By Pete Paulin

COLD CUTS

Although its effects on metal composition are subtle, deep cryogenic tempering can yield dramatic improvements in tool performance.

In the search for cutting tool engineering that can increase productivity, prolong cutting life, and decrease costs, gains of 15% to 20% are considered significant. One recently developed tool treatment is showing far greater promise, in some cases improving tool life by 200% to 400%.

The method, called deep cryogenic tempering, subjects tools placed in a specially constructed tank to temperatures below -300° F for a number of hours using liquid nitrogen as the refrigerant. The process supplements standard heat/quench tempering, completing metallurgical changes that heat treating begins.

Since 1965, when commercial deep cryogenic treatments first became available in the United States, a handful of studies and reports have been released noting the improved performance of treated lathe tools and of tool steels used in the steel industry. According to the literature, some machine elements, such as progressive dies used in metalworking, have lasted six times longer after deep cryogenic treatment. Drills, end-mills, and taps also have shown significant improvement.

Another advantage of deep cryogenic tempering revealed through research is its ability to change the entire structure of the tool material, not just its surface. As a result, the treatment is not negated by subsequent finishing operations or regrinds.

Cool and Controlled

For all its advantages, however, deep cryogenic tempering is no panacea. In some cases it has produced sterling results: One manufacturer of titanium-alloy parts reports that, after treating the M-42 twist drills it uses, the company needed 63% fewer of the tools to do the same work. In another instance, a 400% improvement in tool durability was achieved using cryogenically treated C-2 carbide inserts to mill 4340 stainless steel. However, other metals, such as T-2 tungsten HSS, have been left with little or no change after treatment. Even where deep cryogenic treatment has been shown to be effective, results have not been consistent.

But as researchers and commercial applicators have learned more about the deep-cryogenic process, they have discovered ways to produce more repeat-

TEST RESULTS: Percent of Increase in Wear Resistance After Cryogenic Tempering

AISI#	Description	At -110° F	At -310° F
Materials that showed significant improvement			
D-2	High carbon/chromium die steel	316%	817%
S-7	Silicon tool steel	241%	503%
52100	Standard steel	195%	420%
0-1	Oil hardening cold work die steel	221%	418%
A-10	Graphite tool steel	230%	264%
M-1	Molybdenum high-speed steel	145%	225%
H-13	Chromium/moly hot die steel	164%	209%
M-2	Tungsten/moly high-speed steel	117%	203%
T-1	Tungsten high-speed tool steel	141%	176%
CPM-10V	Alloy steel	94%	131%
P-20	Mold steel	123%	130%
440	Martensitic stainless	128%	121%
Materials that did not show significant improvement			
430	Ferritic stainless	116%	119%
303	Austenitic stainless	105%	110%
8620	Nickel-chromium-moly alloy steel	112%	104%
C-1020	Carbon steel	97%	98%
AQS	Graphitic cast iron	96%	97%
T-2	Tungsten high-speed steel	72%	92%

R.F. Barron study results, Louisiana Polytechnic Institute

The effects of shallow and deep cryogenic treatments on various steels are shown. Percentage increases above 120% are considered statistically significant.

able and predictable effects. The trick is in the precise management of the cooling sequence. The older tanks did not adequately control temperatures as they were brought to deep-cryogenic levels. Today's state-of-the-art deep-cryogenic systems use a computer linked to the tank that duplicates the optimal cooling curve. It carefully regulates the temperature change and brings a measure of consistency to the process.

Under a computer's control, temperatures inside a cryogenic tank are brought down according to a prescribed timetable. The process unit manufactured by 300° Below Inc., Decatur, IL, cools the material slowly to -317° F, holds the temperature at that point for 10 to 40 hours, then raises it to +300° F before slowly returning it to room temperature. It is a dry process that, unlike other deep cryogenic processes, does not bathe the materials in liquid nitrogen, a practice that the designers of 300° Below's unit believe is more likely to cause damage from thermal shock.

For more information, *circle 75*

Chilly Changes

Slowly cooling a tool steel to deep cryogenic temperatures and soaking it at this low temperature for several hours changes the material's microstructure. Almost all of the austenite (a soft form of iron) retained in the steel after heat treating is transformed into a harder form, martensite, by deep cryogenic tempering.

A second result of a deep cryogenic "soak" is the formation of fine carbide particles, called binders, to complement the larger carbide particles present before cryogenic treatment. (Depending on the alloying elements in the steel, these particles might be chromium carbide, tungsten carbide, etc.)

One recent study by Randall Barron, Department of Mechanical Engineering, Louisiana Polytechnic Institute, Ruston, LA, looked at how the changes brought about by cryogenic treatment affected steel's ability to resist abrasive wear. This type of wear occurs when a body penetrates and gouges a material's surface. The gouging body may be a surface asperity on a mating part, a free-abrasive grit particle from an external source, or an internally generated wear particle.

The Barron study found that the martensite and fine carbide formed by deep cryogenic treatment work together to reduce abrasive wear. The fine carbide particles support the martensite matrix, making it less likely that lumps will be dug out of the cutting tool material during a cutting operation and cause abrasion. When a hard asperity or foreign particle is pressed onto the tool's surface, the carbides further resist wear by preventing the particle from plowing into the surface.

Some of these benefits may be achieved through standard tempering, which also transforms austenite into martensite. But standard tempering may not bring about a complete transformation in some tool steels. For example, 8.5% of an O-1 steel remains austenite after it is oil-quenched to 68'F. If M- I is quenched from 2228° F to 212° F, then tempered at 1049° F, the retained austenite is 11 %.

Additional improvements in tool performance can be achieved if this retained austenite can be transformed to martensite. As Barron's study has confirmed, adding a cryogenic step to the treatment process does just that.

In the chart accompanying this article, data drawn from another study of treated metals by Barron indicates which samples exhibited improved abrasive wear after cryogenic treatment. In addition to results obtained from samples treated at liquid-nitrogen temperature (-310° F), the chart also lists results of treatment at dry-ice temperature (-110° F).

Predicting Effectiveness

Knowing how deep cryogenic tempering works, we can predict which materials will benefit most from treatment. Generally, if an alloy contains austenite, and this austenite responds in some degree to heat treatment, further improvements will be seen after deep cryogenic tempering. For instance, ferritic and austenitic (430 and 303) stainless steels generally cannot be hardened by heat treatment. Martensitic (440) stainless steels, on the other hand, *can* be hardened by heat treatment. Therefore, the effect of deep cryogenic treatment should be more pronounced for440 stainless steel than for the other stainless steels.

C- 1020 carbon steel and QS Meehanite iron also show no significant improvements in performance after cryogenic treatment. Because these materials contain no austenite, sub-zero temperatures can cause no further metallurgical changes in them.

Critics

In addition to examining cryogenic treatment's effects on austenite transformation, Barron also looked at other, less obvious metallurgical changes. His data helps answer those critics of cryogenic tempering who doubt the effectiveness of a process that imparts so few visible changes to the metal. These critics say heat treating already changes 85% of the retained austenite to martensite, leaving only 8% to 15% to be transformed by deep cryogenic tempering. Using the process to produce such small results is inefficient, according to the skeptics.

These observations are accurate as far as they go. But they fail to take into account the fact that metals subjected to deep cold develop a more uniform, refined microstructure with greater density. The particles that are formed through the precipitation of additional microfine-carbide fillers take up the remaining space in the microvoids, resulting in a tool steel with a much denser, coherent structure that improves wear resistance.

Metallurgists have known that cryogenic tempering has this effect, but they may not have realized the extent to which the microstructure changes. Researchers in a study conducted at the Jassy Polytechnical Institute in Rumania used a scanning electron microscope equipped with an automatic particle counter to identify and quantify these smaller particles. Through this examination they found that cryogenic tempering creates a significant change in density throughout the tool.

Some people acknowledge the benefits of cold tempering, but they question the need to use temperatures below -110° F. A review of the data from the Barron study, however, shows that some tools, at least, perform significantly better after processing at-310° F than they performed after -110° F tempering. Among cutting tool steels, for instance, the wear resistance of M-1 HSS was almost one-and-a-half times the wear resistance of the untreated material after a-110° F soak. After a-310° F soak, the steel exhibited two-and-a-quarter times the wear resistance of the untreated material. T-1, the traditional tungsten HSS, went from a little under one-and-a-half times the wear resistance after a -110° F soak to one-and-three-quarters the wear resistance after a -310° F treatment.

It may be concluded from these tests that treatment at -110° F does improve wear resistance, but deep cryogenic treatment at -310° F improves wear resistance much more. To allow time for the very fine carbide particles to form and the retained austenite to be transformed into martensite, a long soak at deep cryogenic temperatures is necessary.

Summary

Deep cryogenic treatment has been shown to result in significant increases in the wear resistance of steels such as D-2, M-2, 0-1, and 52100. The basic mechanisms at work during the cryogenic process help control wear by producing a tough surface, which helps to prevent particles from tearing out of the material and resist penetration of the surface by other particles.

About the Author

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