Vacuum tempering is being used for tempering high-speed steels and alloy steels to produce scale-free finish. Additionally, there are several other applications, which make this style furnace very versatile. A vacuum tempering furnace can be used for bright tempering, aging, and annealing. Other less common applications include degreasing, resin bake-off and preferential oxide treatment of carbon steels and tool steels.

Richard L. Houghton
Hayes Heat Treating
Cranston, RI

Vacuum tempering is designed to minimize oxide formation on surfaces when tempering or aging parts. They operate generally as follows:

- The furnace is loaded and the door closed. A vacuum, typically below 0.3 Torr (3.99x10⁻² kPa) is established in the furnace by means of a mechanical pump. If a blower pump is used with the mechanical pump, much lower pressures can be achieved.

- After evacuating the furnace, the furnace is backfilled with an inert gas such as nitrogen or argon to about 500 Torr (66.5 kPa). The parts are heated in this inert atmosphere to the required temperature and held for the required time.

- The furnace constantly purges in nitrogen gas during the heating and soaking of the parts at a rate of 10 cfm (.28 cubic meters per minute) during heating and soaking of the parts. This helps to prevent oxidation of the parts during the tempering process.

**Background**

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A vacuum temper furnace can reduce atmosphere gas usage and total cycle time, as compared to a bell-type controlled atmosphere furnace.

- After soaking, the parts are cooled by circulation of the atmosphere.
- A rear “bung” and a front insulating panel open to force the atmosphere out of the heat chamber and along the cold walls of the vessel. The workload is removed from the furnace when the parts are below 300°F (150°C).

Applications

**Bright Aging and Tempering** — The most common application for a vacuum temper would be for bright aging precipitation hardening materials such as stainless steels, beryllium copper, bright tempering alloy steels, and tool steels (see Figure 2). In practice, it has been found that for tempering carbon and stainless steels, a vacuum temper can produce similar surface brightness as a hydrogen furnace up to 1000°F (538°C). Above this temperature, a hydrogen atmosphere yields a slightly better result.

A vacuum temper furnace can reduce atmosphere gas usage and total cycle time, as compared to a bell-type controlled atmosphere furnace. It takes far less time to pump down the furnace before ramping to temperature than to purge out the air in a bell furnace. Also, it takes much less time after the parts are cool to remove them from the furnace. With an atmosphere bell furnace, the hydrogen has to be purged at the end of cycle. Table 1 shows the productivity improvement possible using a vacuum temper furnace instead on a hydrogen bell furnace.

**Degreasing/Drying** — Vacuum tempers have been used for degreasing oily parts or drying parts that have been cleaned in a hydrocarbon solvent. To degrease, the cycle requires the parts be heated under the partial pressure of nitrogen with a constant purge of gas. The parts are heated to the required temperature to vaporize the oil on the parts. Some of the vapors are removed from the furnace by the vacuum pump. During cooling, some of the vapors condense on the cold wall of the furnace leaving the parts relatively clean and dry. This cleaning application is somewhat crude and may only apply to in-process cleaning between machining operations. Furthermore, the furnace itself gets contaminated with the oil and may not be suitable for other “bright” work before the oil is baked out of it.

If the vacuum temper furnace is used for drying parts dipped in hydrocarbon solvent, the cleaning results are far better. Dipping the parts into a pre-cleaning solvent to dilute the oil will improve the parts’ cleanliness. A vacuum temper can also be used for drying parts cleaned and rinsed in water-based cleaners.

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**Figure 2** — Tool steel bearing components, as vacuum tempered to a bright finish.

<table>
<thead>
<tr>
<th></th>
<th>Bell-Type Retort</th>
<th>Vacuum Temper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnace work zone</td>
<td>36” diameter x 36” high</td>
<td>24x24x36”</td>
</tr>
<tr>
<td>Max Load Size</td>
<td>1000 lbs.</td>
<td>1000 lbs.</td>
</tr>
<tr>
<td>Gas Usage</td>
<td>175 cfh</td>
<td>10 cfh</td>
</tr>
<tr>
<td>Gas Type</td>
<td>Dissociated Ammonia</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>Cycle Load</td>
<td>Load furnace</td>
<td>Load Furnace</td>
</tr>
<tr>
<td>Purge with nitrogen</td>
<td>Establish vacuum</td>
<td>Ramp to 600°F</td>
</tr>
<tr>
<td>Introduce Atmosphere</td>
<td>Ramp to 600°F</td>
<td>Hold for 2-2.5 hours</td>
</tr>
<tr>
<td>Ramp to 600°F</td>
<td>Cool to below 200°F</td>
<td>Backfill</td>
</tr>
<tr>
<td>Hold for 2-2.5 hours</td>
<td>Cool to below 200°F</td>
<td>Unload</td>
</tr>
<tr>
<td>Cool to below 200°F</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purge out with nitrogen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unload</td>
<td>7 hours</td>
<td>4.5 Hours</td>
</tr>
</tbody>
</table>

Table 1 — Bright aging beryllium copper 172 alloy: The process requirement is to ramp to 600°F (315°C) and hold for 2-2.5 hours at temperature. Cool to below 200°F (93°C). The load consists of 160,000 pieces of an electrical contact. There are 80 lots, 2,000 pieces per lot. Each lot has to be kept separate and put into an individual basket. Therefore, the load consists of 80 small baskets loaded into larger framed baskets for support.
Maintenance of the vacuum pump becomes a greater concern since a great deal of water vapor will accumulate in the mechanical pump and affect its performance. Again, anytime a vacuum temper is used for drying of parts a proper bake out of the furnace is needed before processing any bright work.

**Filter Paper Bake-Out** — One unique application for a vacuum temper furnace is the baking out of binders used in the production of filter paper. The filter paper is wound inside a cold rolled steel mesh liner. Once inside the liner, the binders are burned off in air. To reduce emissions into the work environment, the vacuum temper furnace was used instead of a box furnace. The furnace was plumbed with air inlet gas instead of nitrogen. Running a partial pressure of air in the furnace allows for the baking off of the binders. The gases that are formed are drawn through the pumping system and exit the building through ventilation ducts installed on the exit side of the mechanical pump. The vacuum furnace offers a work environment that is user-friendly as compared to the same process being performed in a box furnace.

**Preferential Oxide Treatment** — A new process has been developed using a vacuum temper oven, which yields a corrosion resistant oxide on the surface of low carbon steel. The process requires careful control of the time and temperature parameters during heating, soaking, and cooling, along with the use of partial pressure air in the vacuum furnace. The process results in a uniform greenish-blue oxide layer on the surface of the parts. The process is beneficial for steel parts to be stored or shipped that can not have a rust preventative applied to them.

To prove the corrosion resistance of the oxide layer, a humidity test was performed on test slugs of cold rolled steel. The slugs were first ground to remove any previous corrosion pits. A test slug was put through the preferential oxide treatment process. The treated slug and an untreated one were placed in a humidity chamber for 26 hrs. at 110°F and 98% relative humidity. The untreated slug had its entire surface covered with red rust. The treated slug showed no evidence of red rust forming on the surface.

In production, low carbon steel parts have been processed with this oxide treatment in Rhode Island and shipped to Mexico for assembly. Parts arrive at the customer corrosion-free and oil-free. It should be noted that the oxide layer formed has not been tested for applications in place of steam treating or chemical bluing where increased wear resistance of the surface is desirable. Steam treating is performed at temperatures higher than this process and result in a thicker oxide layer.

Another application for a preferential oxide treatment is for reciprocating saw blades (see Figure 3). These are made from high speed tool steel, which requires double tempering at 1025°F (552°C) for 2 hrs. each. After heat treatment, the blades are painted. If the blades are tempered in air, a scale forms on the blades, which interferes with the paint operation. It would require an additional de-scaling/cleaning operation before painting. If the blades are tempered in hydrogen or vacuum, the finish is bright. However, the parts are susceptible to corrosion and have to be preserved in oil or other rust inhibitor after the heat treatment and before painting. This would then require a cleaning operation before painting.

By performing a preferential oxide treatment on the blades using the vacuum temper furnace at the tempering temperature, a uniform greenish-brown oxide forms that is tightly bonded to the surface. The blades are far less susceptible to red rust and can be shipped without rust inhibitor from the heat treater to the manufacturer. The oxide does not interfere with the paint operation and actually improves the finish of the painted surfaces, as compared with blades processed in hydrogen or vacuum.

**Summary**

Vacuum temper furnaces are very versatile. The design offers the heat treater a single furnace, which can perform a multitude of processes. With the use of different atmospheres, different surface finishes can be achieved. Parts requiring bright finish can be processed followed by parts requiring a drying process. With proper maintenance and bake outs, the furnace can heat treat most applications that a box furnace and a bell retort furnace can perform, combined. Cycle time reductions are achievable, compared with bell retort furnaces, and there is a significant reduction in hydrogen-based atmosphere usage.

The preferential oxide treatment has promise for applications, where having a rust inhibitor on the surface of parts is undesirable. The data indicate that the process is beneficial for short-term exposures to humid conditions.

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**Author Richard L. Houghton is quality manager for Hayes Heat Treating, Cranston, RI. He is also a member of the ASM Heat Treating Society’s R&D Committee. This article was adapted from an original paper presented at the Heat Treating 2003 Conference and Exhibition in Indianapolis, IN.**