GCA CORPORATION
Vacuum Industries Division

TECHNICAL NOTE

APPLICATION OF GAS QUENCHING TO TOOL & DIE HARDENING

Presented by Elliott D. Thompson at ASM Heat Treating Conference, October 1978, Chicago, IL.

Recent advances in gas quenching have opened a whole new area of application. Steels heretofore thought to be hardenable only by oil quenching are routinely gas quenched. This is not meant to imply that all oil hardening steels in all sections sizes are hardenable by gas quenching.

The purpose of this paper is to identify those tool and die steels which may be hardened by gas quenching as contrasted to those hardenable only by liquid quenching. To accomplish this, gas quenching data from two sources will be used. The furst source of data is actual furnace installations which are processing tools daily. The second source is a mathematic model showing the projected cooling rates of various loads and part arrangements in a vacuum furnace equipped with a high-efficiency gas quench system. The model was developed from the heat transfer equations with constants derived from experimentation. By examining data from these two sources and comparing it to the requirements of the Transformation Diagrams, the composition and section sizes of various tool steels that will respond to gas quenching can be determined. From the combinations of cooling data and Transformation Diagrams, anyone who is considering gas quenching for hardening will be able to judge the applicability of gas quenching to his work.

It is not the intent of this paper to describe the mechanics of gas quenching or to suggest the design of a gas quenching system. The intent is to show how a properly designed and built gas quenching system may be used in the heat treating industry.

To begin our discussion of gas quenching we should make a comparison between gas and liquid quenching. By making such a comparison, we will readily see the advantages and limitations of gas quenching.

When a tool is quenched in a liquid, whether it is oil, water or one of the newer synthetic quenches, heat is removed at a rate of several thousands of degrees per minute in the initial stages of quenching.

This extremely rapid rate of heat removal is necessary for the low and medium hardenability tool steels as is illustrated by Figs. 1 and 2. As can

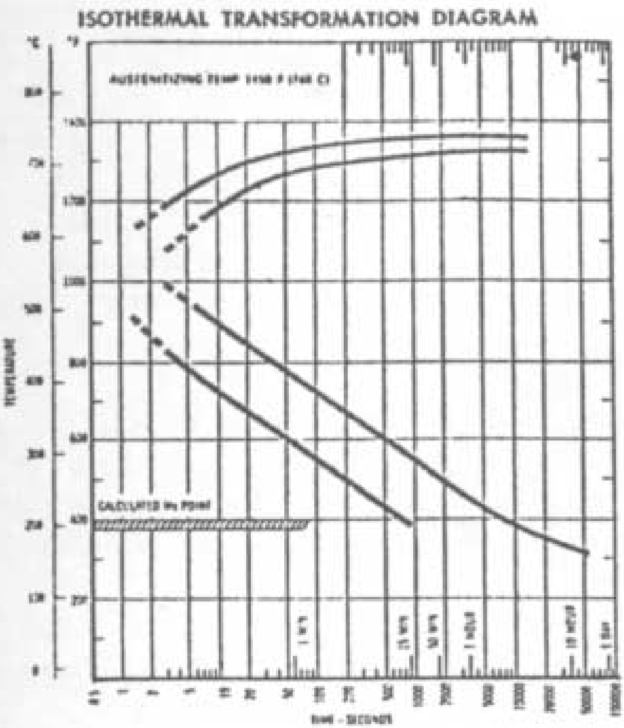

Fig. 1

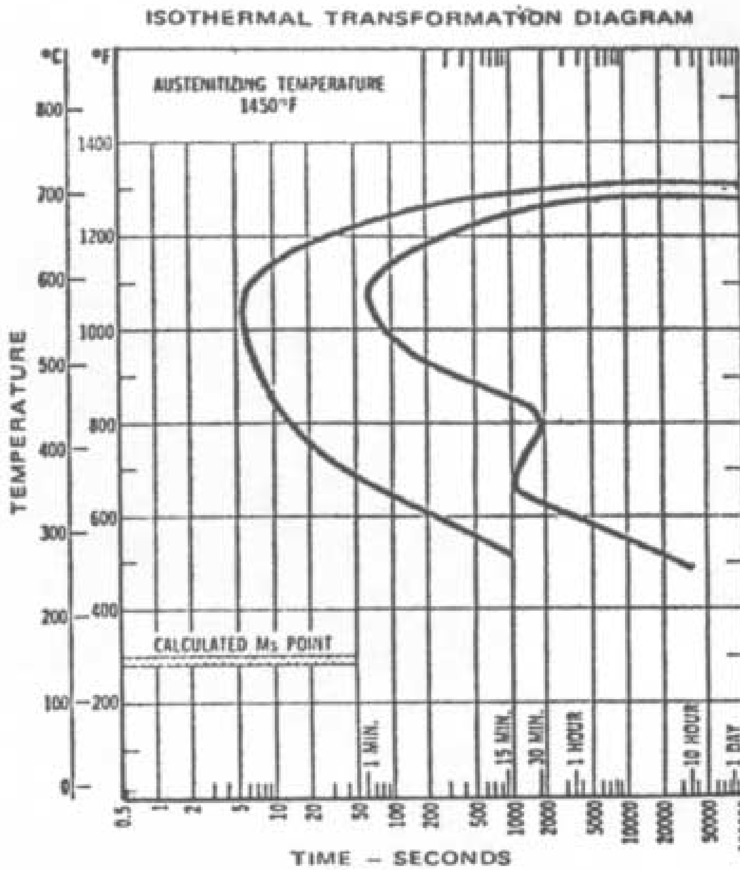

Fig. 2

be seen from the Isothermal diagrams, Figures 1 and 2, heat must be removed at a rapid rate in order to pass the Pearlite nose of the transformation curve and enter the region of martensite transformation. This high rate of cooling is only attainable by water* or brine quenching. Further, only thin sections (1/4" to 1/2") of this material will fully transform. Figure 2, an oil hardening tool steel, shows that the cooling requirement has been reduced to 4500 degrees per minute. This drastic reduction in the required cooling rate is brought about by the addition of alloying elements such as chromium and molybdenum which slow the transformation time and allow sections up to 2" to fully transform in a suitable oil quench. **

* Water will produce cooling rates of 5000°F/Sec. under ideal conditions.
** Oil quenching will attain cooling rates on the order of 100°F/Sec. dependent on oil type.

Cooling rates on the order of 150 to 500 degrees F per minute can be achieved by modern gas quenching systems. This is illustrated in Figure 3 which is a cooling curve generated from a production furnace. Figure 4

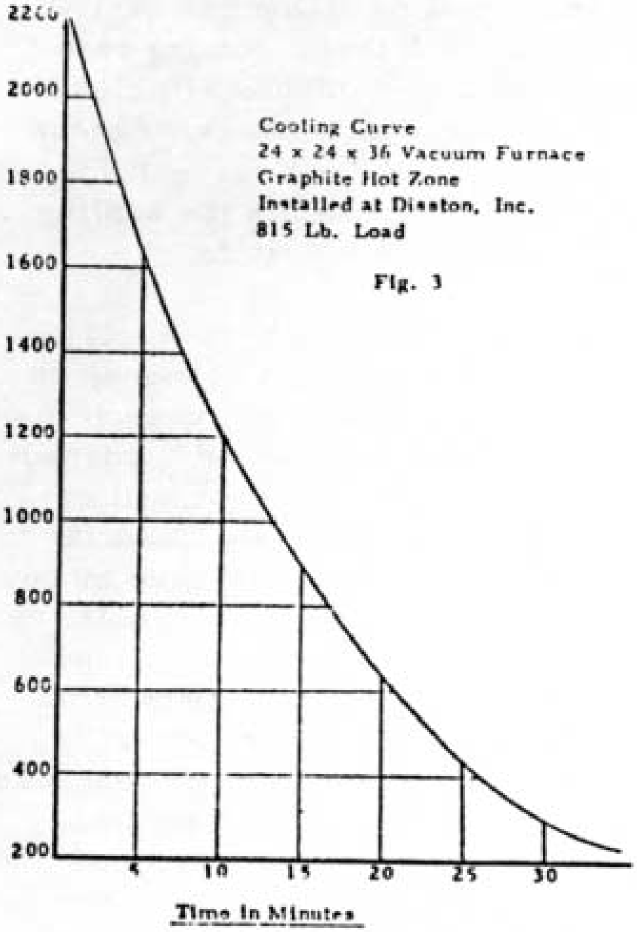

Fig. 3

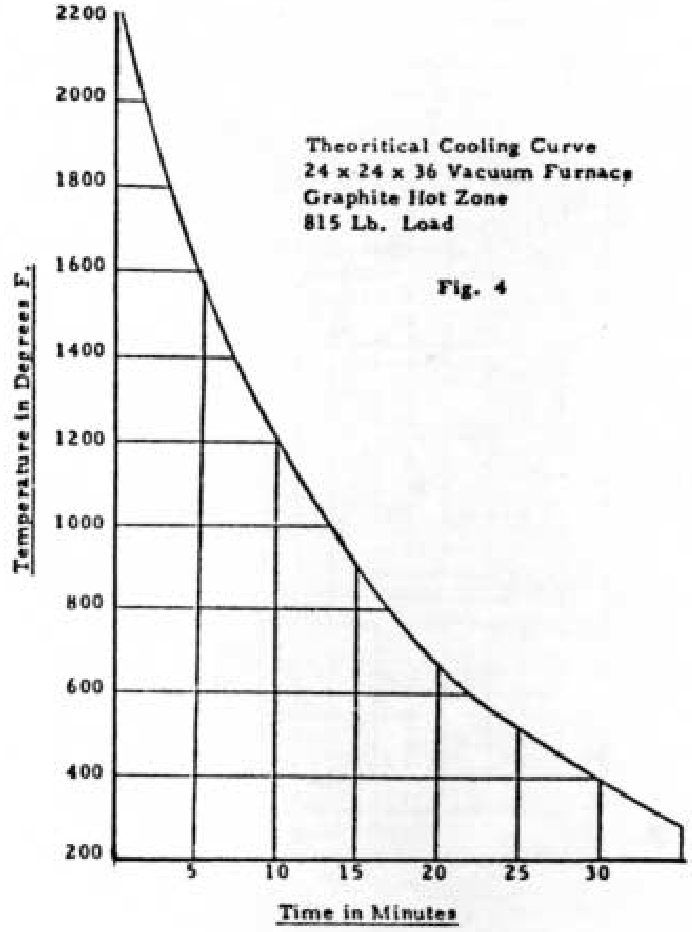

Fig. 4

shows the curve of the mathematical model for the same workload as the load illustrated in Figure 3. Obviously, the model can be substituted when actual test data is not readily available. While these cooling rates in no way compare to the quench speeds of oil or water, they are a vast improvement over earlier gas quenching systems. Recent advancements in blower design and high efficiency heat exchangers are responsible for increasing the cooling rates from the 32 degree F per minute of the old style systems, some of which are still used today, to the 150 to 500 degree F per minute of modern high efficiency systems.

When comparing the cooling rates of a gas quench system to those of oil or water quenches, one might wonder where a system with such a slow cooling rate would fit in the heat treating world. It is intuitively obvious that such a system could not be used to harden even the thinnest section of a water hardening tool steel, and that only in thin sections would one gas quench an oil hardening steel. The obvious question is: What type of tool steels can be gas quenched? The answer is: The group of highly alloyed tool steels known as air hardening steels. They contain high percentages of alloying elements such as chromium and molybdenum and have high carbon contents. This composition moves the Pearlite and Bainite noses to the right (Fig. 5) on the TTT Curve, thus decreasing the cooling rate needed for full martensitic transformation. One can easily see from Figure 5 that a cooling rate of 75 degrees F per minute will clear the pearlite and bainite noses. As can be seen from the cooling curves, Figs. 3 and 4, this is well within the cooling speed of a gas quench system.

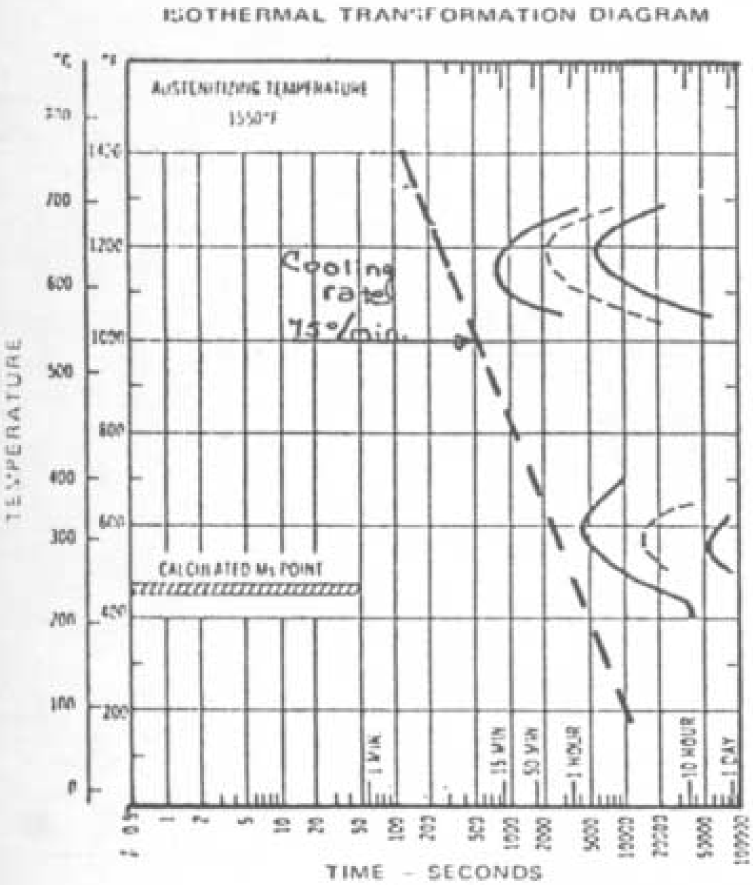

Fig. 5

A legitimate question here would be: Why spend a large amount of money on a vacuum furnace with a gas quench to harden a material that can be hardened by air cooling. This question will certainly be asked by corporate financial people. The answer is: To save money and produce a better, more reliable product. Aside from the basic reduction in operating costs associated with vacuum furnaces, there are other savings by using a gas quench. Because the parts are processed in a neutral environment, they may be machined very close to the finished dimensions in the soft state, thus reducing the finish machining time required and the wear on tools and grinding wheels as well as reducing labor. This is possible because the gas used for quenching is inert (i.e.: Argon or Helium) and will not react with the surface of the material to cause decarburization or scaling, as is the case if the material was air cooled.

The aforementioned benefits from gas quenching are derived from a system that is vacuum tight and when high quality gas is used as a quenchant. This means that the benefits to be derived are directly proportional to the quality of manufacture of the equipment and the quality of gas the user purchases. It should be pointed out that although air hardening tool steel was used as an example to show the benefits of gas quenching, it is not the only tool steel capable of being gas quenched.

There are also groups of tool steels which fall in hardenability between air hardening and oil quenching steels. Some of the steels in these groups are able to be hardened by gas quenching. Table 1 is a partial listing of the AISI designations of the steels that are readily hardenable by gas quenching. One of the most noteworthy groups in this listing is the High Speed Steel group. High speed steels are used extensively in the manufacture of cutting tools for both the metal and wood working industries and account for the major portion of tool steel heat treated.

Heat Treating of Steels

Tool

S-7
A-2 to A-10
D-1, D-2, D-4, D-5, D-7
H-10, H-11, H-12, H-14
H-19 to H-25 in thin sections
6F3 - 6F7, 6H1
T-1 to T-9
M-1 to M-44

Table 1

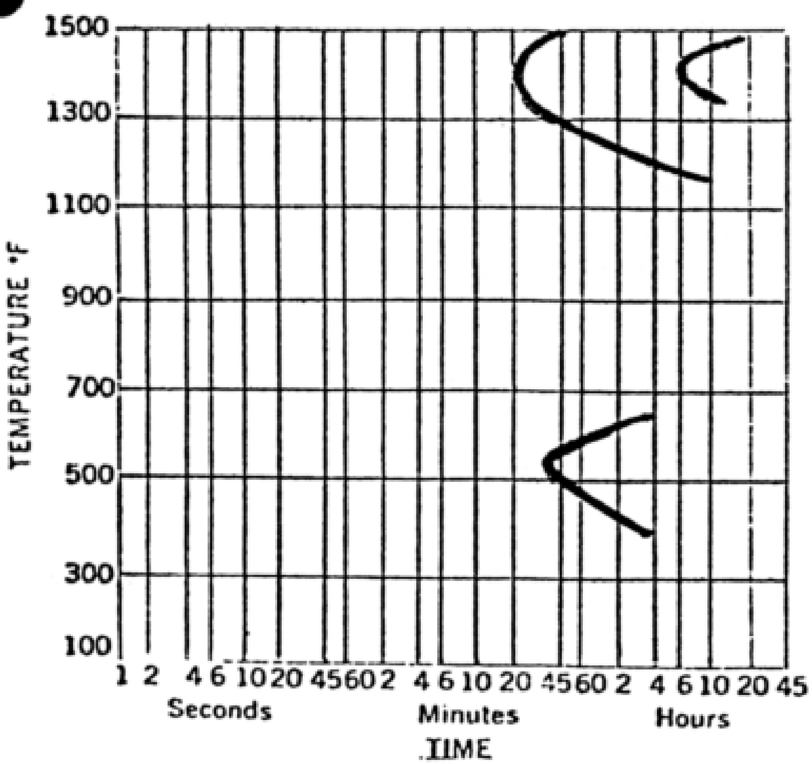

Fig. 6

Let us select a steel from the High Speed Group to illustrate the method of determining the applicability of gas quenching. For the purpose of this discussion, type M-2 high speed steel is selected. All one needs to determine if a steel may be gas quenched is an Isothermal Transformation Diagram for the steel in question (Fig. 6) and a cooling curve applicable to the furnace in which the steel is to be hardened and the load size. It is important that the cooling curve be generated from a load similar in size and weight to the load in question. For example, consider the cooling curve in Figure 3. This curve was generated in a furnace installed at Disston, Inc. in Seattle, Washington. The load was 815 lbs. of 1/2" thick tool steel planer blades. Having the above information, all one need to do is to compare the time and temperatures of the pearlite and bainite noses with the cooling performance of the furnace. This may be done by simply comparing temperatures and time or by plotting the cooling curve on the I. T. diagram as is illustrated in Fig. 7. If the plot shows the cooling is such that both the pearlite and bainite noses are cleared, as is the case in this plot, one may assume the steel will respond to gas quenching. In fact, the 815 lb. load we used to generate the curve in Fig. 3 was type M-2 tool steel. Disston routinely hardens heavy loads of type M-2 as well as air hardening tool steel. To date, sections of up to 1-1/2" have been successfully hardened at the Disston installation.

When an actual cooling curve is not available one may use a curve generated by the mathematical model. While the model is most useful, it is best to be sure the plotted cooling curve clears the pearlite nose by a substantial margin to accommodate and differences between predicted and actual results.

There is another factor to be considered when considering gas quenching. The shape of the part will determine the ease with which the heat is removed, and ultimately, the cooling speed of the quench. While the same thing holds true for liquid quenches, their speed is so high that the few degrees per minute lost due to shape will not even be noticed. This is not the case with gas quenching.

In determining the applicability of gas quenching to a part one must consider the surface area to volume ratio of the part as well as the hardening characteristics of the material from which it is made. Parts such as Planer blades with high surface area and low volume are ideally suited to gas quenching. At the other extreme, a part, which for all intents and purposes is a sphere, would be the poorest choice for gas quenching. Table 2 lists some types of parts which would be good candidates for gas quenching. This is not by any means the only parts suitable for gas quenching, it should be used as a guide in determining whether or not you should consider gas quenching your parts.

In review, to determine if gas quenching may be applied to a tool or die, three things must be examined:

1. Is the cooling speed necessary for full transformation within the range of the gas quench system?

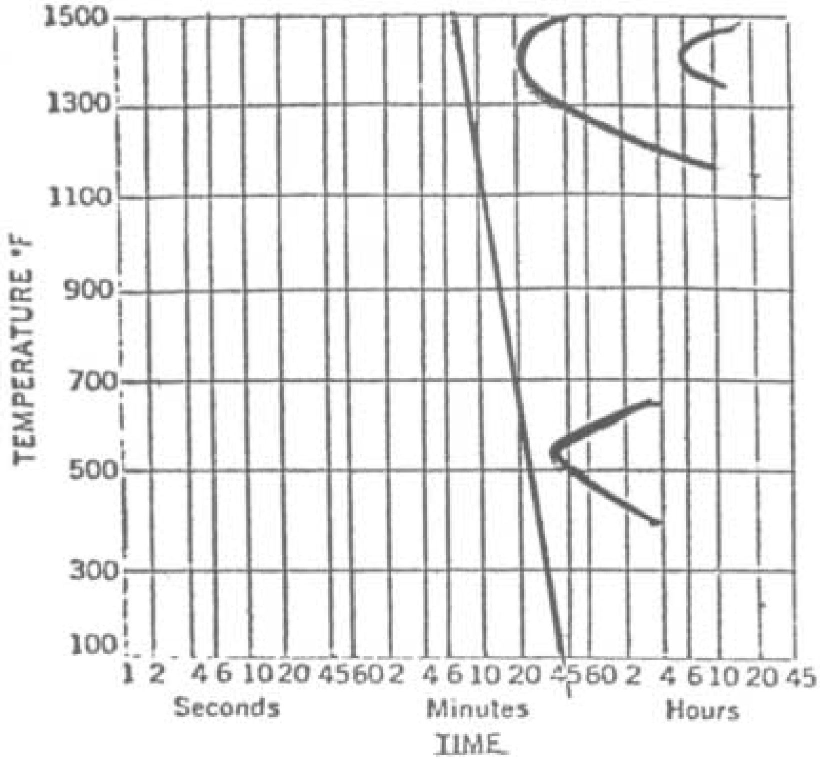

Fig. 7

Examples of Tools & Dies that may be Hardened by Gas Quenching
(by type of material)

Type of Steel	Type of Tool
S-7	- Hot forging punches, dies, cold working dies and punches.
A-2 to A-10	- Large forming dies, trimming dies, feed fingers, precision tools, shear blades, spindles, mandrels, master hubs, coining dies, plastic molds.
D-1 to D-7	- Blanking dies, slitting cutters, cold heading tools, long punches, master tools, drawing dies, intricate punches, extrusion dies.
H-10 to H-14	- Hot forging dies, aluminum extrusion dies, hot piercing and forming punches, bolt dies, die casting dies.
H-19 to H-25	- Punches, hot shear blades, hot piercing punches, small extrusion dies.
6F3 - 6F7 - 6H1	- Hot forging tools and dies.
T-1 to T-9	- Lathe tools, planer tools, taps, hot punches, gear cutters, milling cutters.
M-1 to M-44	- Drills, taps, saws, reamers, broaches, form cutters, end mills, wood knoves, thread chasers, lathe tools.

Martensitic Stainless Steel

Table 2

This is found from the Isothermal Transformation Diagram for the steel from which the part is manufactured.

2. Does the furnace in which the part is to be hardened have a gas quench which will cool a load similar to the one in question with the required speed? Not all gas quench systems cool at the same rate. This can be determined from a cooling curve generated from the furnace in question.

3. Does the part lend itself to gas quenching? If it has a high surface area and low volume, it is a good candidate for gas quenching.

If all the above criteria are positive, then you should not hesitate to try gas quenching. If there are some questionable areas, it would be best to run test samples. If you are buying new equipment, consult your furnace manufacturer, he will be able to give you guidance in the area of gas quenching.