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► BY TECHNICAL EDITOR CHARLES M. BOYLES, CPE

Be Cool

Cryogenics: Sound science or snake oil?

Cryogenics refers to a thermal process in which an object is cooled to -300° F with liquid nitrogen. (It does not, as some believe, refer to cold treatment at -120° F.) The cryogenic process has been touted as a method to increase hardness and wear resistance, relieve stress and improve surface finishes for cutting tools, dies and critical machined parts.

It has also been dismissed as snake oil by some machine shops. To help mitigate the confusion, we present the most current information available on this controversial process. (The article beginning on page 56 explains the metallurgy and implications of cryogenics.)

Cryogenic processing facilitates the conversion of residual austenite to martensite and relieves stresses. There may be as much as 40 percent residual austenite in heat-treated ferrous metals. That percentage can be lowered to as little as 1 percent in some cases.

"Unlike a surface treatment, cryogenic processing is throughout the tool and affects the entire volume of the treated part," said Frederick Diekman, president of Controlled Thermal Processing Inc., Kenosha, Wis. "Also, while hardness can be improved somewhat—1 to 2 points HRC—the variation in hardness throughout the part is reduced. This makes for a more consistent and predictable tool."

The main value of cryogenic treatment lies in its ability to increase cutting tool wear resistance, which leads to longer cutter life and fewer tool changes. Cryogenic treatment also enhances the dimensional stability of a part by relieving residual stresses. This is especially important for progressive dies, where cumulative tolerances are critical.

Best Practice

The best and most predictable results from cryogenic treatment occur in a carefully controlled process. Parts are not directly exposed to liquid nitrogen, but undergo the thermal process in a cryogenic heat exchanger. There, cutting tools or parts transition from ambient temperatures to -300° F during an 8-hour period. The parts then "soak" for 8 to 20 hours at -300° F before being brought back to ambient temperature over another 15 hours. The final step is a retempering of the treated part to stress-relieve the newly formed martensite.

"Retemper at +300° F," recommended Jeffery Levine, Ph.D., the president of Applied Cryogenics Inc., Waltham, Mass. "While some service suppliers don't retemper at all and others retemper at the nominal temper range for a given material, you have to be careful. It's very possible to overtemper a part and render it worthless."

Test Findings

Establishing a scientific basis that cryogenic treatment enhances wear resistance in cutting tools is necessary and, to that end, some rigorous testing has been performed. In 1994, the Iron and Steel Institute of Japan published

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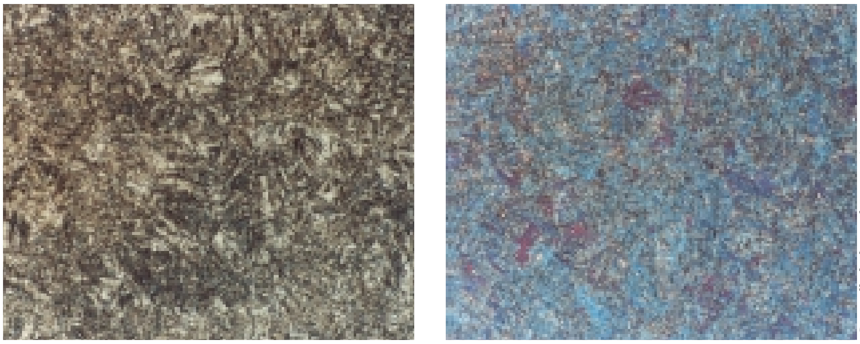
the findings of F. Meng, K. Tagashira, R. Azuma and H. Sohma from the Department of Mechanical Engineering at the Muroran Institute of Technology in Japan*. ISIJ considered cold treatment of steel an integral aspect of the total heat treatment for tool steel. In their tests, the researchers differentiated between cold and cryogenic treatments.



Controlled Thermal Processing

These two photos illustrate the difference in grain structure in treated and untreated steels. The cryogenically treated grain (left) has a white, feather-like martensitic structure and black carbide groups. The untreated sample does not.

Cold treatments can be accomplished with dry ice—solid carbon dioxide—at temperatures of approximately -60° F. Cryogenic treatments reach -300° F and employ liquid nitrogen. The tests were performed on a D-2 tool steel (12 Chrome, 1.4 Carbon, Molybdenum, Vanadium) to quantify the potential improvement in wear resistance after cryogenic treatment and retempering.

While the precise mechanism under which improvements occur in tool steel is not completely understood, the documented results are valid and reproducible. The ISIJ test results illustrate that cryogenic treatments improve wear resistance at high sliding speeds. (Sliding speed refers to the linear distance a loaded friction wheel travels on a piece of material as measured on the wheel's perimeter at speeds from 0.5 to 3.62 meters per second on a sample-on-wheel wear-test machine. In these tests the sliding distance was from 200 to 600 meters, with a wheel load of 21 Newtons.)

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Cryogenic processing equipment is available for less than $45,000. Shown is a cryo unit, computer controls and liquid-nitrogen tanks.

The treatment also promotes the precipitation of fine carbides, as opposed to coarse carbides. As for order of magnitude, "fine" might be thought of as a garden pea and "coarse" as a soccer ball.

Through the precipitation of the fine carbides, the retained austenite becomes martensite. This improves the strength and toughness of the matrix. The precipitation of fine carbides in the martensite during cryogenic treatment enhances wear resistance rather than removing austenite. The cryogenic treatment allows the contraction of iron and other atoms to shift position slightly as the metal lattice deforms.

Costs and Pricing

The cost for cryogenic treatments varies. Some providers base their pricing on the weight of the parts treated. Others offer a per-piece price. For example, a 3-flute endmill might cost $6 to $8 for cryogenic treatment and tempering, while a router bit might cost $3. Larger items and engine parts—camshafts, pistons and rods—might be listed on a company pricing schedule. The value of cryogenic treatment to an operation hinges on the particular cost structure, meaning, "crunch your own numbers."

Besides having tools treated by a vendor, machine shops or other tool users can purchase their own cryogenic equipment. Along with an insulated chamber, these systems require liquid nitrogen. Process cycle times are handled through the control system.

These systems cost less than $45,000 and, if your shop is using a significant number of tools or producing a large amount of hard tooling, having your own equipment in-house may be the most cost-effective approach.

Cemented-carbide and HSS cutting tools and dies are among the most frequently recommended applications for cryogenic treatment. This includes drills, endmills, broaches, reamers and saw blades.

Gage blocks, which are used as length references for precision measuring devices, are cryogenically treated to stabilize their dimensions over time. They also must be made of corrosion-resistant steel alloys to prevent growth via oxidation.

Detractors and Nonbelievers

Some large shops we contacted that have tried cryogenically treated tools did not believe the process made a differ-

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Pages 205 to 210 of the paper from ISIJ International, Vol. 34 (1994), No. 2, is available at www.cryogenius.co.za. (Other definitive tests showing positive results have been made on cryogenic processes for metals by R. F. Barron of Louisiana Technical University in Ruston, La., and D.N. Collins at the National Heat Treatment Center in Dublin, Ireland.)

ence. However, those shops did not establish baseline performance standards or perform any controlled tests to preclude variation in speeds, feeds, DOC or other machining variables.

The following companies contributed to this article:

Applied Cryogenics Inc.
(781) 642-7860
www.metal-wear.com

Controlled Thermal Processing Inc.
(847) 651-5511
www.metal-wear.com

300° Below Cryogenic Tempering Services Inc.
(217) 423-3070
www.300below.com

Another criticism of cryogenics is that a 0.001"-thick skin forms on treated tools, which must be ground away after treatment. (Ergo, the recommendation: Cryogenically treat dull tools then have them resharpened.) The existence of post-cryogenic skin was verified, but an uncommon result among vendors.

As with many industrial processes, cryogenic proponents tend to imply that remarkable gains can be had by those who employ the technology. And though carefully phrased, the information can often be misleading.

If your shop has been making parts with a file and hacksaw, an 800 percent improvement in productivity may be possible. If you apply more sophisticated tools, though, the improvement probably will be less.

As with any process, the only practical way to quantify improvements is to establish a baseline in terms of tool life, cost per pound of chips, power consumption, downtime for tool changes and operator idle time before introducing a process change. Then monitor the results accurately. Over-exuberant endorsements (by those who should know better) should be treated with the utmost skepticism.

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