Alloy Selection for
COLD FORMING

Part I

Stainless steels and high-temperature alloys are available today for virtually any cold heading, forming, upsetting, or extruding operation.
Part I covers stainless steel alloys; Part II (July AM&P) will cover high-temperature and specialty alloys.

Douglas G. Frick
Carpenter Technology Corporation
Reading, Pennsylvania

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 (Fig. 1). 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, defines alloy classes, and describes the applications most suitable for each alloy class.

Selection guidelines

The manufacturer who meets required material specifications has no problem selecting the right stainless steel or high-temperature alloy for a heading job. However, if no specifications are provided, the producer may determine the best alloy by means of an orderly, four-step process.

The following questions, in order of importance, should be answered:

1. How much corrosion resistance is required?
2. What strength is needed, considering that mechanical properties may be affected by heading and heat treatment?
3. Which of the alloys meeting corrosion and strength requirements offer the best headability?
4. How available is the alloy?

Two additional variables should be considered. One is part complexity, which determines the severity of upset or extrusion. The second is the heading wire coating. Especially in the case of an alloy not easily headed, the coating is essential in facilitating forming and providing reasonable tool life.

Alloy classes

Before examining corrosion resistance as a selection requirement, a brief review of the stainless steels and high-temperature alloy classes may be helpful, particularly as they pertain to heading and forming.

• *AISI 400 series:* The simplest stainless steels contain a minimum of about 11% chromium, in addition to iron. They generally are known as the AISI 400 series of stainless steels and, depending on the chromium and carbon contents, may be martensitic or ferritic. The martensitic alloys, which typically contain more than 0.08% carbon, are hardenable by heat treatment. Type 410 stainless is a typical martensitic alloy in this series.

Increasing chromium or reducing carbon results in a ferritic stainless steel, which cannot be hardened by heat treatment. Increasing chromium also increases corrosion resistance. Type 430 stainless (18% chromium), a typical alloy in this family, is more corrosion resistant than Type 410 stainless (12% chromium).

• *AISI 300 series:* The AISI 300 series provides a significant improvement in corrosion resistance. Nickel is the most important alloying element in the 300 series, which includes types such as Custom Flo 302HQ, Type 304, and Type 305 stainless steels. These are the 18-8 stainless steels, containing about 18% chromium and a minimum of 8% nickel. They are austenitic alloys that are not hardened by heat treatment, but they do work-harden by cold working. Molybdenum may be added for greater resistance to chloride pitting (Type 316). Still other alloying elements may be added to enhance fabrication characteristics. For example, the 3 to 4%

Fig. 1 – These are some of the many fasteners cold formed of specialty grades of stainless steels and high-temperature alloys.

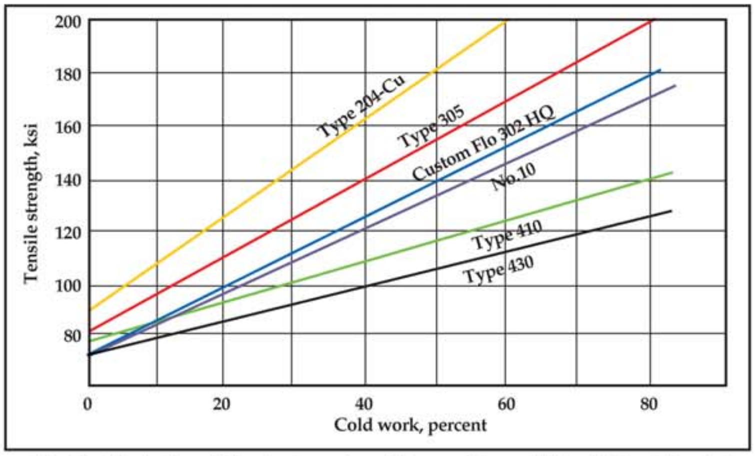

Fig. 2 – Typical work hardening rates of frequently specified cold headable stainless steels demonstrate the influence of alloy composition.

*Relative headability of common stainless steels**

Alloy	Typical maximum tensile strength, 5% cold work, MPa (ksi)	Typical work-hardening rate
430	593 (86)	0.7
410	621 (90)	0.9
No. 10	572 (83)	1.4
302HQ	572 (83)	1.5
305	641 (93)	1.5
316	655 (95)	1.6
304	655 (95)	1.6
304 Mod.	689 (100)	1.8
204-Cu	758 (110)	1.8

** Based on typical maximum tensile strength and work-hardening rates. Work hardening rate is defined as the increase in tensile strength for each percent of reduction in area through cold working.*

copper in Custom Flo 302HQ lowers the work-hardening rate, thus improving headability.

• *AISI 200 series:* Type 204-Cu alloy, a 200 series austenitic stainless, is a recent low-nickel alternative to 18-8 stainless Type 304. The 3% copper in Type 204-Cu alloy gives it a lower work-hardening rate and better headability than other high-manganese, nitrogen-strengthened alloys. High nitrogen content maintains the austenitic structure of the 200 series grade, giving it higher annealed yield and tensile strength than stainless Type 304, with similar headability.

Fasteners that have been made from Type 204-Cu alloy have remained nonmagnetic after cold forming, and have been less susceptible to galling than fasteners formed from high-nickel 300 series alloys. Although properties are similar to those of Type 304 stainless, the cost of Type 204-Cu alloy is virtually unaffected by fluctuations in nickel prices. The low-nickel alloy can be considered as a replacement for Type 304 stainless in fasteners that require high strength and good formability.

• *Precipitation-hardening alloys:* Another stainless steel category includes the age-hardening or precipitation-hardening alloys, such as the following Carpenter alloys: Custom 630 (17Cr-4Ni) stainless, 15-7PH stainless, Project 70+ 15Cr-5Ni stainless, Custom 450 and Custom 455 stainless, and Armco's PH13-8Mo alloy. They provide corrosion resistance at strength levels above those of the 300 or 400 series stainless steels.

• *High-temperature alloys:* The high-temperature alloys comprise a separate classification. Included in this group are grades such as Carpenter Pyromet Alloy 718, Pyromet Alloy A-286, Pyromet Alloy 882, and Carpenter Waspaloy. Like the precipitation-hardening grades, these alloys require much more specialized heading techniques and considerably more energy to head.

Another grade used in specialized applications is Carpenter Ni-Cu Alloy 400. This alloy has relatively high strength and toughness over a wide temperature range. With its relatively low work-hardening rate, this material is easy to head.

Headability of various alloys

The heading process is defined as forming the head on a fastener by upsetting. Headability is determined by the alloy's mechanical properties and its work-hardening rate, the rate at which mechanical properties are increased by cold working.

Tensile strength alone is not a reliable measure of headability, because chemical composition determines the alloy's work-hardening rate. Two alloys with different compositions and the same annealed tensile strength may have different work-hardening rates. If the two alloys are cold-worked by in-line drawing, the one with the higher work-hardening rate will have higher yield and tensile strengths. Consequently, it will be more difficult to head because more force will be needed to shape the part.

Headability depends greatly on the ratio of yield strength to ultimate tensile strength. Yield strength must be exceeded before material can flow; however, the ultimate tensile strength cannot be exceeded or the part will crack.

Stainless grades in the 400 series cold head much like carbon and low alloy steels. Type 430 stainless, with the lowest work-hardening rate, is the easiest to cold form, and Type 440-C stainless is the most difficult. Ni-Cu-400 alloy, listed in the high-temperature/specialty alloys section, offers headability comparable to that of Type 430 stainless.

The 300 series stainless steels are somewhat more difficult to cold form than the 400 series, because alloys in the 300 group have higher work-hardening rates (Fig. 2 and the table). Stainless alloys in the 300 series require more energy to head than the 400 series. Carpenter No.10 stainless and Custom Flo 302HQ stainless, with the lowest work hardening rates in the 300 series, are the easiest to head.

Although Type 304 Modified (Type 304H) is less headable than Type 304, its high work-hardening rate is an asset for fasteners requiring high-strength threads. Type 304 Modified, which has been used in construction type fasteners, can be cold worked to about HRC 40 to 45.

The precipitation-hardening stainless steels and high-temperature alloys are generally more difficult to head because of the alloying elements that impart overall greater strength at cold working temperatures. In the case of PH stainless steels such as Custom 630 stainless (17Cr-4Ni), PH13-8Mo stainless, and Custom 455 stainless, formability usually can be optimized if the material is in the overaged condition. For example, Custom 630 stainless, with the lowest yield strength and tensile strength, has best formability when in the H1150M condition. Material processed by this method must be subsequently solution-treated before aging to reach maximum tensile strength.

Some stainless steels offer cold headers maximum fabricating characteristics for components that require secondary operations such as machining. Carpenter 302HQ-FM stainless is a good example of how certain grades can be modified to meet specific property requirements. This alloy combines the headability of Type 302HQ stainless with the free-machining benefits of Type 303 stainless. It can be cold headed into a variety of parts, then easily machined in secondary operations such as drilling, slotting, and tapping.

Type 409Cb stainless has served extensively in the automotive industry for muffler hangers and brackets, catalytic converter weld wire, and in oxygen-sensor components. Type 409CB-FM, a free-machining variation, has been chosen to improve fabrication performance and tool life where secondary machining operations are required.

Advances in steelmaking technology now make it possible to modify composition and processes to meet more specific requirements. New techniques facilitate better control of grain size, yield strength, shear strength, and surface finish. However, to justify the cost of such modifications, the usual caveat applies — the volume needed must be significant.

Selection diagram

To simplify selection of the best alloy for a heading or forming job, Carpenter has developed a proprietary method which plots relative corrosion resistance and headability. Fig. 3 shows a diagram in which 27 stainless steels and high temperature/specialty alloys are positioned in accordance with these two key characteristics.

To choose an alloy, simply move up for better headability, and to the right for better corrosion resistance. The drawing indicates that stainless Type 409Cb, stainless Type 430, and Ni-Cu Alloy 400 have the best headability, while Waspaloy has the highest corrosion resistance. No. 10 stainless and Custom Flo 302HQ stainless provide a good combination of headability and corrosion resistance.

Obviously, some tradeoffs may be made in the selection process, because each application has its own special requirements. When considering costs, the best choice is the lowest cost alloy that provides the properties needed.

Relative corrosion resistance shown on the diagram should be considered only a general guide. For corrosion resistance to specific environments, consult with the alloy supplier. In general, if corrosion resistance is relatively similar, select the alloy offering the best combination of headability and cost.

• *Stainless Type 409Cb and stainless Type 430* offer the best formability of all the stainless steels, with slightly less corrosion resistance than stainless Type 304. Their formability is similar to that of low alloy steels, which are easy to head. Stainless Type 409Cb has been used for a variety of automotive applica-

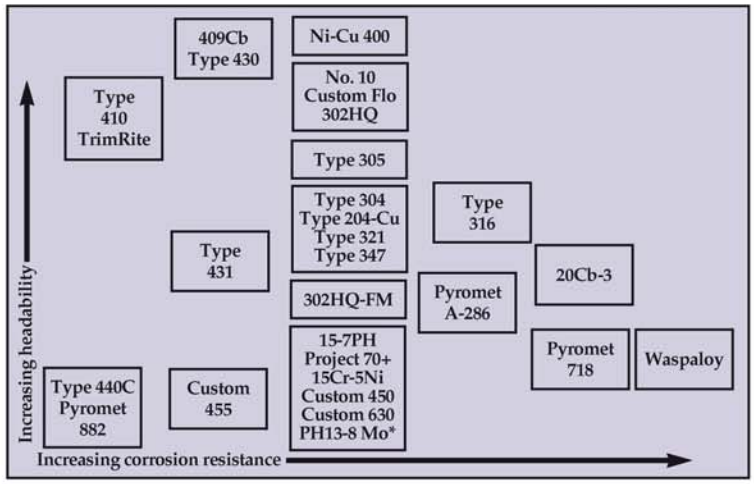

*Fig. 3 – Relative corrosion resistance and headability of commonly headed stainless steels and high-temperature/specialty alloys. *Trademark of Armco Inc.*

tions (mentioned earlier), and stainless Type 430 has been selected for many types of fasteners and bolts.

• *Type 410 is* a hardenable stainless steel with the same tensile strength capability as stainless Type 431 when heat treated. It is less corrosion resistant than stainless Type 431, and has been used most often for sheet metal screws, bolts, and fasteners exposed to atmospheric conditions.

• *Carpenter TrimRite stainless,* specified for self-drilling construction fasteners, has better corrosion resistance than stainless Type 410, the strength of stainless Type 420, and corrosion resistance of stainless Type 430.

• *No. 10 (Type 384) stainless and Custom Flo 302HQ* stainless offer excellent headability and corrosion resistance for severely formed parts. No. 10 stainless, with its high nickel content, remains nonmagnetic after cold working. The 302HQ alloy, which becomes slightly magnetic after cold work, is more readily available than No. 10 stainless.

• *The 302HQ-FM stainless* is a machinable modification of 302HQ stainless that is suitable for both heading and subsequent machining. It has been run in bar form on automatic screw machines to produce parts where thread rolling or cold form tapping operations are critical. Similarly, 409Cb-FM stainless, a modification of 409Cb stainless, offers good formability with improved machinability in secondary operations.

• *Type 305 stainless* is suitable for severely formed parts and fasteners made in multiple heading stages. In addition to its good formability, the alloy is also useful for parts that must remain nonmagnetic after cold working. This grade resists corrosion by severe atmospheres, nitric acid, and foodstuffs.

• *Type 316 stainless* is an easily formed alloy that has superior corrosion resistance, and resistance to pitting corrosion in particular. It is a good choice for fasteners for the chemical process industries.

• *Type 304 stainless,* which resists severe corrosion and corrodents such as nitric acid, is frequently selected for fasteners with simple head designs. Type 304 modified stainless is the alloy of choice for construction type fasteners. Composition of this grade can be adjusted to reduce the work-hardening rate for fasteners that require more severe forming.

• *Type 204-Cu stainless* can be considered for applications where high strength and good formability are required. In addition, the alloy might be appropriate for fastener applications that are currently made of Type 304 stainless. Type 204-Cu stainless offers two additional advantages — fasteners made from the alloy remain nonmagnetic after cold forming, and they are less susceptible to galling than fasteners formed from high-nickel 300 series alloys.

• *Type 431 stainless* can be heat treated to higher strength than Type 304. While Type 431 has slightly less corrosion resistance than Type 304, it has the best corrosion resistance of all the hardenable grades. It has been applied in marine fasteners and aircraft fasteners requiring corrosion resistance and toughness.

• *Type 321 and Type 347* are also austenitic stainless steels that can be cold formed. They resist corrosion and heat, and are suitable for aircraft fastener service at 800 to 1500°F (427 to 816°C).

Corrosion resistant alloys

• *Carpenter 20Cb-3 stainless* should be considered for fasteners or parts that require resistance to chloride stress corrosion cracking, hot sulfuric acid, and/or many aggressive environments that readily attack Type 316 stainless.

• *Precipitation hardening alloys* should be considered if more strength is needed than possible in an alloy such as Type 431. The tradeoff to their typically high mechanical properties is somewhat less formability.

• *Custom 450 stainless* is an age-hardenable steel that can be cold formed in the solution-annealed condition. It has the very good corrosion characteristics of Type 304, along with considerably higher strength capability after aging. It may be hardened to approximately HRC 50.

• *Custom 630 (17Cr-4Ni) stainless* is a precipitation-hardenable steel offering high strength and hardness with excellent corrosion resistance. Its strength level is similar to that of Custom 455 stainless.

• *15Cr-5Ni stainless* is a martensitic age-hardenable stainless with strength and corrosion resistance similar to that of Custom 630 stainless, but with improved forgeability and transverse toughness.

• *15-7PH stainless* is a precipitation hardening stainless that is more easily formed in the annealed condition because of its austenitic structure. It is capable of high strength via cold working and/or thermal treatment to a martensitic structure. 15-7PH stainless has been used to produce rivets for aerospace applications.

• *Type 440-C stainless,* which derives its hardenability and high tensile strength from heat treatment, is the most difficult of all stainless steels to head. It has been used primarily in applications in which balls are headed for stainless bearings. ■

For more information: Douglas G. Frick, Specialist – Coil Technical Services, Carpenter Technology Corp., P. O. Box 14662, Reading, PA 19612-4662; tel: 610/208-2936; fax: 610/736-7299; e-mail: dfrick@cartech.com.