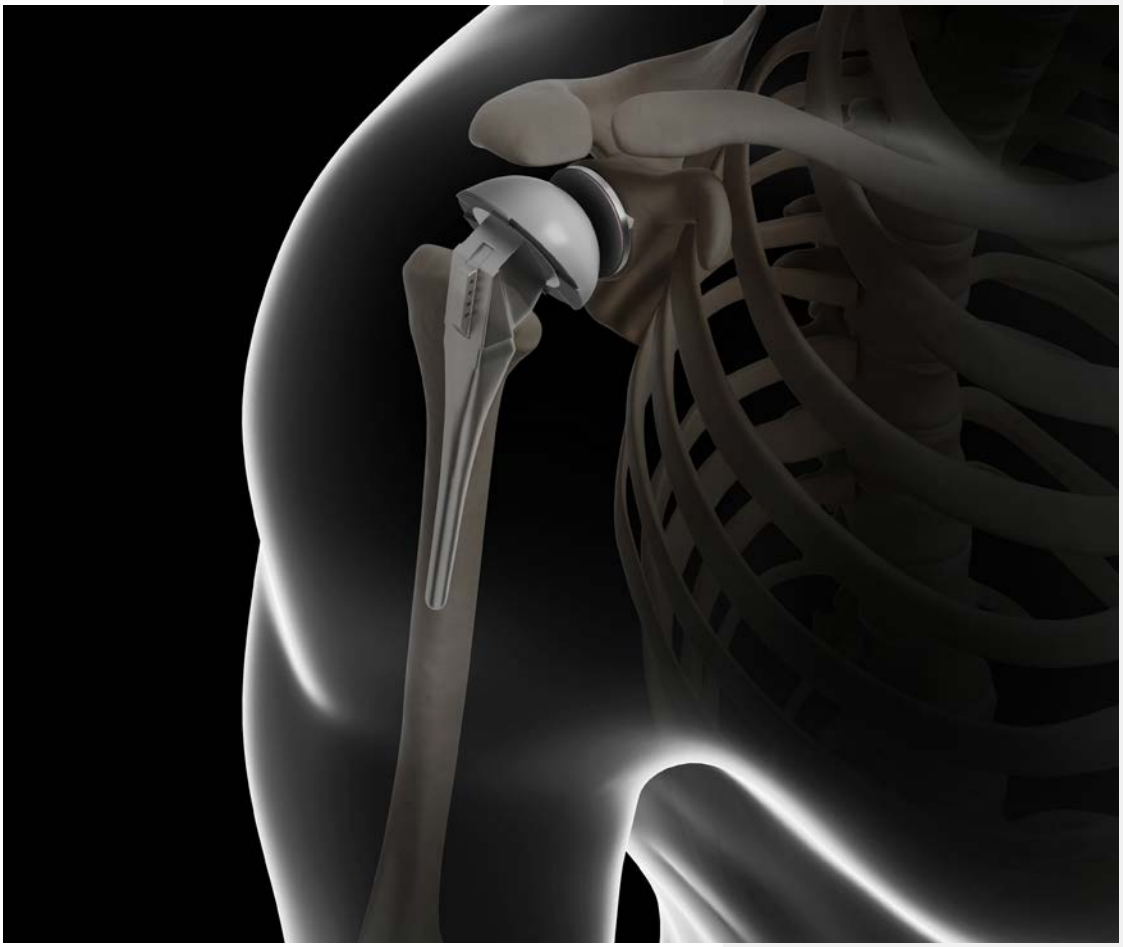
CARPENTER TECHNOLOGY

WHITE PAPER



CARPENTER TECHNOLOGY'S NITROGEN-STRENGTHENED STAINLESS STEELS

Higher modulus, low-cobalt, non-magnetic stainless designed to unlock next-gen compliant solutions

SUMMARY

Stainless steels have been used in medical implants and instrumentation since the early 20th century. As the industry advanced, alloys with greater strength, corrosion resistance and biocompatibility were needed—beyond what traditional stainless steels like Type 304 and Type 316 could provide. Nitrogen-strengthened stainless steels were born.

Adding nitrogen to stainless steel enhances its mechanical properties in several ways:

- **Higher yield strength:** Nitrogen increases the hardness and yield strength of stainless steels, making them more resistant to deformation or failing under stress.
- **Higher modulus:** Nitrogen increases the material's modulus, generating an alloy that is stiffer than its non-nitrogen-strengthened counterpart.
- **Improved corrosion resistance:** Nitrogen enhances resistance to pitting and crevice corrosion, particularly in chloride-containing environments.
- **Enhanced fatigue life:** The presence of nitrogen improves the fatigue strength of stainless steels, making them more suitable for cyclic loading applications.
- **Low magnetic permeability:** Nitrogen-strengthened stainless steels maintain low magnetic permeability, which is crucial for certain medical applications.
- **Stabilized austenitic microstructure:** Nitrogen helps stabilize austenitic microstructure, enhancing the overall mechanical properties and performance of the steel, as well as helping maintain consistency through the cross-section of the product.

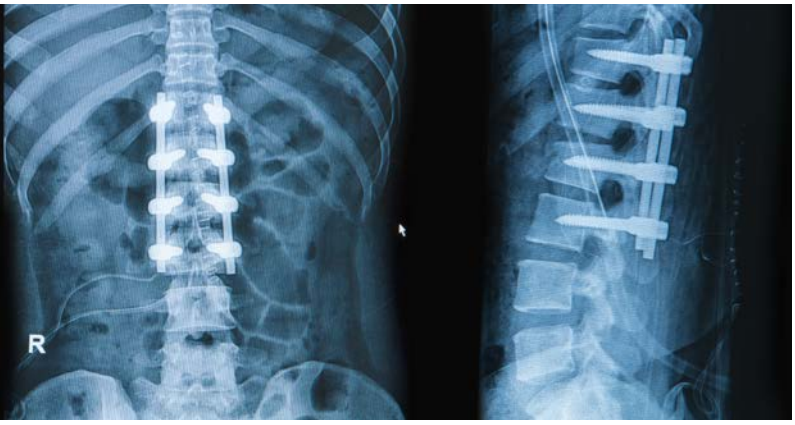
Nitrogen-strengthening has allowed stainless steels to become more effective and reliable in orthopedic implants, prosthetics, surgical instruments, and beyond.

Carpenter Technology has innovated advanced materials solutions since 1889. Our industry-leading nitrogen-strengthened stainless steels are engineered to perform—and last—to meet the demanding requirements of medical implants and their supporting medical instruments.

Global market adoptions

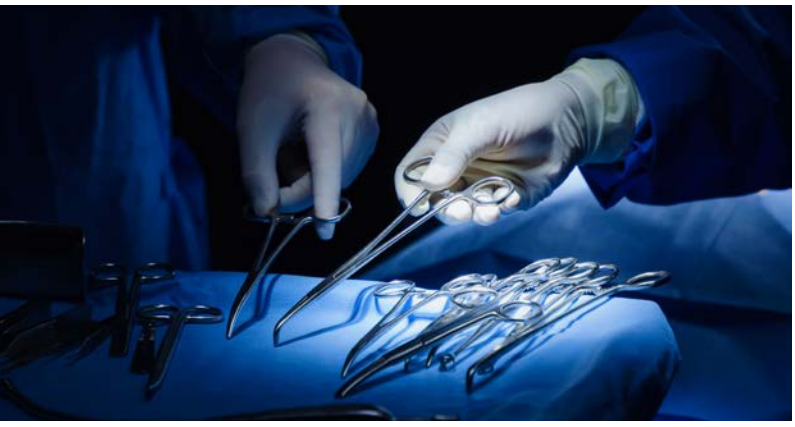
Carpenter Technology's nitrogen-strengthened stainless steels are being used today across numerous end-markets, including advanced **Industrial** components and next-generation **Energy** exploration. These advanced alloys are gaining particular attention in **Medical** implants and instrumentation due to their superior performance characteristics.

The alloys offer excellent corrosion resistance and high strength, making them ideal for components exposed to harsh environments and high pressures. The improved wear resistance and fatigue life ensure long-term reliability and reduced risk.



Medical implants

The biocompatibility and high strength of these alloys make them suitable candidates for medical implants, where mechanical performance and corrosion resistance are critical. Nitrogen-strengthened stainless steels offer improved wear resistance and fatigue life, ensuring the longevity and reliability of medical devices. Furthermore, with the improved strength and higher modulus of elasticity as compared to traditional stainless steels, they could be considered candidates for cobalt-containing material replacements.



Medical instrumentation

Nitrogen-strengthened stainless steels are used in medical instruments due to their high strength and excellent corrosion resistance, but they also provide low magnetic permeability. These properties are essential for maintaining the safety and reliability of medical equipment and ensuring the best patient outcomes in various medical settings.

Alloy portfolio

Carpenter Technology's nitrogen-strengthened stainless steel portfolio is broad, and we continue to innovate in this space. Below is a sampling of some of the nitrogen-strengthened austenitic stainless steels available, some of which are **new** to Medical markets.

BioDur® 108 is known for its high strength and excellent corrosion resistance, particularly in chloride environments. This alloy is used in medical implants and instruments due to its biocompatibility and stellar combination of mechanical properties. BioDur 108 offers this performance while being essentially free of cobalt and nickel, which addresses concerns with **metal sensitivities** and regulatory **EU MDR restrictions.**

BioDur® 734 offers superior fatigue strength and is most often used in medical implants and instruments. The high nitrogen content provides enhanced mechanical properties and corrosion resistance. Similar to BioDur 108, this alloy also offers a cobalt-free chemistry to address **metal sensitivities** and regulatory **EU MDR restrictions.**

Gall-Tough® Plus (also known as N60) is a silicon-doped, nitrogen-strengthened stainless providing good mechanical properties and improved galling resistance. This alloy offers superior strength, wear, and galling resistance over traditional 300-series stainless steels, making it an alternative to consider against high-wear, high-modulus incumbent materials.

22Cr-13Ni-5Mn (also known as N50) offers twice the yield strength of Type 316 and superior corrosion resistance. It is used in various medical and industrial applications due to its excellent combination of mechanical properties and corrosion resistance.

21Cr-6Ni-9Mn (also known as N40) is known for its high strength and good corrosion resistance. This alloy is used in industrial applications where high performance and reliability are required, while also improving temperature resistance with a higher manganese content.

15-15HS Max is a high-strength, non-magnetic, nitrogen-strengthened austenitic stainless steel offering great resistance to general corrosion, intergranular attack, stress-corrosion cracking, and pitting. This alloy is used most often in oil and gas applications where high strength (min 140 yield strength), non-magnetic attributes, and corrosion resistance are a must.

SCF 19® Max offers a combination of high strength and fantastic corrosion resistance, with a pitting resistance equivalent number (PREN) of 40. The stability of its non-magnetic microstructure, combined with its mechanical properties make it an ideal material for harsh environments exposure. Although it has not yet been explored for Medical markets, it may be a viable candidate for evaluation where strength, corrosion resistance, and non-magnetic properties are needed.

SCF 260® is similar in chemistry to SCF 19 Max, with excellent mechanical properties and corrosion resistance for extreme environmental exposure. This material exhibits an excellent combination of strength, fatigue, and corrosion resistance in chloride-containing environments. With a pitting resistance equivalent of >35, SCF 260 would be a great candidate for many applications where these lucrative property combinations are needed.

Type analysis

The table below compares the chemical compositions of nitrogen-strengthened stainless steels.

TABLE 1

CHEMICAL COMPARISON OF NITROGEN-STRENGTHENED STAINLESS STEEL ALLOYS								
ALLOY	**C**	**Mn**	**Si**	**Cr**	**Ni**	**Mo**	**N**	**OTHER ELEMENTS**
BioDur 108	0.08 max	21 – 24	0.75 max	19 – 23	0.1 max	0.50 – 1.50	0.85 – 1.15	<0.1 % Co
BioDur 734	0.08 max	2.0 – 4.25	0.75 max	19.5 – 22	9.0 – 11.0	2.0 – 3.0	0.25 – 0.50	<0.1 % Co, 0.25 – 0.80 Nb
Gall-Tough Plus	0.15 max	4.0 – 8.0	2.5 – 4.5	16.5 – 21	6.0 – 10.0	0.5 – 2.5	0.05 – 0.25	
22Cr-13Ni-5Mn	0.06 max	4.0 – 6.0	1.0 max	20.5 – 23.5	11.5 – 13.5	1.5 – 3.0	0.20 – 040	<0.1 % Co by request, 0.10 – 0.30 V, 0.10 – 0.30 Nb
21Cr-6Ni-9Mn	0.03 max	8.0 – 10.0	1.0 max	19 – 21.5	5.5 – 7.5	0.75 max	0.15 – 0.40	
SCF 19 Max	0.04 max	4.0 – 7.0	0.60 max	18 – 23	16 – 20	4.0 – 6.0	0.35	
SCF 260	0.04 max	16.0 – 19.0	1.0 max	18 – 21	3.5 max	1.5 – 3.0	0.50 – 0.80	
15-15HS Max	0.04 max	18.00	0.50	19.00	3.5 max	3.0 max	0.70 max	

Single figures are nominal except where noted. Values are % weight.

Strength capabilities

Each of the alloys listed in this white paper is a nitrogen-strengthened austenitic stainless steel. Austenitic stainless is a group of stainless that obtains high levels of corrosion resistance, but also means that they obtain higher levels of strength through strain hardening only. They are not hardenable by heat treatment. The nitrogen-strengthening provides performance enhancements as discussed earlier but does not change the fact that the alloy family is only strengthened by strain hardening. Carpenter Technology is well-equipped to provide higher strength variants of these alloys through strain hardening options.

Table 2 shows the yield strength of nitrogen-strengthened stainless steel alloys, adding BioDur® 316LS (also known as 316LVM) as a non-nitrogen-strengthened comparison. Alloys are listed in order of ascending typical yield strength (ksi).

TABLE 2

YIELD STRENGTH COMPARISON IN NITROGEN-STRENGTHENED STAINLESS STEEL ALLOYS

ALLOY	Annealed	10% Strain Harden	30% Strain Harden	"Max" Strain Harden
BioDur 316LS*	36	65	115	137
Gall-Tough Plus	55	90	105	180
BioDur 734	65	90	125	200+
21Cr-6Ni-9Mn	52	100	152	NT
22Cr-13Ni-5Mn	65	130	170	230
BioDur 108	88	140	205	270
SCF 19 Max	145 (Warm Worked)	NT	NT	NT
SCF 260	140 (Warm Worked)	NT	NT	NT
15-15HS Max	70 Annealed 160+ (Warm Worked)	NT	NT	NT

** BioDur 316LS is also known as 316LVM.*
NT = Not yet tested.

CONCLUSION

Carpenter Technology's nitrogen-strengthened stainless steels offer significant advantages over traditional stainless steels.

Their superior strength, corrosion resistance, and fatigue life make them ideal candidates for a wide range of applications across various industries. The adoption of these advanced alloys continues to grow as industries seek materials that can meet their demanding performance requirements.

Competing with complex alloy systems

These advanced nitrogen-strengthened stainless steels are beginning to compete with more complex alloy systems, where **metal allergies** are of concern. The superior mechanical properties, corrosion resistance, and **biocompatibility** of nitrogen-strengthened stainless steels make them viable candidates for applications where next-generation designs preclude the use of previous-generation materials. This can be next-generation performance expectations, increased **magnetic sensitivities**, or, in some cases, **regulatory restrictions**. It is important that next-generation materials support the design needs for next-generation components, while also addressing some of the health, environmental, regulatory, and risk-to-patient concerns.

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Sources:

Carpenter Technology Alloy Finder
Carpenter Technology, "Selecting Stainless Steels for Valves"
Carpenter Technology, SCF 19 Max white paper

For additional information, please contact your nearest sales office:
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