MACHINE DESIGN

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Metallurgy makes or breaks tube fittings

The best tube fittings balance hardness, strength, and corrosion resistance.

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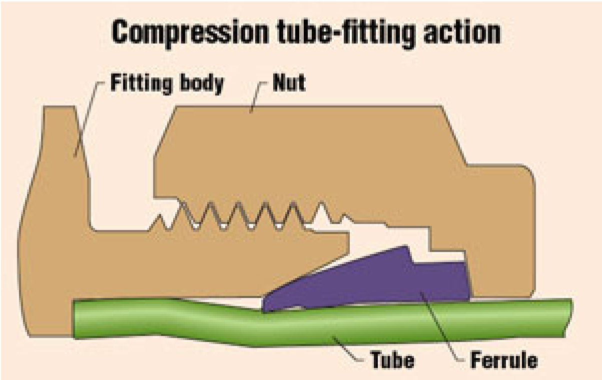
Parker Hannifin's Suparcase ferrule-hardening process does not require the high temperatures and long durations of more-conventional case-hardening procedures that, in turn, lower stainless steel's corrosion resistance. Images show Suparcase (left) and carbonitrided 316-stainlesssteel samples subjected to an ASTM B117 salt-fog test.

Stainless-steel compression tube fittings make it easy to install and maintain measurement and control instruments used in chemical processing, petrochemical plants, paper mills, and many other industrial settings. They seal a broad range of aggressive fluids and chemicals, and resist internal and external corrosion. The fittings grip and seal by compressing the nose of a ferrule into the tubing OD. High-quality compression fittings hold internal pressure without leaks or failure until the tubing fractures. And users can repeatedly disassemble and reassemble them with no loss of sealing integrity.



Compression tube fittings grip and seal by compressing the nose of a ferrule into the tubing OD. To form high-integrity, leak-free connections that can be remade, ferrules must only slide forward during assembly and not rotate with the nut.

Today, fittings are available from many domestic and off-shore suppliers. They tend to look pretty much the same, though they may vary slightly in design details and manufacturing processes. But looks are deceiving.

The ferrule, perhaps the most-critical component in compression fittings, appears rather simple. Yet it is highly engineered and, to function properly, requires considerable design, metallurgy, and production expertise. Not all products on the market meet these stringent requirements.

For instance, the ferrule must precisely deform elastically and plastically during fitting assembly to properly grip and seal the tubing. Its front edge must be harder than the tubing to grip and seal through surface scratches and defects, but if the entire ferrule is too hard, it may not deform properly. Therefore, only the gripping edge of the ferrule is hardened while the rest has different, tightly controlled mechanical properties. Also, the hardening process must not compromise stainless steel's corrosion resistance. And finally, production processes must consistently turn out defect-free ferrules that hold tight tolerances and maintain metallurgical specifications.

DESIGN EVOLUTION

This article focuses on single-ferrule compression fittings, but many of the principles also apply to two-ferrule compression fittings. Ferrules were originally machined from cold-drawn stainless-steel barstock. Cold drawing strain hardens the metal and imparts mechanical strength throughout the ferrule. But the ferrule's front edge was often still not hard enough to seal against tube surface defects such as scratches, weld seams, ovality, and hardness variations, whereas the core hardness was too high to deform properly.

One solution was to plate ferrules with a soft metal (such as silver) for a better seal when dealing with high-pressure gas. This improved resistance to impulse pressures, temperature swings, and vibration.

Many ultrahigh vacuum and high-pressure seals deform hard edges into soft metal gaskets. Deforming the soft component with a hard one provides intimate metal-to-metal contact over the contact surfaces and overcomes surface irregularities. (A good source of detailed information is *Industrial Sealing Technology,* H. Hugo Buchter, John Wiley and Sons, 1979.) Manufacturers applied this concept to tube fittings by case hardening ferrules, which substantially increases surface hardness and lets them shear through surface defects and compensate for tubing variations.

Conventional gas nitriding case hardens the inner surface to a depth of approximately 0.004 in. During assembly, the ferrule front edge shears into the tube. If disassembled, the ferrule remains tightly locked to the tubing, allowing remakes with consistent sealing integrity. The fitting handles internal pressures, impulse pressures, temperature changes, and vibrations until the tubing fractures or fails in fatigue.

However, gas nitriding (as well as carburization and carbonitriding) substantially lowers stainless steel's corrosion resistance. Process refinements let manufacturers harden only a band approximately 0.050 in. from the ferrule nose — sometimes termed a "limited nitrided" ferrule. This reduces the likelihood of corrosion, as the nitrided band is buried in the tubing surface. But it still poses a potential corrosion problem if, due to improper make up or surface defects, chemicals contact the band. Also, uninstalled fittings stored in corrosive environments, such as salt air, sometimes rust on the nitrided band.

CASE HARDENING

Conventional nitriding and carburizing require high temperatures for the hardening constituents, nitrogen and carbon, to penetrate the passive oxide layer that makes stainless steel corrosion resistant. The high temperatures permit chromium, an anticorrosion alloying element, to diffuse through the metal and form chemically stable nitrides and carbides. These compounds give the surface layer most of its hardness, but in this chemically combined form chromium no longer resists corrosion, and the nitrided or carburized layer corrodes in many environments, including seawater and even moist air.

In addition, nitriding and carburizing can "sensitize" austenitic stainless steel exposed to high temperatures for an extended time. Carbon, which has low solubility in stainless steel, precipitates as chromium carbides in the grain boundaries, depleting regions adjacent to the grain boundaries of the chromium necessary for corrosion resistance. This process is known as sensitization.

A new hardening process that was introduced by Parker Hannifin in the late 1980s does not reduce the corrosion resistance of stainless steel. More recently, some other fittings manufacturers have introduced ferrule-hardening processes with similar advantages.

These new processes do not require the high temperatures and long durations that permit chromium diffusion. This keeps chromium in solid solution as a corrosion-resistant alloying element. The hardened layer is continuous, free of defects and voids, as the process tends to fill surface inclusions and substantially reduce end-grain corrosion effects.

The new processes also do not affect the bulk metal. There is no sensitization or change in mechanical strength beneath the hardened layer. The ductile layer deforms with the ferrule during assembly without cracking or spalling.

In these processes, carbon supersaturates the hardened layer. Carbon atoms occupy interstitial sites in austenitic stainless steel's face-centered, cubic crystal lattice, strengthening the hardened layer. The hard crystal-lattice structure would like to expand to accommodate the carbon atoms, but is constrained by the unhardened substrate. As a consequence, high compressive stress further enhances hardness. Compressive stress has the added benefits of substantially increasing a ferrule's fatigue and stress-corrosion resistance.

In general terms, the process removes the passive oxide layer from the steel surface, letting carbon atoms diffuse directly into the metal lattice without traversing the passive layer barrier. The carbon atoms diffuse at lower temperatures than other alloying elements, thus avoiding problems caused by formation of carbides and nitrides.

MECHANICAL ACTION

A balance of metallurgical properties is critical to a ferrule's mechanical action during fitting assembly. For instance, the front edge of Parker Hannifin's CPI single-ferrule fitting shears down into the tubing, while the body arcs and clasps the tubing at the trailing edge. The front-edge grip prevents blow-out under pressure.

The ferrule must also work equally well across the tubing diameter tolerance range, typically ±0.005 in., and handle surface defects such as scratches that may be several thousandths of an inch deep. The arcing action turns the ferrule into a spring of sorts, letting it maintain tension against the tubing and the proper seat angle to seal despite vibration, mechanical shock, and thermal expansion. The back of the ferrule also loosely grips the tubing, damping vibrations that would otherwise transmit to the sealing interface.

Mechanical properties such as yield strength and hardness must be precisely controlled to effect this action. An extremely hard ferrule will be too stiff during assembly and will not bow and properly grip the tubing. But if it is too soft, the underlying material will not support the case-hardened surface. The result is an eggshell effect: the gripping front edge collapses during assembly and cannot hold the tubing under pressure. It also reduces the arcing spring effect.

Cold working is the only way to increase hardness and strength of Type 316 austenitic stainless steel after annealing. However, work-hardening rates change with the steel's composition, and constituent percentages can vary within an allowable range. Cold working can also reduce corrosion resistance. Thus, manufacturers must precisely control composition to maintain consistent mechanical properties and retain the austenitic structure, and case hardening must not uncontrollably change these.

LUBRICATION

Stainless-steel parts that rub together under high pressure have a strong tendency to cold weld and seize. And to form high-integrity, leak-free tubing connections, ferrules must only slide forward during assembly and not rotate with the nut. To prevent seizing and ensure only linear ferrule movement, engineers must precisely control surface conditions and lubrication at the nut/ferrule and nut/body interfaces.

All mating surfaces must be smooth and free of defects, which exacerbate seizing. A bonded molybdenum-disulfide coating is the recommended lubricant for many compression fittings.

Solid molybdenum disulfide readily adheres to surfaces, is noted for its lubrication and anti-seizing properties, and the solid does not squeeze out like liquid or soft, waxy lubricants under extreme pressure. The result is low assembly torque and consistent performance, even with repeated remakes.

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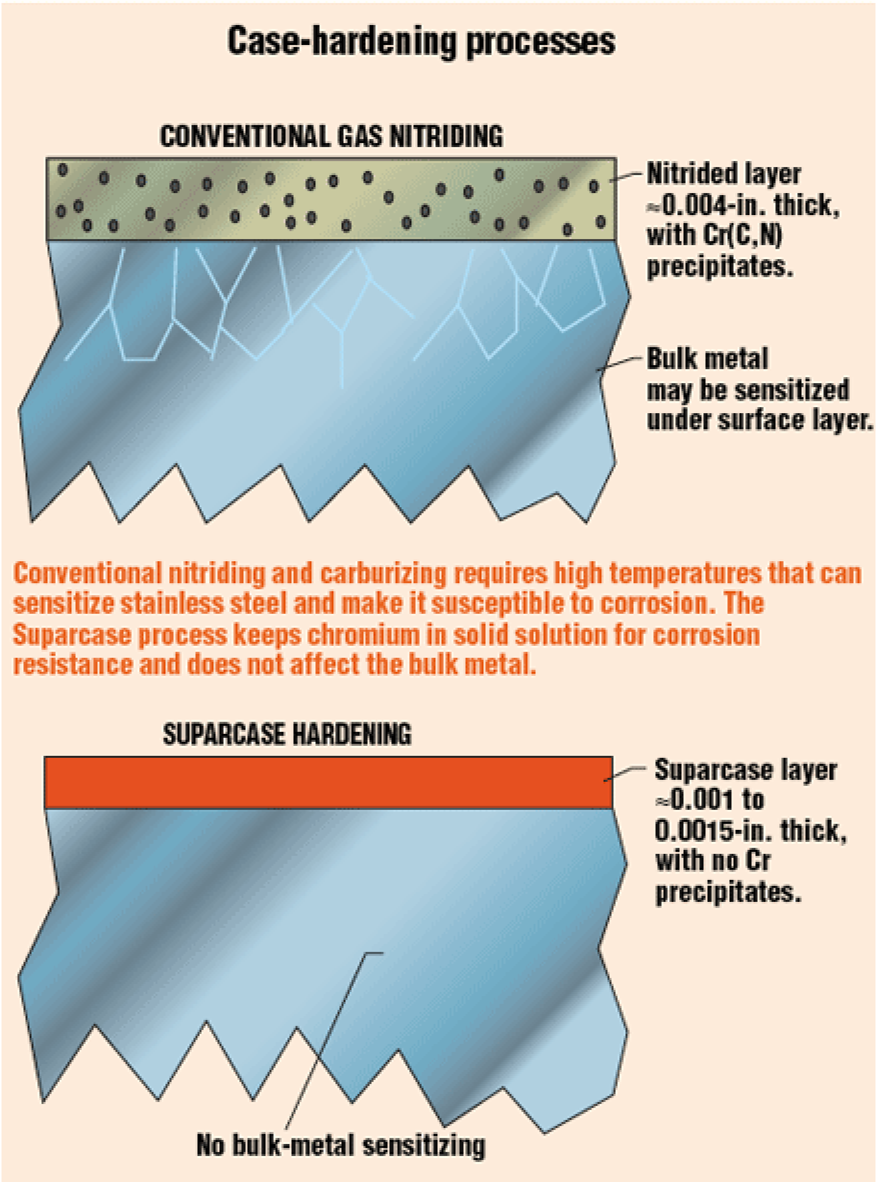
Case-hardening processes
CONVENTIONAL GAS NITRIDING
Nitrided layer ≈0.004-in. thick, with Cr(C,N) precipitates.
Bulk metal may be sensitized under surface layer.
Conventional nitriding and carburizing requires high temperatures that can sensitize stainless steel and make it susceptible to corrosion. The Suparcase process keeps chromium in solid solution for corrosion resistance and does not affect the bulk metal.
SUPARCASE HARDENING
Suparcase layer ≈0.001 to 0.0015-in. thick, with no Cr precipitates.
No bulk-metal sensitizing