WHITE PAPER

INTRODUCING GNB200 RIFLE BARREL ALLOY

Maximizing strength, toughness, and wear in a hammer forgeable alloy

SUMMARY

A new generation of weapons is being developed in response to a demand for better barrel life and performance, and these cutting-edge designs cannot be engineered from 50-year materials like the typical chromium-molybdenum steels used in the iconic M16/M4 family. AISI 4140 and 4150 alloys have served assault rifle barrel applications well for decades but simply are not strong and tough enough to optimize barrel performance.

Higher strength and toughness are not particularly challenging attributes, and could be solved with Carpenter Technology's Aermet 100, 340, 360 or Ferrium C61, C64. For a high-performance rifle barrel with high strength, high toughness, and temper resistance, plus a targeted hardness range conducive to room temperature formability for hammer forging and rifling, a more holistic approach to alloy selection and alloy innovation was required.

Using Integrated Computational Materials Engineering (ICME) and precision melt control, Carpenter Technology developed GNB200, a premium remelted alloy steel specially formulated for high temperature wear resistance requiring high mechanical strength combined with very high toughness. The clean microstructure produced by ARC/AOD melting followed by vacuum ARC refining allows for the development of very tough properties.

The new GNB200 rifle barrel alloy meets the increasingly rigorous demands of the weapons industry, delivering holistically enhanced performance within proven mass production processes.

MATERIAL REQUIREMENTS

Through customer and United States Department of Defense engagement, Carpenter Technology identified the critical parameters for a next-generation barrel alloy that can be produced with traditional practices (Table 1).

The key technical requirement for barrel innovation is wear resistance. There are a wide variety of barrel inspection methods and accelerated wear tests available to metallurgists, but the underlying microstructural mechanism provides a complete picture of the interaction of chemical and mechanical attack. The alloy solution requires a tenacious bond between the barrel steel and chrome coating, which is critical for wear life. GNB200 developments will focus on the interaction between this bond needed between the steel barrel and the chrome coating.

Service temperature must also be addressed by a new barrel alloy. At one extreme is the heat generated by high rates of fire — barrels are assumed to reach 1000°F during combat operations. At the other end of the temperature range, there is considerable debate among user communities on the relevance of impact strength at extremely low temperatures. The standard set for traditional dirty steels has been 40 ft·lbs at -40°F (which is also -40°C) in order to ensure operator safety — if something should go wrong, the steel needs to stay together and not fragment. The target is to achieve impact values of nearly 100 ft·lbs at -40°F to address the most severe conditions, but to date, a standard has not been set for today's clean steels. As shown in Table 1, an acceptable value has been set at 40 ft·lbs.

TABLE 1

HOLISTIC TARGET PROPERTIES FOR NEXT-GENERATION BARREL ALLOYS

ATTRIBUTE	PRIORITY	MEASUREMENT	MINIMUM ACCEPTABLE VALUE	TARGET VALUE
Diameter RND bar	H	in.	1–3	1.5–2
YS > 150 KSI	H	ksi	> 150	150
Charpy V-notch impact @ -40°F > 40 ft-lbs	H	ft·lbs	40	100
Tempering temperature > 850°F	H	°F	850	> 1000
GFM cold hammer conducive	H	Y/N	Y	Y

ALLOY MODELING

As a primary metal producer, Carpenter Technology understands the need to innovate to provide solutions for our customers. Ongoing advancements in critical industries like defense, energy, aerospace, electrification, and medical devices drive a continuous demand for new materials. New product and process development, enhancements, and troubleshooting often begin in the Research and Development laboratory, where there is access to numerous small-scale tools to design and manufacture alloys at a cost-effective, short time scale. The true challenge is taking knowledge from the lab and scaling up to industrial manufacturing.

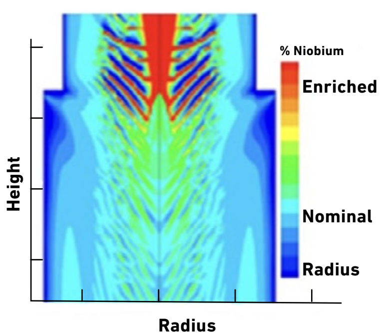
Industrial-scale processing for a specialty alloy producer might mean an experimental scale of 30 tons of metal that needs to be heat treated for 72 hours, followed by forging, rolling, machining, cold working, and numerous thermal handling steps. Considering the value of the raw materials used and the opportunity cost of displacing high-end aerospace products, costs can easily exceed hundreds of thousands of dollars.

Computational modeling tools and ICME can reduce the costs of development by reducing the number of experiments and accelerating trials to short-circuit the process needed to bring new materials to market. These tools include modeling packages that give our R&D experts the capability to model aspects of every manufacturing step, including melting, remelting, annealing, forging, rolling, machining, finishing, and testing. Carpenter Technology uses a combination of process models based on finite element and finite difference techniques, computational alloy design, physics-driven analytical models, and empirical approaches to understand the process-properties leg of the Materials Pyramid.

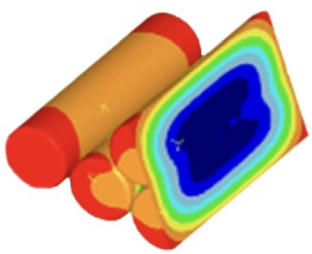
With advanced codes and techniques to simulate alloys based on their chemistry, Carpenter Technology has access to nearly the entire periodic table to scan for new compositions to meet customer needs. When we join these techniques in ICME, we can capture all aspects of modern metallurgy. This is bolstered by emerging approaches, or Industry 4.0, where machine learning and artificial intelligence are used to ingest large data sets and make connections to performance readily apparent to the subject matter expert. Each of these tools and each step of this approach are strengthened by characterization and testing capabilities and the workforce's wealth of experience.

FIGURE 1 — EXAMPLES OF COMPUTATIONAL MODELING.

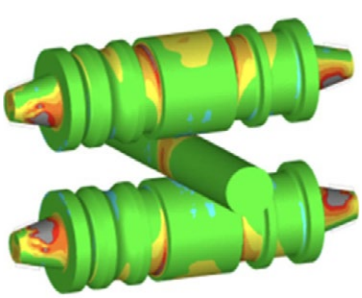
A. Elemental segregation during solidification



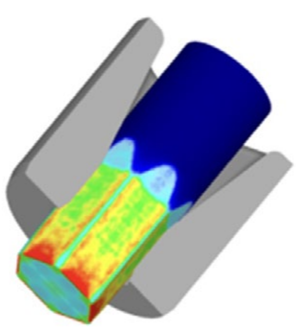
B. Heat transfer of large bars in a furnace



C. Deformation modeling of a rolling process



D. Deformation modeling of cold drawing process



PRODUCTION

GNB200 is revolutionary in the small arms barrel application, but this alloy family has been evolving for defense needs for more than a decade. Through modeling and mill trials in both melting and hot working, Carpenter Technology metallurgists have been able to balance the properties needed and reliably produce a product that meets the product goals for the application.

GNB200 is produced through an AOD/VAR process to achieve the specific property balance and costs necessary for OEM success. The premium alloy is available at full heat lot scale in typical sizes of 1.0 to 3.0 in. diameter bar and can be tailored to customer specifications. Test and evaluation materials are available upon request with field metallurgist support.

TYPICAL PROPERTIES

The target properties for GNB200 were previously laid out in Table 1. Data from a full production heat confirmed properties obtained from our lab scale studies were achievable in a full-sized, 30-ton production heat. By using a tempering temperature between 1150 and 1160°F, we can fine-tune this alloy to achieve the necessary tensile strength, impact strength, and hardness needed to produce an advanced gun barrel. Tensile strength is shown in Figure 1, followed by impact strength characterization in Figure 2. These high tempering temperatures are critical to retain strength and achieve the wear resistance at higher temperatures. The resulting hardness using a 1150–1160°F tempering temperature were 38–39 HRC, which is the appropriate hardness to provide a product that is conducive to hammer forging.

FIGURE 1 — AGING CURVE FOR TENSILE STRENGTH.
TENSILE STRENGTH PROPERTIES AS FUNCTION OF TEMPERING TEMPERATURE.

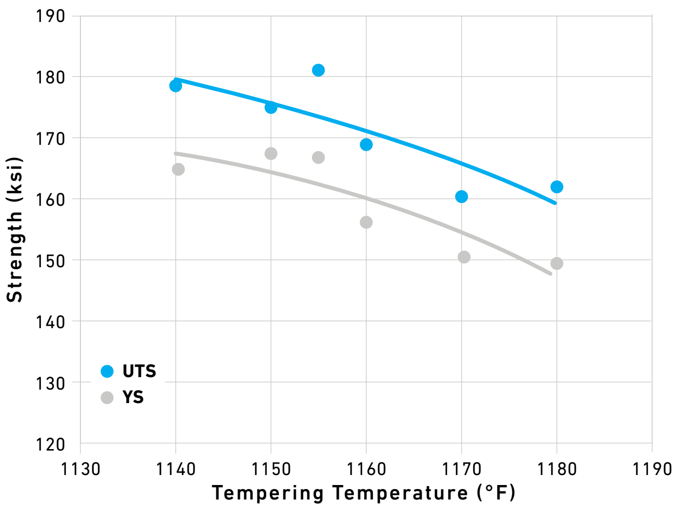


FIGURE 2 — AGING CURVE FOR IMPACT STRENGTH.
IMPACT PROPERTIES TESTED AT -40°F AS FUNCTION OF TEMPERING TEMPERATURE.

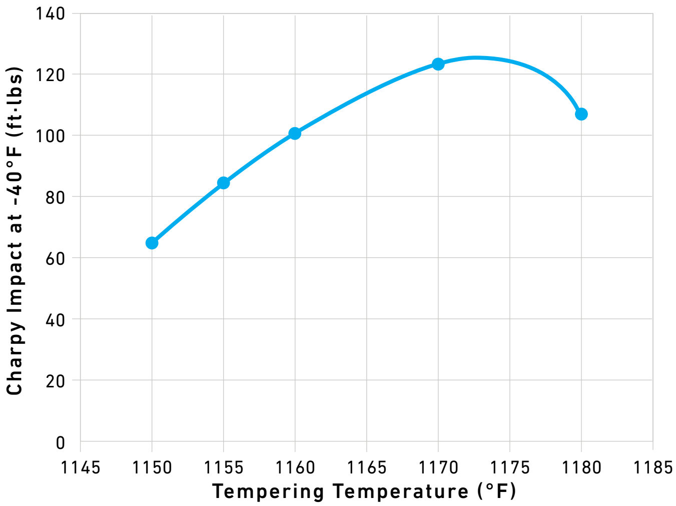
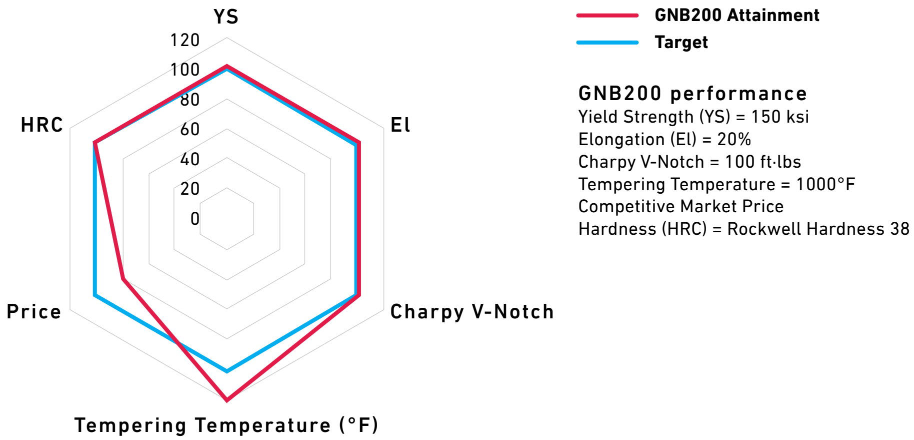


Figure 3 is a radar map illustrating GNB200's performance versus holistic targets of yield strength, elongation, Charpy V-Notch, tempering temperature, price, and hardness. The blue line set at 100%, meaning the target values. The orange line shows GNB200 attainment in percentage form.

FIGURE 3 — GNB200 PERCENTAGE ATTAINMENT VERSUS HOLISTIC TARGETS.



CONCLUSION

GNB200 was developed to meet the increasingly rigorous demands of the weapons industry, delivering high performance within proven mass production processes. The approach used to develop the premium remelted alloy steel was made possible with modern modeling techniques. As a result, GNB200 meets or exceeds the holistic set of targets outlined in this paper, as shown in Figure 3. The alloy's high mechanical strength combined with very high toughness makes it an ideal rifle barrel alloy for next-generation weaponry.

CARPENTER TECHNOLOGY

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