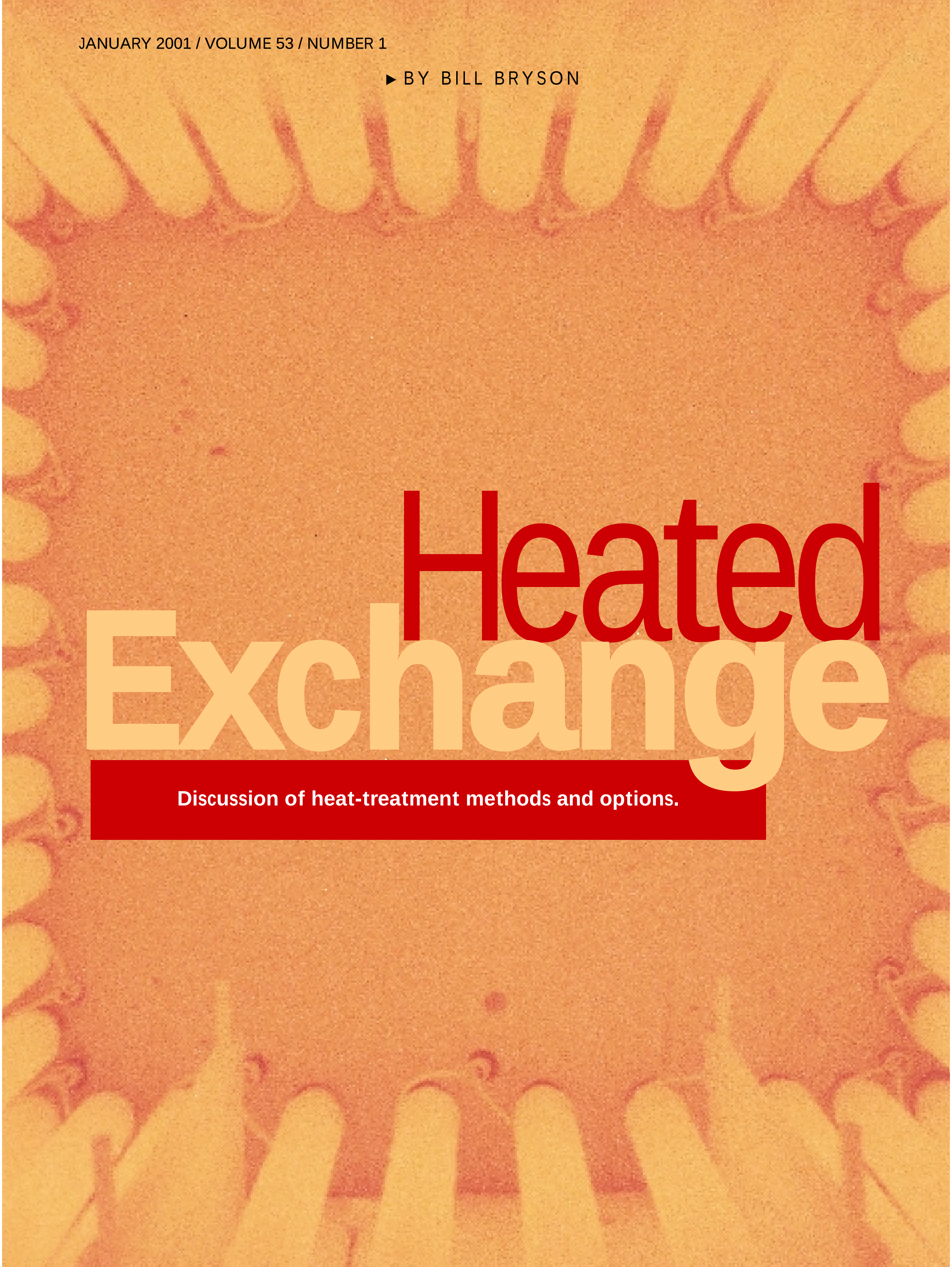
JANUARY 2001 / VOLUME 53 / NUMBER 1

▶ BY BILL BRYSON

Heated Exchange

Discussion of heat-treatment methods and options.



Images provided by All Trend Corp.

Metalworking companies have some important decisions to make when it comes to heat treating steel. Among them are how to protect the surfaces of their parts, which type of heat-treating process to use and the economic feasibility of the method chosen.

Ferrous metal heated above 400° F is subjected to two types of deterioration. The first occurs between 400° F and roughly 900° F and is called "scaling," or surface oxidation. It's caused by the reaction of the heated metal surface to oxygen, water vapor or carbon dioxide. At 400° F, the material's color begins to resemble light straw, then grows progressively darker as the temperature rises. At 600° F, it begins to turn blue and then, eventually, blue-black.

The second type of deterioration is more chemical in nature and occurs when carbon dissipates into the atmosphere. This is called decarburization and takes place any time a ferrous metal is heated to high temperatures (1,000° F and above) without a protective atmosphere.

The hardness level in a heat-treated ferrous metal is dependent upon its carbon content. If carbon has dissipated, it affects the surface hardness. Time is another critical component. The longer the heated metal is exposed to atmosphere, *and* the higher the austenizing (heat-treat soak) temperature, the greater the depth and totality of decarburization on the surface.

For most applications, it is imperative that the heat-treated surface be clean, bright and shiny. The need is not so much cosmetic as it is a need to ensure a proper metallurgical structure. An oversized part can be ground to finish size by grinding away the decarburized surface, but this is labor-intensive and costly.

Surface Protection Methods

There are several methods that can be employed to protect surfaces. However, each may not be economical, sound or practical for all situations, as will become evident in the following pages.

Stainless steel foil.

Pros: Enveloping the part in stainless steel foil is a good method of surface protection for air-hardening steels, as long as austenization is under 2,100° F—the protection limit of stainless steel. A small degree of surface deterioration still will take place, but by placing a small piece of paper within the envelope, the atmosphere can be made quite acceptable.

Cons: The part will have a dull and grayish surface, not a bright and shiny one. A finish grinding will be necessary, albeit just a few thousands of an inch deep. This method is also quite labor-intensive and costly in terms of the material required to form the sealed envelopes, which are razor sharp and may cause deep cuts in a worker's skin.

Stainless foil is really only practical for small batches. And, it should not be used for oil- or water-quenched parts, as it produces nonuniform quench shielding. That can inhibit proper grain formation and cause severe stress risers. Additionally, a sharp part corner can easily puncture the envelope. This will ruin the enclosed parts by exposing them to air, which causes deep decarburization.

Atmospherically controlled furnace.

Pros: This is great for nonferrous applications or ferrous metal applications that do not require quenching, such as stress relieving, annealing or brazing. Often, a reducing atmosphere (such as 95 percent nitrogen with 5 percent hydrogen) can be used to scrub the surface clean. It's usable with water- or oil-quenched parts and, by keeping the parts in a protective inert gas while at the austenizing temperature, reduces decarburization. The surface will decarburize while being transferred from the furnace to the quench, and quench-bath scale will form.

Cons: Ferrous metals removed from the furnace for quenching will be exposed to atmosphere. To prevent this, the furnace must have a drop bottom and be entirely sealed, and have the chamber and quench tank flooded with a protective inert gas. This method is totally useless for air-hardening grades of ferrous metals, due to decarburization.

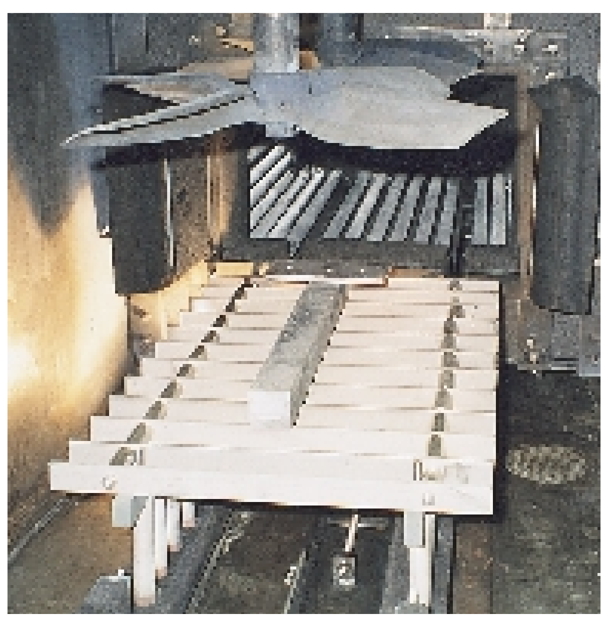
Pressure-quench vacuum furnace.

Pros: These units will produce bright, shiny parts that look as good coming out of the furnace as they did going in. The parts are placed in the furnace and a vacuum is applied to the chamber to evacuate atmosphere. Then, depending on the furnace design and recipe, the vacuum pump is turned off. Valves seal the chamber, and a low-pressure inert gas fills it during the austenization stage. After the parts have been soaked at the proper austenizing temperature for the designated length of time, the chamber is flooded with a pressurized inert gas. It cools the furnace and then the load.

Cons: There are four main drawbacks to the pressure-quench vacuum furnace:

1. Extreme caution needs to be exercised during the treatment process, as these furnaces occasionally explode because of the high pressures involved. The constant flexing caused by pressurization and vacuum cycles can cause fatigue stress in weld joints, leading to catastrophic failure.

2. The high-pressure inert gas is often introduced through nozzles within the insulation. The nozzles are aimed at various areas of the workload, which can cause parts to quench unevenly. This often leads to tremendous stress developing in parts. Tests have shown that there are wide discrepancies in cooling uniformity within an empty furnace. This lack of uniformity often worsens when the mechanics of cooling a load is added to the mix.



A piece of HSS comes out of the furnace in a bright and shiny condition.

Images provided by All Trend Corp.

3. New pressure-quench furnaces are very costly. Because of the special pressurized vessel chamber and requisite door-locking mechanism, these furnaces can range in price from $300,000 to several million dollars.

Often, the first 30 to 40 seconds of applied high-pressure quench does little or nothing to actually quench the parts. Because of the design of these furnaces, the quench gas must cool the hot furnace and hot zone before a temperature change becomes evident in the parts being heat-treated. This can lead to problems.

With a HSS tool, for example, 30 to 40 seconds of overcooking without an immediate quench can ruin the grain structure. HSS demands a very short, precisely timed soak at austenization temperatures. In examining soak times, researchers found that a 1" cube of M-4 needs to be soaked for precisely 4 minutes 30 seconds. This soak, followed by an immediate quench, yields the ultimate transformation of austenite to martensite. Martensite is the grain structure most desired and sought after from the heat-treating process.

The greater the amount of transformation and the finer the desired grain size, the more critical it is to have the proper temperature, soak duration and quench speed. During the testing mentioned earlier, the first cube was soaked for precisely 4 minutes 30 seconds, followed by an immediate quench. Subsequent samples were soaked for 4 minutes 35 seconds, then quenched, 4 minutes 40 seconds and so on. By the eighth specimen, which equates to just 5 minutes 10 seconds of austenitic soak, the structure was greatly deteriorated and, under stringent conditions, would be considered unusable in the particular application for which it was designed. By the 10th cube—which soaked just 50 seconds longer than the

Cryogenic treatment puts freeze on cutting tool wear

BY RENKA GESING

Standard heat/quench tempering processes do not quite complete the phase changes necessary to give the steel alloys used in cutting tools the highest possible toughness and wear resistance. The only known way to complete that microstructural transformation is to have the heat-treated material undergo a deep freeze—approximately -300° F. This process is known as deep cryogenic treatment, or, simply, cryo-treatment or cryo-processing.

"It's amazing that not everyone knows about it," said John Koucky, vice president of 300 Below Inc., Decatur, Ill. "Even big companies don't know how far the industry has come."

When steel is heated above 1,300° F, it's transformed to a ductile phase called austenite—a softer form of iron that is unstable at room temperature unless significant quantities of alloying elements, such as chromium, are present. As hot steel is quenched, plates of a hard, brittle phase called martensite form in the austenite grains. The more austenite that is transformed, the harder the steel.

However, the degree of transformation from austenite to martensite is strictly dependent on the final quench temperature and, in the case of the tool steel compositions, it is rarely 100 percent complete. The best rate that heat-treaters can deliver is about 95 percent, and only if they are very precise and use proper timing at all steps of the process.

Cryogenic processing down to about -300° F is the only known method that can complete the transformation to 100 percent martensite. In addition, superfine carbide particles (iron carbide, chromium carbide, tungsten carbide, etc., depending on the alloying elements in the steel) are precipitated during the long cryogenic soak of 20 to 60 hours. This partially relieves the residual transformation stress and produces a strong and tough material with minimum reduction in hardness and wear resistance—an ideal combination of mechanical properties for a cutting tool.

A number of companies offer cryogenic processing. One lists the following improvements in wear life for tools that have been cryogenically treated: C-2 carbide inserts, 400 percent; HSS taps, 800 percent; and cutting dies, 300 to 400 percent.

"Almost any kind of tool steel or dynamic part, for whatever application, will exhibit some kind of increased life," stated Ed Bush of Cryo-Tech, a Detroit company that 300 Below recently acquired.

The cost of treating a tool or part is minimal, particularly when compared to the cost of replacing a tool. Applied Cryogenics, Fort Smith, Ark., charges about $10/lb. for small parts or small orders, and $2.50/lb. for a large part.

Even very large parts can be treated. 300 Below can treat parts weighing up to 27,000 lbs. and 18' long.

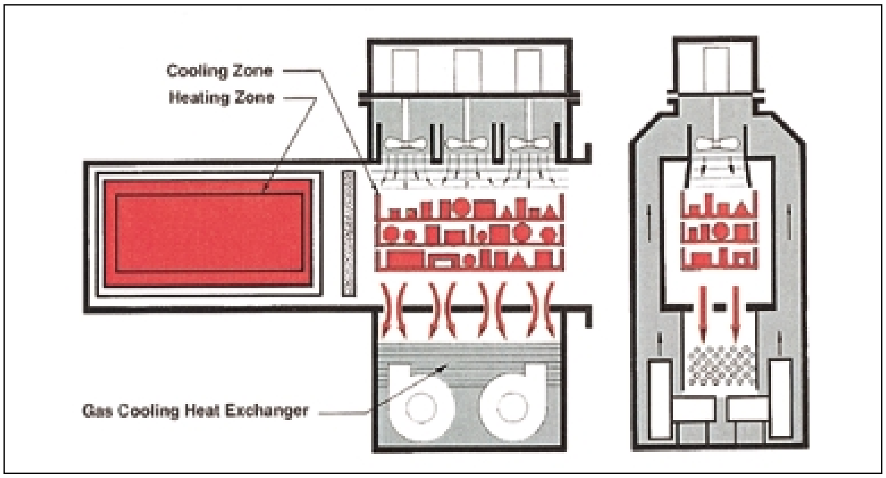
A big plus is that the cryogenic treatment affects the entire material, not just the surface. Therefore, resharpening or redressing worn tools won't diminish the effects of the process.

Cryogenic treatment doesn't work for all materials in all situations, but it is certainly worth investigating for those cases where the durability and life of cutting tools could be significantly improved. Businesses that have a large demand for cryo-treatment might even consider purchasing their own cryo-processor.

Cryogenics International, Scottsdale, Ariz., has a popular model for just under $15,000. "Every year, we sell more and more systems," said the company's president, Charles Beresford. "A lot of our customers start by sending us tools for treating, then they decide it's smarter for them to buy one of our systems. A mid-size or larger company can spend from $100,000 to a million-plus on cutting tools. If they buy a system from me for $50,000, within the course of one year, they will have paid for the system."

About the Author

Renka Gesing is a freelance writer who lives in Windsor, Ontario.



The two-zone system extracts heat from the workload by transferring the load from the heating zone to the cooling zone. Then, inert gas is blasted directly down onto the workload from high-speed fans positioned overhead.

prescribed soaking—the metal was considered scrap.

Two-zone vacuum furnace.

Pros: These furnaces produce bright, shiny, clean parts as well. In operation, the workload is placed on a machine-driven transfer dolly that enters the hot zone, located at the rear of the chamber. A pair of internal doors close. Then a vacuum removes atmosphere and the heat-treat cycle begins. After reaching the austenizing stage and having been soaked for the proper amount of time, the element power is turned off, the vacuum valve closes, the inner doors open mechanically and the workload is quickly transferred into the quench area in the front half of the chamber. The entire operation lasts approximately 6 seconds.

Once the dolly is in the quench zone, the inner doors close, retaining the heat in the hot zone. Inert gas is drawn from under the load—through a heat exchanger—and cycled through high-volume blowers overhead and back down through the load, causing a uniform and thorough quench. Once the parts have cooled to less than 400° F, the outer doors are opened, the parts are removed and another load is sent into the still-warm hot zone. This conserves energy, making the two-zone furnace less expensive to operate than a pressure-quench unit.

Cons: As with pressurized furnaces, the two-zone furnace's thick cross-sections don't shed heat fast enough to allow proper quenching of oil- and water-hardening grades. (Water-hardening steels could only be quenched if the parts were nearly paper-thin.) Both types of furnaces try to simulate the speed of withdrawing heat from metal without using water or oil quenching.

Affordable Option

A company's size usually determines how it heat-treats parts. Larger companies that produce parts in high enough volumes to support in-house heat treating might consider a high-cost, high-pressure-quench vacuum furnace. If not, they will need to find a commercial heat-treating company able to meet its part quantity and quality needs.

Small- and medium-size companies also face the same decisions. But they are unable to negotiate reduced processing fees because they don't constantly send out batches of parts for treatment like larger companies do.

Smaller concerns often have to wait longer for delivery of their heat-treated parts, too. Since it's not profitable for the heat-treater to process a small load in a large furnace, small-shop work waits in queue until other small orders arrive from other customers. This reality impacts the shop's delivery schedule and, potentially, its cash flow and production schedule.

A pressurized vacuum furnace is probably not a high investment priority for most shops. If the choice comes down to purchasing a pressure-quench furnace or buying eight to 10 CNC machines, which are income generators, there's little doubt where a small- to medium-size company will put its budget dollars.

An affordable heat-treating option for many companies is the two-zone vacuum furnace. Everything from small toolroom-size furnaces to large commercial units are available.

One manufacturer of two-zone furnaces has produced a desktop-size model. It's intended for brazing, stress relieving and annealing small-batch loads. Because the unit has no quick-quenching blowers or a heat exchanger, it's priced at under $20,000. That makes in-house heat treating a reality for many shops that currently outsource the process.

About the Author

Bill Bryson is the author of two books about heat treating and has conducted over 240 industry seminars on the subject. Bryson is the president of Advisor In Metals, Milton, N.H., and he answers questions about heat treating via e-mail (hisaim@worldpath.com).