



A-21[®]

The world's first and only truly
stainless carburizing steel

SUMMARY

We have been taught that it is not possible to have everything we want in one material—that compromise is necessary. We can't have high strength *and* high toughness, for example, or good wear resistance *and* excellent corrosion resistance. Don't believe it.

A-21 changes all that.

For the first time ever, A-21 makes it possible to have high strength, high toughness, great wear resistance *and* stainless properties—all in one remarkable new steel.

A strong, tough, wear-resistant, stainless steel has always been the goal for many high-performance applications, such as firearm bolts and bolt carriers, gun barrels, gears, and bearings. Even kitchen cutlery and everyday carry knives could benefit from a steel that exhibits high hardness, excellent edge retention, and remains stainless even in harsh environments such as warm salt fog. The problem with conventional stainless gun barrel alloys, including 410, 416, and 416R, is that they have limited corrosion resistance and low impact toughness, especially at cold temperatures. And high-carbon stainless steels used for cutlery, such as 440C, BG-42, and CPM S90V¹, have poor corrosion resistance in salt spray environments, and very low impact toughness after heat treatment. Enter carburized A-21.

A-21 is different from all other stainless steels because it develops a deep, hard, stainless case, while maintaining a strong, tough, and ductile core.

The thickness of the hard case can be varied to achieve the desired balance with the non-hardened core. A-21 can also be carburized to form a through-hard structure for thin gauge strip and sheet products, like knife blanks, in which the high case hardness continues throughout the thickness of the knife. Most remarkable, however, is that it is possible to custom-design an A-21 stainless knife that is impervious to warm, salt fog, has a very hard cutting edge, excellent edge retention, and high strength, toughness, and ductility elsewhere in the same knife blade.

A-21 can also be nitrided, where it develops a thin (~0.002 in.), galling- and corrosion-resistant case with very high surface hardness (i.e., 70 HRC), while maintaining a strong and extremely tough core (> 100 ft-lb impact energy).

Finally, A-21 can be quenched and tempered, where it exhibits an unsurpassed combination of high strength, high toughness, excellent heat check (thermal fatigue) resistance, and is an economical alternative to many precipitation hardening (PH) stainless steels.

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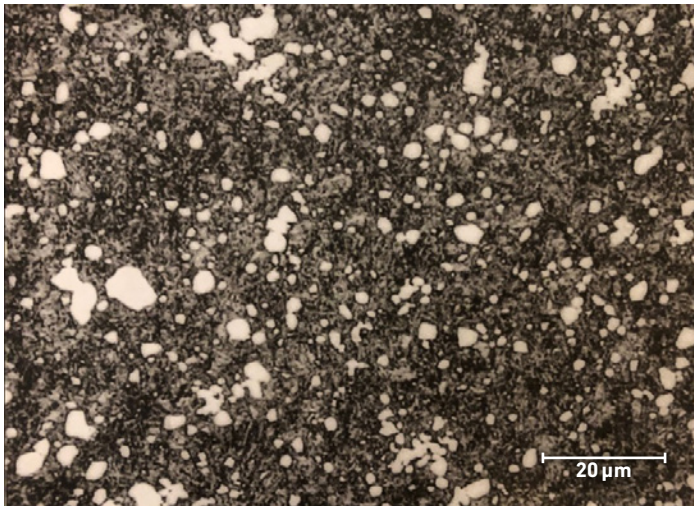
¹CPM is a registered trademark of Crucible Industries

CHALLENGES AND OPPORTUNITIES

The problem with conventional stainless steels

Conventional through-hardened, high-carbon (>1% carbon) stainless steels used for cutlery, including 440C, BG-42, and CPM S90V, can be heat treated to a peak hardness of 58–62 HRC. Hardness in these steels typically scales with volume fraction of hard alloy carbides, the majority of which are chromium-rich M7C3 and M23C6; these carbides form during hot working and subsequent heat treatment. Precipitation of chromium-rich carbides depletes the surrounding matrix of chromium and reduces the localized corrosion resistance in the vicinity of the carbides. If the local chromium content falls below about 10.5%, the microstructure is no longer stainless and rusting will occur more easily. Moreover, the large volume fraction of chromium-rich carbides in this class of steel results in relatively low impact toughness. A typical microstructure of a conventional through-hard stainless steel, BG-42, is shown in Figure 1, where a very large volume fraction of chromium-rich carbides (white particles) is present.

FIGURE 1—TYPICAL MICROSTRUCTURE OF BG-42.

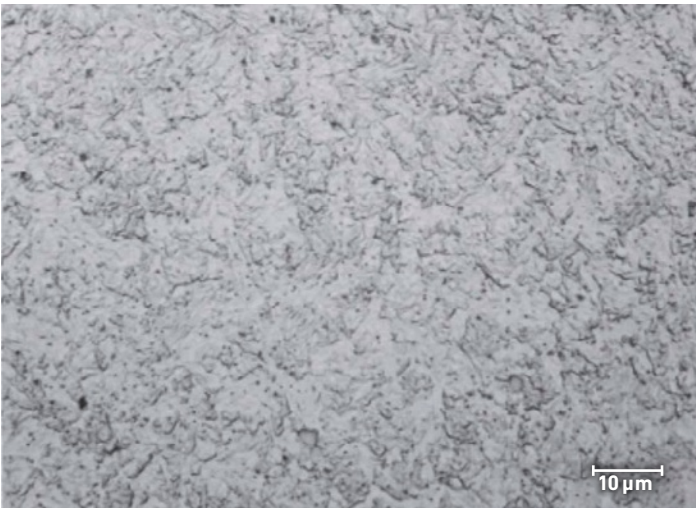


Conventional stainless steels used for gun barrel applications, including AISI 410 and its free-machining sister alloy AISI 416, offer minimal corrosion resistance, but relatively poor Charpy V-notch impact toughness, especially at cold temperatures. These alloys may not need to be chrome-plated if used as gun barrels, but neither steel can meet the low temperature impact toughness requirement of MIL-B-11595E.

A different alloy design approach

A-21 (UNS S41429) is a new, unique carburizing, nitriding, and quenched and tempered martensitic stainless steel that uses titanium instead of chromium to precipitate with carbon to form TiC particles, not chromium-rich precipitates. By doing so, titanium protects the chromium and maximizes corrosion resistance. Titanium carbides are small and closely spaced precipitates that are uniformly distributed and thermodynamically stable. Their presence limits grain growth, and results in a fine grain microstructure, good elevated temperature strength, and excellent thermal fatigue (heat checking) resistance. Figure 2 shows the microstructure of A-21 after rolling to 0.406 in. RD bar. The grain size is ASTM #15 and the microstructure is fully martensitic. Retained austenite and delta ferrite are not present. A-21 is offered as air melt, vacuum arc remelted (VAR), and vacuum induction melted- vacuum arc remelted (VIM-VAR) in bar, billet, rod, wire, strip, sheet, plate, and tubing.

FIGURE 2— TYPICAL MICROSTRUCTURE OF A-21 (0.406 IN. RD BAR). GRAIN SIZE IS ASTM #15.



The chemistry of A-21, given in Table 1, is lean and unique. High chromium and nickel content results in significantly greater hardenability versus common carburizing alloy steels such as 9310 (UNS G93106). Good hardenability of A-21 permits large through-thickness components to be gas or oil quenched after carburization. A-21 does not contain expensive alloying elements, such as cobalt and tungsten.

TABLE 1

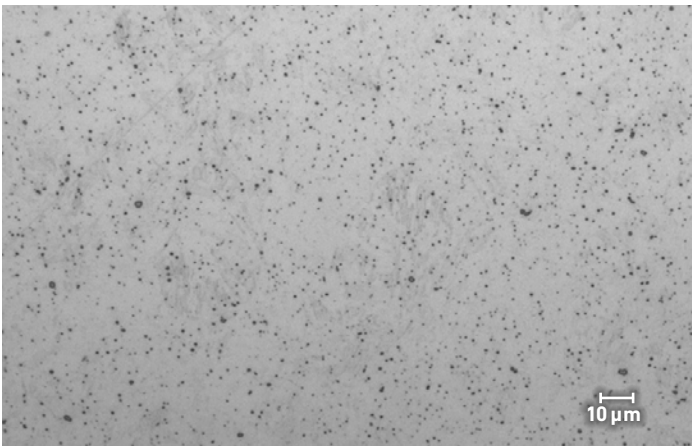
| NOMINAL CHEMISTRY OF A-21 AND CONVENTIONAL STAINLESS STEELS | | | | | | | | | |
|---|--------|-------|--------|-----------|-----|---------|-----------|--------|-----|
| ALLOY | C | SI | MN | CR | NI | MO | TI | V | W |
| A-21® | < 0.11 | < 1.0 | < 0.75 | 10.5–14.0 | 2–3 | 0.4–0.8 | 0.15–0.75 | < 0.25 | — |
| BG-42 | 1.15 | 0.3 | 0.50 | 14.5 | — | 4.0 | — | 1.2 | — |
| 440C | 1.00 | 0.7 | 0.50 | 17.0 | — | 0.5 | — | — | — |
| CPM S90V | 2.30 | 0.5 | 0.50 | 14.0 | — | 1.0 | — | 9.0 | 0.4 |

CARBURIZED MICROSTRUCTURE AND PROPERTIES

Uniform microstructure

A-21 may be carburized using either low pressure (vacuum) or gas (atmosphere) carburization techniques. A typical A-21 carburized case is shown in Figure 3, where the microstructure has been lightly etched to reveal the uniform dispersion of fine TiC precipitates. Note the absence of large, blocky chromium carbides. In the carburized condition, A-21 has only minimal retained austenite, which contributes to its dimensional stability in service.

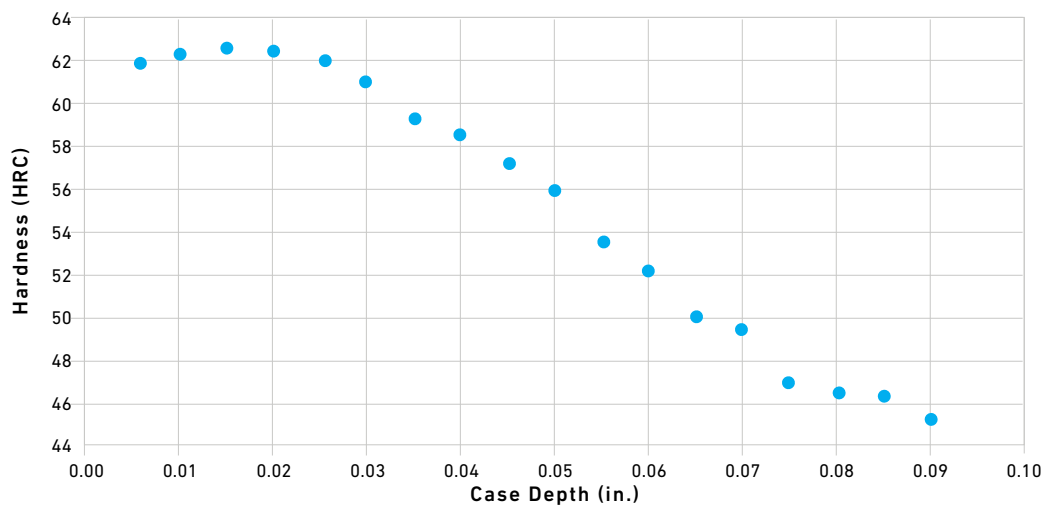
FIGURE 3—TYPICAL A-21 CARBURIZED CASE MICROSTRUCTURE. MICROGRAPH CASE DEPTH 0.005 IN.



Hardness

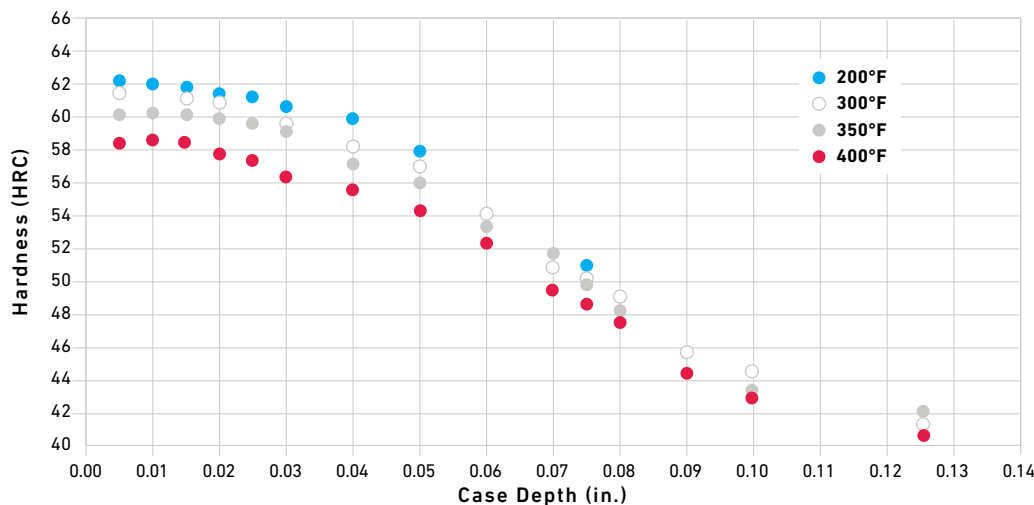
A typical hardness profile of A-21 after low pressure carburizing is shown in Figure 4. The effective case depth (the depth at which the hardness decreases to below 50 HRC) is about 0.065 in. (1.65 mm) with peak hardness of 62.6 HRC in the untempered condition.

FIGURE 4—TYPICAL A-21 CARBURIZED CASE HARDNESS PROFILE, UNTEMPERED.



The effect of tempering temperature on carburized case hardness is shown in Figure 5. Highest case hardness (62.3 HRC) is obtained when the tempering temperature is the lowest, 200°F, while the lowest case hardness (58.7 HRC) results when A-21 is tempered at the highest temperature, 400°F.

FIGURE 5. EFFECT OF TEMPERING TEMPERATURE ON CASE HARDNESS PROFILE IN CARBURIZED A-21.



Corrosion resistance

The most unique quality of A-21 is that it can be carburized and heat treated and still retain its excellent corrosion resistance, even after extended exposure to a very corrosive environment: hot, moist salt fog per ASTM B117. The ASTM B117 corrosion test involves exposing test samples to a constant 95°F temperature and 100% relative humidity comprised of 5% NaCl fog for a given period. Figure 6 shows the results of such a test when conventional stainless steels 440C, BG-42, and CPM S90V, as well as carburized A-21, are exposed to the ASTM B117 salt fog corrosion test for 200 hours. All four materials were exposed to the same environment at the same time, for the same time period. All samples also received the same surface preparation of polishing test surfaces using 600 grit sandpaper.

FIGURE 6.

ASTM B117 SALT FOG CORROSION TEST RESULTS AFTER 200 HOURS



The stunning results indicate that all three conventional stainless steels containing greater amounts of chromium than A-21—440C, BG-42, and CPM S90V—rusted badly, while the carburized A-21 sample remained pristine and rust-free even after 200 hours of exposure.

A-21 is the world's first and only truly stainless carburizing steel. No other metal can offer surface hardness of 62 HRC while remaining stainless and tough like A-21.

TABLE 2—CARBURIZED CASE AND CORE PROPERTIES

| CARBURIZED CASE PROPERTIES | |
|----------------------------|---|
| Process | Vacuum or gas carburize + cryo + temper |
| Peak hardness | ~62 HRC |
| Effective case depth | ~0.065 in. (1.6 mm) |
| Corrosion resistance | Stainless after 200 hours to ASTM B117 |
| Rotating bending fatigue | > 140 ksi (965 MPa) 30M cycles runout |

| CORE PROPERTIES | |
|---------------------------|--|
| Tempering temperature | 200–400°F (93–204°C) |
| Yield strength | 140–150 ksi (965–1034 MPa) |
| Ultimate tensile strength | 175–185 ksi (1207–1276 MPa) |
| Elongation | 10–20% |
| Reduction of area | 30–40% |
| Hardness | 39–40 HRC |
| Hardness (annealed) | 302 HB, max. |
| CVN impact toughness | 34–50 ft-lb (46–68 J) |
| Grain size | ASTM #6–7 |
| Fracture toughness | 82–100 ksi √in (90–110 MPa √m) |
| Rotating bending fatigue | 85 ksi (586 MPa) 30M cycles runout |
| Axial fatigue | 140 ksi (965 MPa) 10M cycles runout, R=0.1 |
| | 86 ksi (593 MPa) 10M cycles runout, R=-1.0 |



CARBURIZED APPLICATIONS

Revolutionary alloy capabilities

The ubiquitous and standard gun barrel material is 4150V with hexavalent chrome plating on the bore for hardness and corrosion resistance. 4150V is used because it offers good strength and toughness (> 40 ft-lb) at -40°F and can be easily chrome plated. The chrome coating is only about 0.0005–0.001 in. thick and eventually spalls. The spalling process is accelerated by the thermal fatigue seen by the barrel during repeated firings. When even a small area of chromium coating spalls, the resulting defect allows hot combustion gases in the barrel to attack and corrode the unprotected alloy steel base metal. This is the failure mechanism that limits barrel life.

The goal of many gun manufacturers (and users) is to increase barrel life. Concurrently, many would also like to eliminate the toxic hexavalent chrome plating of the bore entirely. Until now, however, no material could offer all three critical properties: high surface hardness, stainless, and toughness.

Carburized A-21 is a potential game-changing solution that could revolutionize the gun barrel industry. Carburized A-21 has the potential to eliminate hard chrome coating on the bore of gun barrels, while still offering stainless properties and good core toughness to increase barrel life.

Everyday carry knives and kitchen cutlery could also benefit from the unique properties offered by carburized A-21. Until now, the vast majority of knives were hard throughout, without the possibility or opportunity to vary the properties (hardness, toughness, etc.) within the same blade.

A-21 can be selectively hardened during the carburization process, resulting in a knife that is hard only where it's needed – along the cutting edge – while maintaining excellent toughness elsewhere.

See Figure 7 in which only the cutting edge and part of the spine of the A-21 knife has been hardened

FIGURE 7 — A-21 KNIFE BLADE WITH CUSTOM HARDENING.

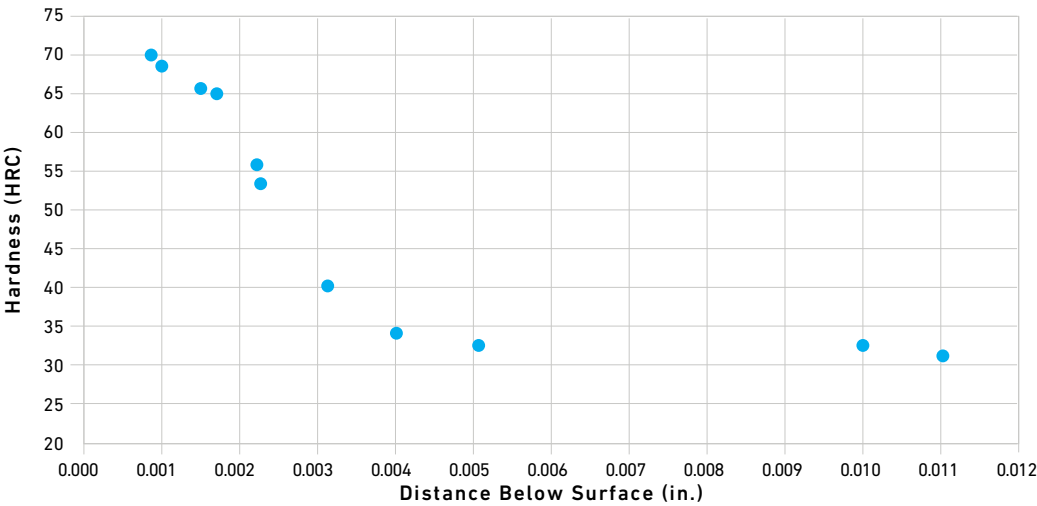


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ESEE Knives

NITRIDED MICROSTRUCTURE AND PROPERTIES

A-21 can be nitrided to form a very hard, galling- and corrosion-resistant surface, while maintaining a strong, very tough and very ductile core. A-21 has been gas nitrided as well as salt bath nitrided with success. Defense applications that could benefit from nitrided A-21 include bolts, bolt carriers, firing pins and gun barrels. A typical hardness profile after salt bath nitriding is given in Figure 8. Peak surface hardness is 70 HRC with a case depth of about 0.002 in. (0.051 mm).

FIGURE 8 — TYPICAL A-21 HARDNESS PROFILE AFTER SALT BATH NITRIDING.



Core hardness is 32– 33 HRC after tempering and nitriding at 1075°F (580°C). The microstructure of the nitrided case is shown in Figure 9. Note the absence of the traditional “white” layer, commonly seen after nitriding.

FIGURE 9 — A-21 SALT BATH NITRIDED SURFACE LAYER.

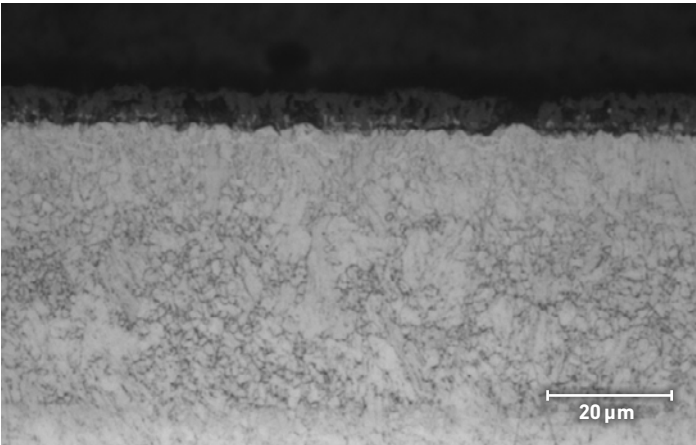


TABLE 3 —NITRIDED CASE AND CORE PROPERTIES

| NITRIDED CASE PROPERTIES | |
|---------------------------|-----------------------------------|
| Process | Salt bath or gas nitride + temper |
| Peak hardness | ~70 HRC |
| Case depth | ~0.002 in. (0.05 mm) |
| NITRIDED CORE PROPERTIES | |
| Tempering temperature | 1075°F (580°C) |
| Yield strength | 126–136 ksi (869–938 MPa) |
| Ultimate tensile strength | 132–143 ksi (910–986 MPa) |
| Elongation | 19–22% |
| Reduction of area | 70–75% |
| Hardness | 28–33 HRC |
| CVN impact toughness | 96–166 ft-lb (130–225 J) |
| Grain size | ASTM #10 |

QUENCHED AND TEMPERED MICROSTRUCTURE AND PROPERTIES

A-21 can also be used in the quenched and tempered (Q+T) condition, where it offers an excellent combination of strength and toughness, as well as good heat check (thermal fatigue) resistance. For many applications, Q+T A-21 is an economical alternative to more expensive precipitation hardening stainless steels. Non-surface-hardened applications for the defense industry include bare or chrome-plated gun barrels, such as the one pictured in Figure 10.

FIGURE 10 — A-21 BAR GUN BARREL SPLIT TO SHOW CHAMBER AND BORE RIFLING.

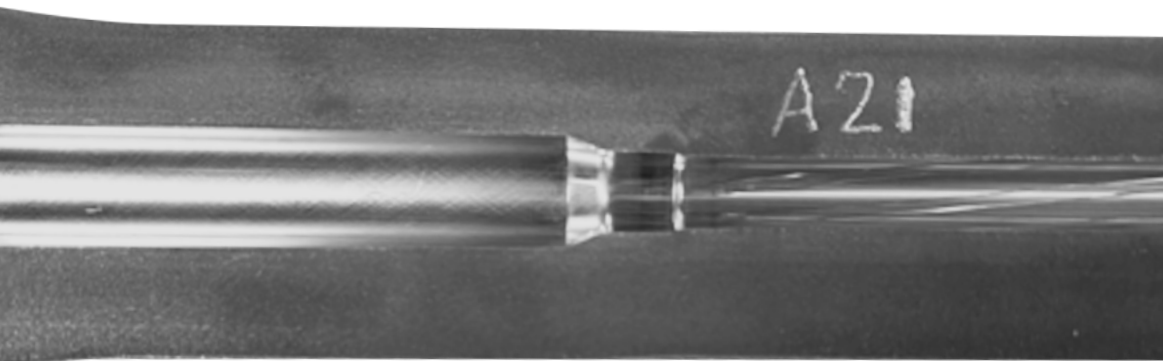


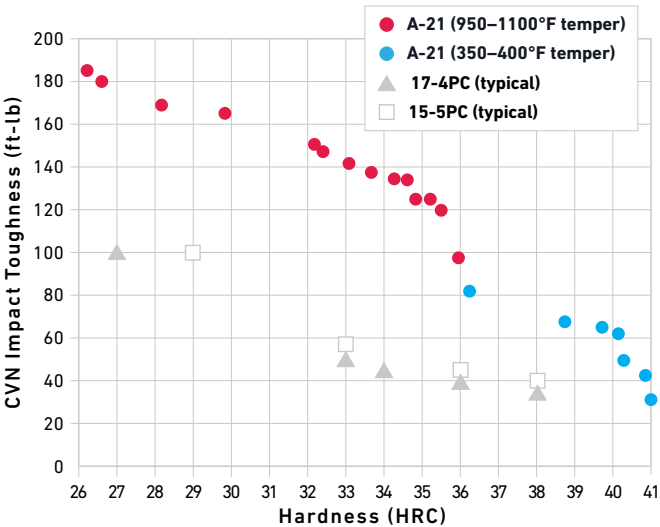
Photo credit: Gwynedd Manufacturing, Inc.

TABLE 4 — QUENCHED AND TEMPERED TYPICAL MECHANICAL PROPERTIES FOR GUN BARREL APPLICATIONS

| QUENCHED AND TEMPERED TYPICAL MECHANICAL PROPERTIES FOR GUN BARREL APPLICATIONS | | | |
|---|------------|------------|------------|
| Bar size, in. (mm) | 1.500 (38) | 1.125 (29) | 1.625 (41) |
| Yield strength, ksi (MPa) | 135 (931) | 147 (1014) | 138 (952) |
| Ultimate tensile strength, ksi (MPa) | 142 (979) | 162 (1117) | 151 (1041) |
| Elongation, % | 23 | 21 | 21 |
| Reduction of area, % | 72 | 72 | 67 |
| CVN impact toughness, ft-lb (J), RT | 145 (197) | 120 (163) | 97 (132) |
| Hardness, HRC | 32.0 | 35.5 | 35.9 |
| Grain size, ASTM # | 9.5 | 9.5 | 9.0 |

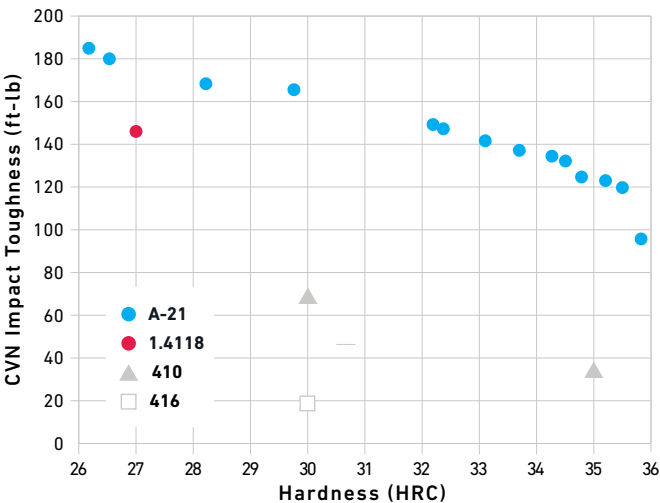
Charpy impact toughness versus hardness data for A-21 after various heat treatments are shown in Figure 11 and compared to conventional precipitation hardening stainless steels, 17-4PH and 15-5PH. Typical properties for the PH grades are shown. The mechanical properties of A-21 shown in Figure 11 are after tempering within a high temperature range (950–1100°F) and low range (350–400°F). At all hardness values between 26.0 and 40.6 HRC, A-21 offers significantly greater impact toughness than 17-4PH and 15-5PH.

FIGURE 11 — IMPACT TOUGHNESS VS. HARDNESS OF Q+T A-21 COMPARED TO CONVENTIONAL PH STAINLESS STEELS.



In Figure 12, the properties of A-21 quenched and tempered at a high temperature are compared to the toughness and hardness of common martensitic stainless steels used for gun barrels: 416, 410, and 1.4118. At all hardnesses between 26 and 36 HRC, A-21 exhibits significantly greater toughness than the conventional stainless barrel steels.

FIGURE 12 — IMPACT TOUGHNESS VS. HARDNESS OF Q+T A-21 COMPARED TO CONVENTIONAL MARTENSITIC STAINLESS STEELS USED FOR GUN BARRELS.



CONCLUSION

A-21 (UNS S41429) is an advanced martensitic stainless steel that is used in the carburized, nitrided, and quenched and tempered condition. As carburized, it develops a deep, hard stainless case, and a strong, tough, ductile core. Typical applications include everyday carry knives, kitchen cutlery, firearm bolts, and bolt carriers. Conventional hard-chromed gun barrels may be able to be replaced with carburized A-21 barrels.

A carburized A-21 gun barrel has the potential to revolutionize the gun barrel industry, as does a carburized knife, in which the properties within the knife can be customized to the user's preference.

In the nitrided condition, A-21 exhibits a very hard and corrosion-resistant case with a strong, very tough and ductile core. Nitrided applications include firing pins and gun barrels.

Quenched and tempered A-21 offers an excellent combination of high strength and toughness (even at low temperatures), as well as outstanding heat check resistance.

A-21 is ideally suited to replace martensitic stainless steels including 416, 416R, 410, and 1.4118, as the state-of-the-art stainless chromed and bare gun barrel material.

In the Q+T condition, A-21 is also an economical alternative to conventional precipitation hardening stainless steels, where A-21 offers higher toughness at a given hardness than conventional martensitic stainless PH grades such as 17-4PH and 15-5PH.

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