Alloy Selection for COLD FORMING

Part II

Stainless steels and high-temperature alloys are available today for virtually any cold heading, forming, upsetting, or extruding operation. Part I (June 2003) covered stainless steel alloys; Part II covers high-temperature and specialty alloys.

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Specialty grades of stainless steel and other specialty alloys have been designed for virtually every cold heading, forming, upsetting, and extruding operation. They are necessary for the growing number of fastener components that must have the corrosion resistance and strength to withstand harsh environments, high operating temperatures, and great pressures, as well as requirements for special magnetic properties. For all such components, alloy selection has also been governed by the need to reduce part costs and secondary machining operations, thus improving productivity.

This article discusses selection guidelines for High Temperature / Specialty Alloys, defines alloy classes, and describes the applications most suitable for each alloy class.

High-performance applications

Many more manufacturers are cold heading fasteners and forming parts today from high-temperature and other specialty alloys. Initially, these alloys were needed for aircraft applications. More recently, applications have spread to other industries as well.

In a non-aircraft example, design engineers for a nuclear fusion test reactor selected Pyromet Alloy 718 and Pyromet Alloy A-286 for high strength, close-tolerance fasteners to position and hold down compression plates separating the toroid's field coils (Fig. 1). The fastener producer, having chosen Pyromet Alloy 718 for its high strength and nonmagnetic properties, was able to thread roll these large diameter fasteners (1.25 to 2.25-in. sizes) in the age-hardened condition. The alloy was supplied with a strength of 200 ksi (1379 MPa). The company thread rolled the large fasteners at a hardness of 44 to 46 HRC, after modifying existing equipment and manufacturing methods. In addition, the company made spanner nuts from Pyromet Alloy A-286 for the fusion reactor.

The automotive industry makes continual efforts to reduce the weight of vehicles. In these applications, high-strength materials permit smaller bolts without sacrificing strength. Energy exploration, with its harsh environments, also demands alloys that can withstand high temperatures and provide high levels of strength.

The analysis and relative strength properties of the commonly headed high-temperature and specialty alloys can be seen in Tables 1 and 2. Their relative headability and corrosion resistance are included in the diagram shown in Fig. 2.

Many of these alloys are cold-formable despite their initial high strength levels. They are offered in their lowest-strength form for maximum cold formability in the solution-treated condition, because maximum requirements for part integrity and fatigue life can be met with seam-free products. When heading the precipitation-hardening and high-temperature alloys, a controlled pattern must be established during the first deformation to avoid excessive initial hardening.

Alloys such as Pyromet Alloy 718 and Waspaloy work harden in the formed areas to approximately 50 to 56 HRC during final forming. Other alloys,

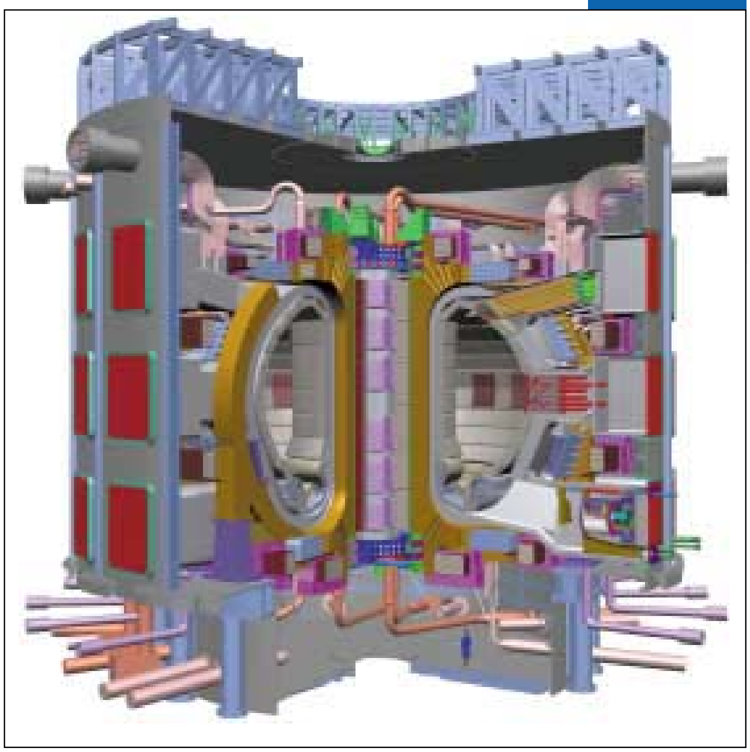

Fig. 1 — High-temperature specialty alloys have been selected as the fastener materials for compression plates separating the toroid field coils in a nuclear fusion test reactor such as the one depicted here. (Image from www.iter.org.)

*Table 1 — Composition and strength of batch annealed stainless steels **

Alloy	(UNS No.)	Composition	Typical max. tensile strength as annealed or overaged		Max tensile strength, 5% cold worked	
			MPa	ksi	MPa	ksi
409Cb	(S40940)	0.06C max; 1.00Mn max; 0.045P max; 0.04 S max; 1.00 Si max; 10.50-11.75 Cr; 0.50Ni max; (10 x C min) / 0.75Cb	483	70	552	80
430	(S43000)	0.12 C max; 14.00-18.00Cr	517	75	593	86
410	(S41000)	0.15C max; 11.5-13.5Cr	538	78	621	90
TrimRite	(S42010)	0.15 / 0.30C; 1.0Mn max; 1.0Si max; 0.04P max; 0.03S max; 13.5 / 15.00Cr; 0.25 / 1.00Ni; 0.40 / 1.00Mo	621	90	655	95
No. 10	(384) (S38400)	0.08C max; 15.00-17.00Cr; 17.00-19.00Ni	538	78	572	83
302HQ	(S30430)	0.08C max; 2.00Mn max; 0.045P max; 0.03S max; 1.00Si max; 17.00 / 19.00Cr; 8.00 / 10.00Ni; 3.00 / 4.00Cu	517	75	572	83
302HQ-FM	(S30431)	0.06C max; 2.00Mn max; 0.040P max; 0.14S max; 1.00Si max; 16.00 / 19.00Cr; 9.00 / 11.00Ni; 1.30 / 2.40Cu	665	85	641	93
305	(S30500)	0.12C max; 17.00-19.00Cr; 10.00-13.00Ni	572	83	641	93
316	(S31600)	0.08C max; 16.00-18.00Cr; 10.00-14.00Ni; 2.00-3.00Mo	655	85	655	95
431	(S43100)	0.20C max; 15.00-17.00Cr; 1.25-2.50Ni	724	105	793	115
304 / 304 Mod.	(S30400)	0.08C max; 18.00-20.00Cr; 8.00-11.00Ni	641	93	655 / 689	95 / 100
204-Cu		0.15C max; 6.50-9.00Mn; 15.5-17.50Cr; 1.50-3.50Ni; 0.05-0.25N; 2.00-4.00Cu	689	100	758	110
321	(S32100)	0.08C max; 17.00-19.00Cr; 9.00-12.00Ni; Ti (5xC min)	641	93	689	100
347	(S34700)	0.08C max; 17.00-19.00Cr; 9.00-13.00Ni; Cb + Ta (10xC min)	641	93	724	105
20Cb-3	(N08020)	0.07C max; 2.00Mn max; 1.00Si max; 19.00 / 21.00Cr; 30.00 / 38.00Ni; 2.00 / 3.00Mo; 3.00 / 4.00Cu; Cb +Ta (8xC min / 1.00% max)	724	105	793	115
15-7PH	(S15700)	0.09C max; 1.00Mn max; 0.04P max; 0.03S max; 1.00Si max; 14.00-16.00Cr; 6.50-7.75Ni; 2.00-3.00Mo; 0.75-1.50Al; Fe balance	896	130	1000	145
15Cr-5Ni	(S15500)	0.07C max; 1.00Mn max; 0.04P max; 0.03S max; 1.00Si max; 14.00-15.00Cr; 3.50-5.50Ni; 2.50-4.50Cu; 0.15-0.45(Cb+Ta); Fe balance	931	135	1000	145
Custom 450	(S45000)	0.05C max; 0.50Mn max; 0.040P max; 0.030S max; 0.50Si max; 11.00 / 17.50Cr; 7.50 / 9.50Ni; 0.80 / 1.40Ti; 0.10 / 0.50Co and Ta; 1.50 / 2.50Cu; 0.50 Mo max	1034	150	1103	160
Custom 455	(S45500)	0.05C mx; 0.50Mn max; 0.040P max; 0.030S max; 0.5Si max; 11.00 / 17.50Cr; 7.50 / 9.50Ni; 0.80 / 1.40Ti; 0.10 / 0.50Co and Ta; 1.50 / 2.50Cu; 0.50Mo max	1034	150	1103	160
Custom 630	(17Cr-4Ni) (S17400)	0.07C max; 15.50-17.50Cr; 3.00 / 5.00Ni; 3.00 / 5.00Cu; 0.15-0.45(Cb+Ta); 1.00Mn max; 0.04P max; 0.03S max; 1.00Si max	1034	150	1103	160
PH13-8Mo	(Armco) (S13800)	0.05C max; 0.10Mn max; 0.01P max; 0.008S max; 0.10Si max; 12.25-13.25Cr; 7.50-8.50Ni max; 0.90-1.35Al; 2.00-2.50Mo; 0.01N max	1034	150	1138	165
440C	(S4404)	0.95 / 1.20C; 1.00Mn max; 0.040P max; 0.03S max; 1.00Si max; 16.00 / 18.00Cr; 0.75Mo max	793	115	931	135

**Strand annealed properties are higher.*

Table 2 — Analysis and properties of the most commonly formed high-temperature/specialty alloys, listed in order from easiest to most difficult to form

Alloy	(UNS number)	Alloying elements	Typical max. tensile strength as annealed MPa	Typical max. tensile strength as annealed ksi	Typical max. tensile strength, 5% cold worked MPa	Typical max. tensile strength, 5% cold worked ksi
Ni-Cu alloy 400	(N04400)	0.3C max; 2.0Mn max; 0.5Si max; 0.024S max; 63.0 / 70.0Ni; 2.5Ni; 2.50Fe max; Cu balance	517	75	579	84
Pyromet A-286	(K66286)	0.08C max; 2.00Mn max; 1.00Si max; 13.50 / 16.00Cr; 24.00 / 27.00Ni; 1.00 / 1.75Mo; 1.90 / 2.30Ti; 0.10 / 0.50V; 0.35Al max; 0.003 / 0.010B; Fe balance	655	95*	655	95*
Pyromet 718	(N00718)	0.08C max; 0.35Mn max; 0.35Si max; 0.015P max; 0.015S max; 17.00 / 21.00Cr; 50.00 / 55.00Ni; 1.00Co max; 2.80 / 3.30Mo; 4.75 / 5.50Cb + Ta; 0.65 / 1.15Ti; 0.35 / 0.80Al; 0.001 / 0.006B; 0.15Cu max; Fe balance	827	120*	931	135*
Waspaloy	(N07001)	0.02 / 0.10C; 0.50Mn max; 0.75Si max; 0.020 S max; 18.00 / 21.00Cr; 3.50 / 5.00Mo; 12.00 / 15.00Co; 2.75 / 3.25Ti; 1.20 / 1.50Al; 0.02 / 0.12Zr; 0.003 / 0.008B; 0.10Cu max; 2.00Fe max; Ni balance	896	130*	965	140*
Pyromet 882	(T20881)	0.40C; 1.00Si; 5.00Cr; 1.50Mo; 0.4V; Fe balance	655	95	689	100

**Depends on grain size and heat treated mechanical property requirements.*

such as Pyromet Alloy A-286 and Custom 455 stainless, have been designed for less-rapid work hardening. They harden to only about 36 to HRC 45 in the final forming step. Warm and hot heading techniques often improve formability of these and other high-temperature alloys.

Aircraft engine bolts have been cold-formed from alloys such as Pyromet Alloy 718 and Waspaloy. As an alloy with good mechanical properties to 1300°F (700°C), Pyromet Alloy 718 is useful for high-temperature fasteners.

Pyromet Alloy A-286, which is suitable for a variety of aerospace and automotive applications, has notch rupture strength superior to any other alloy with comparable high-temperature properties. It has been chosen for service in temperatures up to 1300°F (700°C). This popular grade is available in several different cold-drawn conditions to meet specified property requirements after heat treatment.

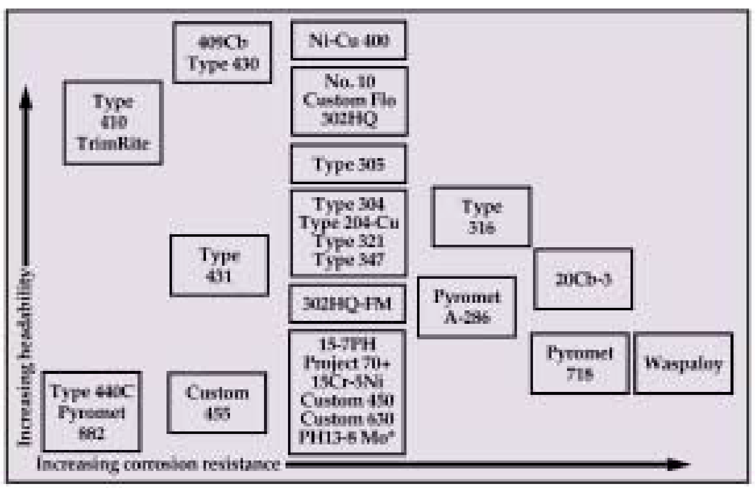

Fig. 2 — Relative corrosion resistance and headability of commonly headed stainless steels and high temperature/specialty alloys.

Strength and corrosion resistance

Waspaloy (AISI Type 685) functions well in gas turbine engine parts that require considerable strength and corrosion resistance at temperatures up to 1600°F (870°C). This alloy can be cold headed, although it is more difficult to cold form than Type 316 stainless. Tensile strength ranges from about 110 to 140 ksi (758 to 965 MPa) depending on the grade and the condition in which it is supplied.

Similar opportunities are possible with other high temperature alloys and precipitation hardening stainless steels such as Carpenter 15-7PH stainless, Carpenter PH 13-8 Mo alloy, Custom 630 (17Cr-4Ni), and Pyromet alloy A-286. Pyromet alloy A-286, for example, has been chosen for bolts to hold superchargers on engines, and to fasten together small instrumentation packages that can withstand the harsh environments and elevated temperatures needed for energy exploration.

Custom 630 and PH 13-8 Mo alloys have good fabricating characteristics, and can be age-hardened. PH 13-8 Mo alloy, compared with other ferrous-based materials, offers a high level of useful mechanical properties under severe environmental conditions.

Another grade, Pyromet alloy 882 (AISI Type H-11), has solved many cold-working problems in which extra toughness was required at the sacrifice of some wear resistance. This steel has also served as aircraft structural material for critical components in aircraft and missiles. In these applications, it has reached very high

Table 3 — Classification systems for commonly headed stainless steels and high-temperature/specialty alloys

UNS	Producer designation	AISI	ASTM	ASME	AMS	SAE	Military/ Federal
Stainless Steels							
S43000	430	Type 430	A493, 580	-	5627	J-405	QQ-S-763 QQ-W-423 Std. 66
S41000	410	Type 410	A193, 194, 493, 580	SA 194	5613	J-405 J-412	QQ-S-763 QQ-W-423
S42010	TrimRite Alloy	-	-	-	-	-	-
S43100	431	Type 431	-	-	-	-	-
S38400	No. 10	Type 384	A493	-	-	-	-
S30430	302HQ	-	A493	-	-	-	-
S30500	305	Type 305	A313, 368, 478, 492, 493, 580	SA 193, 194, 320	5685, 5686	J-405	QQ-S-763 QQ-W-423
S31600	316	Type 316	Numerous	SA 193, 194, 320, 403	5648, 5690, 5691	J-405	QQ-S-763 QQ-W-423
S30400	304 304 Modified 304 Forming quality	Type 304	A493	-	5639	J-405	QQ-S-763 QQ-W-423
S20430	204-Cu	-	A313	-	-	-	-
N08020	20Cb-3 Alloy	-	B471, 473, 475	-	-	-	-
S45000	Custom 450 alloy	-	A564	-	5763	-	-
S17400	Custom 630	-	A564	SA 564	5643	-	-
S45500	Custom 455 alloy	-	A313, 564	SA 564	5617, 5672	-	-
S44004	440C	Type 440-C	A493, 580	-	5618, 5630	J-405	QQ-S-763
High-Temperature/Specialty Alloys							
N07718	718	-	-	-	5662	-	-
S66286	A-286	-	-	-	5731, 5732, 5734, 5735, 5736, 5737	-	-
N07001	Waspaloy	-	-	-	5708	-	-
N04400	Ni-Cu 400	-	-	-	-	-	QQ-N-281

strength levels, some in excess of 260 ksi (1793 MPa).

Of all the materials in this category, Ni-Cu alloy 400, with its very low work-hardening rate, is easiest to form. Its headability relative to other alloys can be seen in Fig. 2. Its analysis and strength properties are shown in Table 2. Ni-Cu alloy 400, operating at temperatures up to 800°F (430°C), has excellent corrosion resistance to seawater, and is virtually immune to chloride stress corrosion cracking. The alloy is widely preferred for rivets.

Classification systems

Parts manufacturers can be misled by terms such as "stainless fastener" or "high strength fastener." Orders specifying these broad terms tend to be ambiguous because so many alloys are in this category. Each offers a distinct set of properties in the finished product.

Disappointment most likely awaits the producer who tries to substitute one stainless or high-temperature alloy for another in an attempt to save raw material costs, boost production, or gain other advantages. If the fasteners must be nonmagnetic, for example, neither Type 430 stainless nor Type 410 stainless would be appropriate, despite their excellent formability. Also, if an 18Cr-8Ni alloy is designated, then 302HQ stainless cannot be substituted without the approval of the specifier, because it contains an intentional addition of 3 to 4% copper.

Great effort has been expended to make the alloy selection easier through improved specification standards. In the broad sense, the Unified Numbering System (UNS) represents an attempt to establish a universal method for classifying alloys.

The need for such a system is obvious when you examine Table 3 and see how many classifications can cover a single alloy. This table lists the basic headable stainless steels and high temperature alloys, and shows how each grade is specified according to several classification systems.

In a further attempt at standardization, the American Society of Testing and Materials (ASTM) has developed specifications for stainless steel. For example, F593 is for bolts, hex cap screws, and studs; while F594 is for nuts, and F738 covers metric bolts, screws, and studs.

Numerous stainless grades are included in the ASTM specifications. Although these ASTM fastener standards do not include all headable stainless steels, they do provide broad coverage and include stainless grades for machined fasteners.

Specifications such as F593, F594, and F738 are designed to place general limits on stainless alloys, classifying them by the percentage and types of elements included in each alloy's composition. However, specifications by their very nature are not always the last word.

For example, seven headable stainless grades - Types 430, 410, No. 10, 305, 316, 304, and 440-C - meet the Society of Automotive Engineers (SAE) specifications for cold-finished annealed wire. Those specifications are insufficient to guide selection when considering the obviously wide gulf between the corrosion resistance of Type 410 stainless and Type 316 stainless. Selection of the proper alloy must depend upon both the corrosion resistance and strength level demanded by the particular application.

When considering a stainless steel for a forming application, the user should always refer to ASTM specification A493 for wire feedstock. For the header, it is the most useful guide for specifying wire because it gives each alloy's chemical composition and mechanical properties. Assuring the composition and properties defined is the natural responsibility of the wire supplier. ■

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