide since embedded silicon carbide could decompose and increase the carbon content of the weld.

Postweld Cleaning

Another important step is removal of surface discoloration or oxide to provide optimum corrosion resistance for the weldment. Slags and fluxes must be removed after each weld bead is made using stainless steel chipping tools, wire brushes, or files. Carbon steel tools must not be used because of possible iron contamination, which will degrade corrosion resistance. For the same reason, grinding wheels previously used for carbon steels should not be used for stainless steels.

Welding Martensitic Stainless Steels

General Considerations: In some cases, such as large sections or a high degree of restraint, welding materials in the annealed condition may be advantageous to better accommodate shrinkage stresses in the base material. However, the starting condition (annealed, hardened + tempered, etc.) has less effect on weldability than the air-hardening capability of these alloys. This capability can lead to cold cracking of the brittle martensite in the weld and heat-affected zone (HAZ) from constriction stresses. The susceptibility to cracking increases with the hardness capability, which increases with the carbon content.

For this reason, higher-carbon grades such as Type 420 and the Type 440 series are not generally suggested for welding, although it may be necessary to do so. Type 420 is, however, commonly used as an overlay material.

The following table summarizes the relationship between carbon level and welding practice. These are guidelines only and vary somewhat from reference to reference:

CARBON	TYPICAL GRADE	PREHEAT	HEAT INPUT	POST-WELD HANDLING
<0.10	Type 410S	Not necessary	Standard	None required
0.10-0.20	Type 410	400-500°F	Standard	Slow cool/heat treat
0.20-0.50	Type 420	500°F	Standard	Heat treat
>0.50	Type 440 series	500°F	High	Heat treat before weld cools below 500°F

Since hydrogen plays a role in cold cracking, welding practices should focus on avoiding sources of hydrogen, for example, moisture. Fluxes and covered electrodes must be kept dry. Low-hydrogen welding techniques include the insert-gas processes, GTAW and GMAW, as well as EBW and LBW.

Filler Metals: Standard matching filler metals include E/ER410 and ER420. Higher-carbon filler metals are not typically available. E/ER410NiMo, a low-carbon Ni-bearing grade, is also available and may be used for its good combination of as-welded strength and toughness. When mechanical properties (or physical properties, such as thermal expansion) matching those of the base metal are not needed, an austenitic filler metal, such as AWS E/ER308, E/ER309 or E/ER310 can be used. E/ER312, which has a high ferrite potential, may be used for higher-carbon grades, where dilution could otherwise result in a fully austenitic weld prone to hot cracking. The austenitic filler metal can also improve weldability by yielding, and thereby reducing strains in the heat-affected zone (HAZ); in addition, austenite has a higher solubility for hydrogen, reducing diffusion of hydrogen to the less tolerant base metal. Austenitic welds have good toughness, and their use may allow elimination of a postweld heat treatment, assuming the limited ductility and toughness of the HAZ are acceptable for the application. Slow cooling of the weld will help minimize cold cracking in this case.

Free-Machining Grades: Free-machining grades such as Type 416, 416Se, 420F and 440F are not usually recommended for welding because of their crack sensitivity. However, if they must be welded, an austenitic filler metal such as E/ER308, E/E309, or preferably the high-ferrite E/ER312 can be used. Dilution of the weld metal with the free-machining agent (S or Se) should be minimized by keeping heat input to a minimum. Avoid pickup of hydrogen, which could react with the free-machining agent to produce porosity in the weld.

Welding Ferritic Stainless Steels

General Considerations: The main problems associated with the welding of ferritic grades are in the development of coarse grains in fully ferritic alloys. Grains will reduce ductility and toughness and the formation of austenite at elevated temperatures which, depending upon the alloy, can transform to brittle martensite upon cooling to room temperature. We will distinguish between the original, conventional ferritic grades and the newer grades developed to minimize these problems.

Austenite formation depends on the balance of ferrite and austenite formers, particularly chromium and carbon+nitrogen in the conventional ferritic grades. The risk of cracking from the transformation of this limited amount of austenite to martensite is significantly less than for the martensitic grades. However, if left untempered, the martensite can reduce ductility and toughness. On the positive side, the presence of some austenite at elevated temperatures will limit grain growth. In fact, this represents an earlier method of reducing grain growth. A further complication is that rapid cooling from temperatures above 1650°F (900°C) can result in sensitization and embrittlement.

To minimize the above problems, newer grades of ferritic stainless steels have significantly reduced carbon and nitrogen, and are usually stabilized with titanium and/or niobium (columbium). This minimizes austenite formation and sensitization. The titanium or niobium carbides also serve to restrict grain growth. Grain growth can still occur, but with low carbon and nitrogen, the degradation of ductility and impact strength is reduced. However, excessive levels of stabilizers can cause hot cracking. In addition, titanium and niobium behave differently. Autogenous welds in titanium-stabilized ferritics typically have an equiaxed zone at weld centerline, while niobium-stabilized alloys typically have a columnar zone, which is more prone to cracking.

Another development used in Type 409 (11.5Cr-Ti) and Type 409Cb (11.5Cr-Nb) is the addition of a small amount of nickel so that austenite will form, limiting grain growth. However, because the martensite so formed is a nickel martensite with low carbon and nitrogen, it has reasonable toughness, allowing the part to be used in the as-welded condition.

Although martensitic hardening is significantly reduced or even eliminated in ferritic grades, preheating to 300-450°F (150-230°C) may still be advisable for thicker sections; for parts where a high degree of restraint is present; for higher-chromium grades, like Type 443 (21Cr-1Cu) and Type 446, which typically have low toughness even at room temperature; and for grades whose balance (lower chromium and/or higher carbon+nitrogen) will result in significant martensite upon cooling to room temperature. On the other hand, excessive preheat should be avoided since it can contribute to grain growth. Heat input during welding must be sufficient to ensure complete fusion, but excessive heat input must be avoided to help minimize grain growth.

When making full penetration welds, nitrogen should not be used as a backing gas to protect the root side of the weld, because the nitrogen will degrade toughness, ductility and corrosion resistance. Welding practices should also focus on eliminating sources of hydrogen, e.g. moisture, to avoid cracking or porosity.

Filler Metals: Matching filler metals such as E/ER430 are available. Austenitic filler metals, such as E/ER309, may also be used if there are concerns about weld ductility or toughness, particularly in the as-welded condition. If the carbon level of the ferritic grade is low, an austenitic L grade should be used to avoid increasing the carbon level of the ferrite. In addition, if the weldment is to be annealed, an L grade should be used, since the annealing temperature for conventional ferritics is in the sensitization range for standard (higher-carbon) austenitic alloys. E/ER316L filler metal may be used for the chromium-molybdenum ferritic grades.

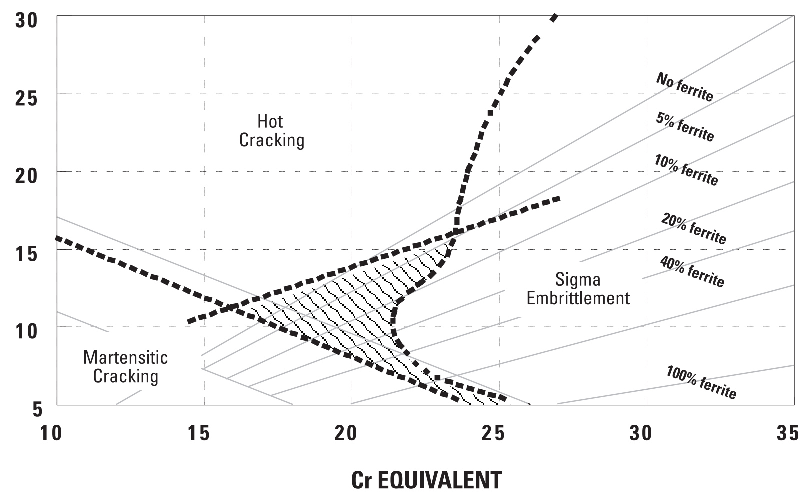
Use of an austenitic filler metal will be undesirable for applications requiring magnetic performance, since the austenite will create a magnetic “air gap.” Another concern is the large difference in thermal expansion between the austenite and ferrite, which may induce stresses leading to cracking. For a closer match in thermal expansion, a suitable nickel-base filler metal can be used.

Postweld Handling: Postweld annealing may be needed to restore intergranular corrosion resistance and enhance ductility, particularly for conventional higher-carbon/nitrogen, non-stabilized alloys, such as Type 430 with autogenous welds or matching filler metal. Annealing may also be needed to optimize magnetic properties.

Free-Machining Grades: Free-machining grades such as Type 430F are not usually recommended for welding because of their crack sensitivity. However, if they must be welded, an austenitic filler metal such as E/E309 or E/ER312 can be used. Dilution of the weld metal with the free-machining agent (S or Se) should be minimized by keeping heat input to a minimum. Avoid pickup of hydrogen, which could react with the free-machining agent to produce porosity in the weld.

Welding Austenitic Stainless Steels

Consider these issues when welding austenitic stainless steels:



1. The high coefficient of thermal expansion, low thermal conductivity and high elevated-temperature strength of austenitic stainless steels can result in a greater propensity for distortion during welding and greater residual stresses in the welded part. Alignment of the pieces to be welded is important. Also, avoid excessive heat input. Copper chill bars and backing bars can assist in heat removal.
2. Sensitization occurs in the range of 800-1600°F (425-870°C), depending on carbon level. Sensitization is precipitation of chromium carbides at grain boundaries, which results in a chromium-depleted zone. This can lead to intergranular corrosion, also known as “weld decay,” in certain environments. The propensity toward sensitization can be reduced by using a low-carbon grade or a grade stabilized with titanium or niobium (columbium).
3. Fully austenitic alloys are susceptible to hot cracking. Hot cracking can take several forms, most notably solidification cracking. The relationship between composition and the propensity for weld hot cracking is shown in the diagram above, which is based on the Schaeffler diagram. Alloys having compositions (Cr and Ni equivalents) falling within the shaded zone are resistant to weld hot cracking. This corresponds to alloys containing some ferrite in the as-cast condition, as opposed to those that are fully austenitic as cast.

Besides cracking, another defect that may occur in welds is porosity, which commonly results from moisture or contamination from greases, oils, etc. However, it may also be seen in nitrogen-strengthened grades that are close to the solubility limit for nitrogen. The latter problem can be aggravated in electron-beam welding due to the use of a vacuum; however, it is difficult to autogenously weld high-nitrogen grades (about 0.3% nitrogen and above) via any technique without encountering porosity. As a further complication, loss of nitrogen will increase ferrite content, adversely affecting cryogenic impact properties. To minimize nitrogen loss, a good gas cover must be maintained.

Filler Metals: Matching filler metals are commonly available for a wide range of austenitic stainless steels. E/ER308 or E/ER308L are the standard filler metals for the 18-8 austenitics, like Types 302, 304, 304L, 302HQ, 305, etc. The carbon level of the filler metal should be matched to the carbon level of the base metal. Because titanium is so reactive, E/ER347 is commonly used for both T347 and T321. ER321 can be used for GMAW with good inert gas shielding. Shielding is important in any case, since nitrogen pick-up from the atmosphere can decrease the ferrite content of the weld.

Nickel-base filler metals with over-matched molybdenum levels are often used for high-molybdenum superaustenitic grades to avoid localized corrosion in the weld due to segregation of molybdenum. For the high-nitrogen austenitics, E/ER2209 (22Cr-13Ni-5Mn with reduced nickel and nitrogen) is commonly used, although other matching fillers may be available.

Preheating austenitic grades is unnecessary, and, in fact, undesirable because it may aggravate hot cracking and sensitization. In addition, dilution of the filler metal with the base metal is also to be avoided since excessive dilution can result in a fully austenitic weld, which is prone to cracking.

Fully austenitic, highly alloyed grades like Type 310 (25Cr-20Ni), Type 330 (18.5Cr-35Ni-1.25Si) and 20Cb-3® stainless require special considerations to avoid hot cracking. Since ferrite is not an option, welding consumables should contain low residuals including sulfur, phosphorus and silicon. For that reason, a special low-residual filler metal, E/ER320LR (20Cb-3LR) was developed by Carpenter specifically for 20Cb-3® stainless.

Ferrite may also be undesirable in the welds of lower-alloyed grades for a variety of reasons. These include its effect on magnetic behavior, cryogenic toughness, corrosion resistance, and possible transformation to sigma phase.

Besides control of solidification mode and residual elements, hot cracking can be minimized by reducing the thermal or mechanical stresses imposed on the weld during solidification. Techniques to accomplish this include keeping the heat input low, limiting interpass temperature to 300°F (150°C) maximum, and minimizing joint restraint. The latter must be balanced against the need to prevent distortion during welding. Keeping the heat input low also aids in avoiding sensitization by allowing a faster cooling rate.

Another technique is the use of stringer beads, i.e., many narrow beads laid in a straight line rather than the fewer, wider beads produced by weaving from side to side (transverse oscillation). Finally, lower current and a slow travel speed provide a weld pool shape (elliptical versus tear-drop shaped) that is less prone to hot cracking.

Differences in cooling rate of weldments can affect the ferrite content needed to avoid hot cracking. For example, the rapid cooling rate of electron beam or laser beam welds with their narrow weld zone can shift the solidification mode from primary ferrite to primary austenite. This can also occur at higher welding speeds in conventional arc processes.

Postweld Handling: Postweld annealing may be needed to restore intergranular corrosion resistance, depending on the carbon content and cooling rate of the weldment. Even the low-carbon grades (up to 0.03%) can be sensitized if cooled extremely slowly through or held for very long periods in the sensitization range. However, that is unlikely under normal circumstances. Therefore, the “L” grades, e.g. Type 304L versus Type 304, can often be used as-welded. If an anneal is not needed after welding, weldments may be stress-relieved, if necessary, for several hours at 700-800°F (370-425°C).

Low-temperature sensitization, i.e., sensitization after long-term exposure at temperatures lower than the traditional sensitization range, such as 750°F (400°C), has been observed even in L grades. Use stabilized grades or L grades with increased nitrogen in this situation.

Stabilized grades may need a stabilization anneal if they are going to be exposed to the sensitization range in use. This is because titanium or niobium (columbium) carbides will be solutioned in a zone adjacent to the weld. If they are not reprecipitated with a stabilization anneal, grain boundary chromium carbide will be precipitated upon subsequent elevated-temperature exposure. This can result in “knife-line” attack if the weldment is then exposed to an appropriate corrosive environment.

Autogenous welds in high-molybdenum superaustenitic grades may require an anneal to alleviate molybdenum segregation in the weld, which will otherwise reduce localized corrosion resistance.

Free-Machining Grades: Free-machining grades are not usually recommended for welding because of their crack sensitivity. However, if they must be welded, an austenitic filler metal such as E/ER312 can be used for higher-carbon grades or E/ER308L for lower-carbon grades. Dilution of the weld metal with the free-matching agent (S or Se) should be minimized by keeping heat input to a minimum.

Welding Precipitation-Hardenable Stainless Steels

General Considerations: Martensitic and semi-austenitic precipitation-hardenable stainless steels pose no particular problems in welding. They are usually welded in the solution-treated or annealed condition. They may be welded in an overaged condition if you anticipate unusual welding stresses from highly restrained conditions or heavier sections. Shielding gas must be carefully maintained for those alloys containing reactive age-hardening agents, such as aluminum in Carpenter 13-8 and titanium in Custom 455 stainless.

Preheating is not needed in order to avoid cracking. However, stress concentrations such as notches or partial penetration welds should be avoided.

Filler Metals: When a filler metal is needed, a matching composition, if available, should be used for mechanical properties similar to those of the base metal. The most readily available “matching” filler metal is E/ER630 (17Cr-4Ni). If high weld strength is not needed, an austenitic alloy such as E/ER308L can be used. E/ER308 can be used for the higher-carbon semi-austenitic alloys.

Postweld Handling: If welded in the solution-treated condition, martensitic PH grades can be used as welded, if appropriate for the grade, or directly aged after the alloy has cooled to room temperature. However, for the optimum combination of strength, ductility and corrosion resistance, the alloy should be solution-treated before aging. If welded in the overaged condition, the part must be solution treated before aging to higher strength levels.

If welded in the annealed condition, semi-austenitic grades will require a conditioning treatment prior to aging, or tempering in the case of Pyromet 350 and 355. As for the martensitic grades, the optimum combination of properties is obtained by following the complete heat treating cycle, starting with an anneal.

Welding Duplex Stainless Steels

One of the main concerns when welding duplex stainless grades is the phase balance after welding. Corrosion resistance and mechanical properties of modern duplex grades depend in part upon a balance of approximately 50% austenite and 50% ferrite.

However, as shown in the diagram on page 77, alloys that are duplex at lower temperature will transform to ferrite at suitably elevated temperatures. In addition, the molten metal will solidify as primary ferrite, with austenite precipitating out of the ferrite. The precipitation or reprecipitation of austenite is dependent upon cooling rate, with faster cooling rates, as may be encountered in welds, restricting the precipitation of austenite. Conversely, very slow cooling rates may allow the precipitation of undesirable phases in these highly alloyed grades.

The proper phase balance can be restored by annealing autogenous welds or welds with matching filler metal.

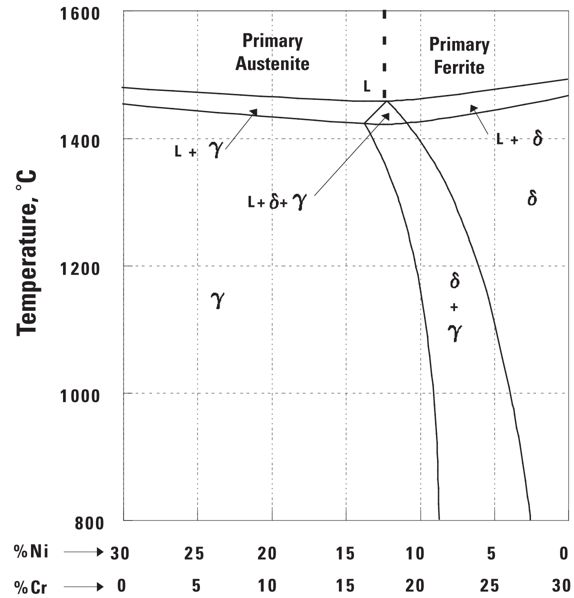
However, annealing is not always possible. Therefore, use the following procedures to help maintain the desired phase balance:

a. Avoid low heat inputs due to the faster solidification rates that accompany them. Welding techniques that result in a fast solidification rate, such as short-circuiting GMAW, electron-beam welding and laser-beam welding, should be avoided if possible.

b. Avoid too high a heat input, particularly with the more highly alloyed duplex grades because of their propensity to form detrimental intermetallic phases. In this case, heat input may be reduced for subsequent passes. Stringer beads are preferred.

c. Enriched-nickel filler metals will assist in ensuring that the weld metal contains the proper balance of austenite and ferrite when postweld heat treating is not possible. (Matching filler metals should be used if a postweld heat treatment is to be performed.)

Because of the sensitivity of these grades to welding technique, qualification of welding procedures must be more rigorous than for other types of stainless steels, and besides mechanical property testing includes phase balance assessment, microstructural evaluation and corrosion testing.



Dissimilar Welds

Because of the potential for cracking, alloy or carbon steel consumables must not be used when welding alloy or carbon steel to stainless steels, and 400 series stainless consumables must not be used when welding 400 series stainless to austenitic stainless.

When welding an austenitic stainless steel to a martensitic or ferritic stainless steel or to a carbon or alloy steel, the non-austenitic side of the joint is first "buttered" or coated with an austenitic weld rod such as E/ER309 or 312, which has sufficiently high alloy content to prevent martensite formation and contains sufficient ferrite to prevent hot cracking. Preheat is used as necessary, and the steel can be heat treated after buttering as needed. Then the joint can be made using the austenitic filler normally used for the austenitic stainless steel side of the weld.

When welding a martensitic or ferritic stainless steel to carbon or alloy steel, both sides of the joint can be "buttered" or coated with an austenitic weld rod such as E/ER309, using preheat and heat treating after buttering as necessary. Then the joint can be made without the need for preheat. Alternatively, the joint can be made using austenitic filler without the initial overlays; however, control of dilution is critical in this case.

A good source of additional information is *Welding of Stainless Steels and Other Joining Methods*, published by the Committee of Stainless Steel Producers.

GALLING AND CARPENTER STAINLESS STEELS

Adhesive wear results from two metals being rubbed together under a load sufficient to break through the oxide film, allowing the mating surfaces to come into contact at the high points. When the cohesive force between the two metals exceeds the strength of either metal, adhesion or cold welding occurs. Under low stress, this adhesion usually results in a complex process, which wears away one or both of the mating surfaces at a slow rate. At higher stresses, cold welding occurs more rapidly and over a greater area of the mating surfaces. This higher degree of cold welding is referred to as galling and may cause equipment to seize or freeze up. If not dealt with at the outset, galling can be a worrisome and recurring problem, particularly in the application of stainless steels.

Prevention

The probability of galling occurring between two metals can be minimized or prevented by

1. control of surface roughness,
2. use of lubricants,
3. decreasing the contact load, and
4. proper alloy selection.

Of these four measures, contact load may be the least subject to manipulation but, nevertheless, must be controlled to the extent that excessive loads are avoided. Control of surface roughness, coupled with the use of a high-quality lubricant such as a moly-disulfide reinforced grease, is all that may be required in many applications to prevent galling.

The ideal surface is one that is free of machining burrs, fins and tears and is not overly rough or overly smooth. For most applications, a surface roughness in the range of 15 to 50 micro-inches (rms) is best.

Alloy Selection

Most stainless steels are more susceptible to galling than carbon and alloy steels. However, not all stainless steels are equally susceptible and, in fact, some are quite resistant to galling. That is, resistant grades have a high threshold galling stress (TGS).

Threshold galling stress as discussed here is determined by a laboratory test. Threshold galling is the stress required to produce galling when a 1/2" (12.7 mm) diameter button is rotated against a flat plate with no lubrication. A single revolution of the button is normally used. However, when evaluating galling-resistant alloys, such as Gall-Tough® stainless, a procedure with three alternating revolutions is used to simulate more severe service. The button and plate may be the same or different alloys. Because of the many possible extraneous factors such as lubrication, temperature, roughness and others, TGS is not necessarily the lowest or, conversely, the highest stress that will produce galling in actual practice. Nevertheless, TGS has proven to be a valuable guide in selecting stainless steels with increased resistance to galling.

Threshold Galling Stress for Carpenter Alloys

To help the user and engineer select alloys for applications where galling could occur, Carpenter has applied the above procedure to determine TGS for numerous stainless steels. For some alloys, TGS was determined in two ways. In the first test, both button and base plate were the same alloy. In the second, base plate and button were two different alloys or conditions. Results from the various test are shown in *Tables 1, 2, and 3*. Note that *Tables 2 and 3* present results for single-rotation tests, while *Table 1* presents results for triple-rotation tests.

Large differences in TGS are seen among the various alloys and, of course, the resistance to galling increases with the TGS. Differences less than 2 to 4 ksi (14 to 28 MPa) between alloys, however, are not considered to be significant for the single-rotation test.

Observations Based on Our Data

Contrary to popular belief, cold working does not increase the resistance of an austenitic stainless steel to galling and, in fact, can be deleterious. On the other hand, increasing hardness via heat-treating is generally beneficial. Martensitic stainless steels such as Type 410 and Type 416 in the annealed or tempered conditions are similar or less resistant to galling than annealed austenitic stainless steels such as Type 304 and 316.

The addition of free-machining additives to both the 300 and 400 series stainless steels and the restriction of nickel in the nitrogen-strengthened alloys increase resistance to galling.

The TGS for a combination of two different alloys frequently lies between the values for the individual alloys in a self-mated condition.

Gall-Tough stainless has the highest TGS of any stainless steel produced by Carpenter and should be considered for those applications now using alloys such as Types 302, 304, 316 and 22Cr-13Ni-5Mn where galling has been a problem or is likely to be a problem.

Table 1 – Triple-Rotation Threshold Galling Stress Results for Various Stainless Steels Self-Mated, Unlubricated Ground Finish

ALLOY	CONDITION	ROCKWELL HARDNESS	THRESHOLD GALLING STRESS	
			ksi	MPa
Gall-Tough® stainless	Mill Annealed	B 92	15 *	103 *
Gall-Tough	Cold Drawn	C 38	15 *	103 *
Gall-Tough PLUS® stainless	Mill Annealed	B 95	7	48
Type 440C	Tempered 400°F	C 56	2	14
Custom 455® stainless	H 950	C 46	<1 *	<7 **
Type 304	Annealed	B 76	<1 **	<7 **
Type 316	Annealed	B 80	<1 ***	7
18Cr-2Ni-12Mn	Annealed	B 95	2	14
Type 430	Annealed	B 77	<1 **	<7 **
Type 420	Tempered 400°F	C 51	1	7

* Testing at higher stress not performed

** Galled at lowest stress evaluated

<None>Table 2 – Single-Rotation Threshold Galling Stress Results for Dissimilar (1) Stainless Steel Couples
Unlubricated Ground Finish

ALLOY(2)	CONDITION	ROCKWELL HARDNESS	THRESHOLD GALLING STRESS		ALLOY(2)	CONDITION	ROCKWELL HARDNESS	THRESHOLD GALLING STRESS	
			ksi	MPa				ksi	MPa
Gall-Tough® Stainless Type 410	Annealed Tempered 500˚F	B 96 C 42	15.0	104	Type 410 Type 440C	Tempered 600°F Tempered 500°F	C 42 C 55	5.0	34
Project 70+® Type 304 Project 70+ Type 304	Cold Drawn Annealed	C 27 B 86	4.0	28	Type 410 Custom 450 Stainless	Tempered 600°F H 900	C 42 C 43	1.0	7
Project 70+ Type 304 Type 440C	Annealed Tempered 500°F	B 86 C 55	4.0	28	Project 70+ Type 416 Project 70+ Type 416	Tempered 1000°F Annealed	C 32 B 83	11.0	76
Project 70+ Type 304 Custom 450® Stainless	Annealed H 900	B 86 C 43	3.0	21	Project 70+ Type 416 Type 440C	Tempered 600°F Tempered 500°F	C 37 C 55	23.0	159
Project 70+ Type 316 Project 70+ Type 316	Annealed Cold Drawn	B 82 C 27	8.0	55	Type 440C Type 630	Tempered 500°F H 900	C 55 C 45	5.0	34
Project 70+ Type 316 Type 440C	Annealed Tempered 500°F	B 82 C 55	2.0	14	Type 440C Custom Flo 302 HQ	Tempered 500°F Annealed	C 55 B 74	12.0	83
22Cr-13Ni-5Mn Project 70+ Type 304	Hot-Worked Unann. Annealed	C 32 B 89	6.0	41	Custom 455® Stainless Project 70+ Type 304	H 950 Annealed	C 48 B 86	18.0	124
22Cr-13Ni-5Mn Project 70+ Type 304	Annealed Annealed	B 97 B 89	3.0	21	Custom 455 Stainless Custom 630	H 950 H 900	C 48 C 45	11.0	76
18Cr-2Ni-12Mn Project 70+ Type 304	Annealed Annealed	C 23 B 86	15.0*	103*	Custom 455 Stainless Custom 630	H 950 H 1050	C 48 C 38	8.0	55
Type 430 18Cr-2Ni-12Mn	Annealed Annealed	B 98 C 23	10.0	69	Carpenter 13-8 Custom 630	H 1000 H 900	C 46 C 45	9.0	62
7-Mo® Stainless Project 70+ Type 316	Annealed Cold Drawn	C 25 C 27	1.5	10	Carpenter 13-8 Custom 630	H 1000 H 1025	C 46 C 38	2.0	14
7-Mo Stainless Project 70+ Type 316	Aged 1300°F 24 hrs. Annealed	C 41 B 82	5.0	34	Carpenter 13-8 Al-bronze	H 1150 Annealed	C 35 C 23	15.0*	104*

(1) Dissimilar means that the button and block are either different materials or the same material in different conditions.
(2) The first material listed for each dissimilar couple is the button.
* Did not gall at 15 ksi.

Table 3 – Single-Rotation Threshold Galling Stress Results for Various Stainless Steels
Self-Mated, Unlubricated Ground Finish

ALLOY	CONDITION	ROCKWELL HARDNESS	THRESHOLD GALLING STRESS		ALLOY	CONDITION	ROCKWELL HARDNESS	THRESHOLD GALLING STRESS	
			ksi	MPa				ksi	MPa
Austenitic Stainless Steels					**Precipitation Hardenable Stainless Steels**				
Gall-Tough® Stainless	Annealed	B 95	15.0 *	104 *	Custom 455® Stainless	H 950	C 48	13.0	90
Gall-Tough PLUS® Stainless	Annealed	B 95	15.0 *	104 *	Custom 455 Stainless	H 1050	C 43	8.5	59
22Cr-13Ni-5Mn	2050°F Annealed	B 97	5.0	34	Custom 455 Stainless	H 1150	C 36	4.0	28
21Cr-6Ni-9Mn	Annealed	B 96	7.0	48	Custom 450® Stainless	Solution Annealed	C 29	10.0	69
18Cr-2Ni-12Mn	Annealed	C 23	14.0	97	Custom 450 Stainless	H 90	C 43	8.0	55
Type 204Cu	Annealed	B 88	5.0	34	Custom 450 Stainless	H 1050	C 38	2.5	17
Project 70+® Type 304/304L	Annealed	B 89	8.0	55	Custom 450 Stainless	H 1150	C 33	2.0	14
Project 70+ Type 304/304L	Cold Drawn	C 27	2.5	17	Custom 630 Stainless	H 900	C 45	10.0	69
Project 70+ Type 316/316L	Annealed	B 82	7.0	48	Custom 630 Stainless	H 1150	C 34	5.0	34
Project 70+ Type 316/316L	Cold Drawn	C 27	5.0	34	Carpenter 13-8	H 1000	C 46	3.0	21
Custom Flo 302 HQ	Annealed	B 74	5.0	34					
Project 70+ Type 303	Annealed	B 85	15.0 *	104 *					
20Cb-3® Stainless	Annealed	B 87	2.0	14					
Martensitic Stainless Steels					**Ferritic and Duplex Stainless Steels**				
TrimRite® Stainless	Tempered 400°F	C 50	15.0 *	103 *	Type 430F	Annealed	B 92	2.0	14
TrimRite Stainless	Tempered 500°F	C 47	9.0	62	Type 430	Annealed	B 98	1.5	10
Type 410	Annealed	B 87	1.0	7	7-Mo® Stainless	Annealed	C 25	1.0	7
Type 410	Tempered 500°F	C 43	3.0	21	7-Mo Stainless	Aged 1300°F 24 hrs.	C 41	7.0	48
Type 416	Annealed	B 95	3.0	21					
Type 416	Tempered 600°F	C 37	9.0	62					
Type 416	Tempered 1000°F	C 32	6.0	41					
Type 420	Tempered 400°F	C 51	15.0 *	104 *					
Type 420	Tempered 500°F	C 49	8.0	55					
Type 440C	Tempered 500°F	C 55	15.0 *	104 *					

* Did not gall at 15 ksi

CARPENTER

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