Developments in Stainless Steel Instrumentation Tube Fittings
Ferrule Technology - White Paper
Introduction
This article discusses the evolution of ferrule design and hardening technology, using the example of the Parker Hannifin CPI™ single ferrule compression fitting (Fig 1), but the basic principles also apply to two ferrule compression fittings, such as Parker Hannifin’s A-LOK®, as well as the high pressure design.

Stainless steel compression tube fittings for instrumentation applications have continued to evolve to meet requirements for ease of installation and high sealing integrity in increasingly demanding conditions. A recent example is the introduction of a fitting rated for sealing with hard drawn or thick walled stainless steel tubing at twice the allowable working pressure compared to previous stainless steel fittings with the standard safety factor of four. This is the MPI™ fitting by Parker Hannifin. These compression-principle fittings eliminate the problems with the cone and thread assembly fittings previously used, for instance, for running down high pressure, deep water oil wells.

The ability of compression fittings to provide the high performance demanded of them, depends on innovations of the ferrule, the most critical part of instrumentation fittings. It is highly engineered and requires considerable expertise and care in design, metallurgy and production processes. The ferrule must deform elastically and plastically in a very controlled manner during assembly of the fitting to properly grip and seal the tubing. The front edge of the ferrule must be harder than the tubing to grip the tube and seal through any surface scratches or defects, but the entire ferrule cannot be too hard or it will be too strong to deform properly. Therefore the hardening process used to achieve this should be applied to selected regions of the ferrule and the rest of the ferrule should have different, tightly controlled mechanical properties.

In addition, the hardening process must maintain the excellent corrosion resistance of stainless steel. The production processes must be developed and maintained to consistently produce defect-free ferrules with very tight geometric tolerances and metallurgical specifications.

Fig 1. Parker CPI™ Single Ferrule

Evolution of Ferrule Design and Development
The original CPI™ ferrule was machined from cold drawn stainless steel barstock. Cold drawing strain hardens the barstock for higher hardness and mechanical strength. This design was very successful but had limitations on sealing integrity and tube holding ability in some applications. Strain hardening allowed the ferrule to grip the tubing but did not provide sufficient hardness to the ferrule front edge to seal some tube surface defects such as scratches, weld seams, ovality and hardness variations.

Ferrules were sometimes plated with a soft metal (i.e. silver) for a better seal on tube surface defects in high pressure gas applications. This design was somewhat resistant to impulse pressures, thermo-cycles and vibration but the next generation of ferrule design would improve upon this considerably.

Many of the sealing technologies designed for optimum sealing integrity under either ultrahigh vacuum or high pressure utilize the concept of a hard edge deforming into a soft metal gasket1. This is discussed in some detail in Chapters 1 and 2 of Buchter2. The deformation of the soft component (the gasket) by the
Stainless Steel Case Hardening Processes

Conventional nitriding and carburizing processes for stainless steel must be performed at a high temperature in order for the hardening constituents, nitrogen and carbon, to penetrate the passive surface oxide layer that gives stainless steel its corrosion resistance. This high temperature allows chromium, the corrosion resisting alloying element, to diffuse through the metal. Chromium forms chemically stable nitrides and carbides, and therefore exists primarily as these compounds in the hardened layer. These very hard nitrides and carbides contribute most of the hardness of the layer. In this chemically combined form, however, the chromium is no longer available to resist corrosion, and the nitried or carburized layer is very susceptible to corrosion attack in many environments, including seawater and even moist air. Best suit the application.

The main criteria of any enclosure designed to protect instrumentation from severe cold is its thermal conductivity – the higher the conductivity, the greater the heat loss to the external ambient. The bigger the difference between internal and external temperatures, the higher the running costs, mitigated only by the thermal insulation qualities of the enclosure. Parker has a vast experience of providing the fully fitted enclosure with the pre-installed components that is more reliable and easy to assemble in proper manufacturing plant conditions rather than on site in a cold environment. Optimal thermal insulation saves a lot of energy.
In addition, the stainless steel immediately under the layer often is sensitized due to carbon contributed by the process, and the entire bulk metal may be sensitized by the temperature and time required for the process. Sensitization is a phenomenon that can occur in austenitic stainless steel exposed to high temperatures. Carbon, which has a very low solubility in these types of stainless steel, precipitates as chromium carbides in the grain boundaries, depleting the regions adjacent to the grain boundaries of the chromium levels necessary to maintain corrosion resistance. Stainless in this condition is very susceptible, “sensitized”, to corrosion. A diagram illustrating these effects is shown in Figure 2.

![Diagram of conventional gas nitrided stainless steel](image)

**Fig 2. Cross section of conventional gas nitrided stainless steel.**

The revolutionary Parker Suparcase™ ferrule hardening process does not require temperatures and times sufficient for diffusion of the chromium. The chromium therefore remains in solid solution as an alloying element available for corrosion resistance. Also, the bulk metal is unaffected by the process; there is no sensitization and the mechanical strength properties are not changed. The Suparcase™ hardened layer is continuous, free of defects and voids. This is shown diagrammatically in Figure 3.

![Diagram of Suparcase™ hardened stainless steel](image)

**Fig 3. Cross section of Suparcase™ hardened stainless steel.**

The process tends to “fill in” inclusions intersecting the surface, substantially reducing end grain corrosion effects. The Suparcase™ layer is ductile, able to deform with the ferrule during fitting assembly without cracking or spalling.

A micrograph of a polished and etched cross section of the front edge of a Suparcased™ ferrule is shown in Figure 4.

The etching process has not affected the Suparcase™ layer, demonstrating its resistance to chemical attack, i.e. corrosion.

In order to demonstrate the improvement in corrosion resistance of the Parker Sferrule hardening process, tubular test piece were machined...
related alloys to pitting and crevice corrosion when exposed to oxidizing chloride environments. The results predict performance in certain real environments, such as natural seawater at ambient temperature and strongly oxidizing low pH chloride environments. The test results are shown in Table 1.

<table>
<thead>
<tr>
<th>Condition</th>
<th>ASTM B 117 Salt Fog Test Results (6 Samples)</th>
<th>ASTM G 48 Ferric Chloride Test Results (Average of 3 Samples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-machined (Cold Worked)</td>
<td>No corrosion</td>
<td>6.1 % weight loss</td>
</tr>
<tr>
<td>As-machined + Carbonitrided</td>
<td>Red rust</td>
<td>11.5 % weight loss</td>
</tr>
<tr>
<td>As-machined + Suparcase™</td>
<td>No corrosion</td>
<td>0.0 % weight loss*</td>
</tr>
<tr>
<td>Annealed + Carbonitrided</td>
<td>Red rust</td>
<td>9.0 % weight loss</td>
</tr>
<tr>
<td>Annealed + Suparcase™</td>
<td>No corrosion</td>
<td>No corrosion</td>
</tr>
</tbody>
</table>

Table 1: Test results.

* One of the three samples had a small corrosion site that appeared to be crevice attack at a material defect.

Examples of the results of the Salt Fog test are shown in Figure 5. The test pieces case hardened by the Suparcase™ process were unaffected by the salt fog exposure, whereas the test pieces case hardened by a conventional carbonitriding process exhibited significant red rust corrosion.

**Figure 5. ASTM B 117 Salt Fog test results on an as-machined and Suparcased test piece versus a test piece case hardened by a conventional carbonitriding process.**
corrosion initiating on surfaces that are perpendicular to the drawing direction of the barstock from which the product was made. This corrosion is typically initiated at the intersections of microstructural inhomogeneities such as inclusions with the perpendicular surface.

The test piece that was case hardened by a conventional carbonitriding process had both general corrosion attack over its whole surface and pitting corrosion. The pitting corrosion was most severe on the end grain surfaces, but also appeared on the other surfaces.

The test piece that was case hardened by the Parker Suparcase™ process was not corroded by the Ferric Chloride solution. Its surface was as bright as before the test. It is apparent from these results that the Parker Suparcase™ process actually improves the resistance of cold worked stainless steel to pitting corrosion in environments simulated by the Ferric Chloride test.

Recently additional lower temperature case hardening processes for stainless steel have been developed [5,6,7,8,9,10]. In the last few years other compression fitting manufacturers began to introduce their versions of stainless steel ferrules utilizing some of these developments.

Mechanical Action of the Ferrule

In addition to the hardening process, the mechanical properties of the ferrule must be designed and controlled precisely to achieve the proper functioning during assembly and use of the fitting. This requires that the composition of the Type 316 austenitic stainless steel used to manufacture these fittings be controlled within a much narrower range to ensure that consistent hardness and strength levels are attained.

Figure 7. ASTM G 48 Ferric Chloride test results on an as-machined test piece and test pieces case hardened by a conventional carbonitriding process and by the Parker Suparcase™ process.

References: