DIE CASTING ENGINEER

Official Publication of
THE NORTH AMERICAN DIE CASTING ASSOCIATION (ISSN 0012-253X)

Advances in Heat Treatment of Premium H-13 Die Steel Announced, NADCA Die Materials Committee Writes New Standard

John A. Fitzgerald
Chairman, NADCA Heat Treatment Task Group
Manager, F.P.M. Heat Treating, Elk Grove, Illinois

The creation of the NADCA 207-90 specification for Premium H-13 has been widely accepted as the standard for defining H-13 steel quality. Standardization of a heat treating specification became the next needed improvement. A task group comprised of members of the NADCA Die Materials Committee has worked for the past two years to write a heat treating standard that will optimize the capabilities of Premium H-13. The task group is made up of technical representatives from four major producers of Premium H-13, three leading die steel heat treaters, two die casters, and an independent metallurgical testing laboratory.

Introduction

North America's aluminum die casting industry has suffered hundreds of millions of dollars in lost production time and replacement tooling costs due to premature die failure. Many of these die failures are the result of inadequate heat treating processes that yield inferior mechanical properties. Good steel properties provide resistance to thermal fatigue, heat checking and catastrophic failure that often is the result of low fracture toughness and impact strength.

Over the past several years, Premium H-13 and other similar grades of hot work steel have been improved with costly remelting and refining processes. NADCA, in its 207-90 specification has set the standard for microcleanliness, annealed microstructure, and the impact strength capability of Premium H-13. Many die casters and die builders are now specifying high quality "premium grade" die steels but are not specifying the corresponding high quality heat treatment. Understanding and requesting a heat treating process that optimizes desired properties can significantly improve die life.

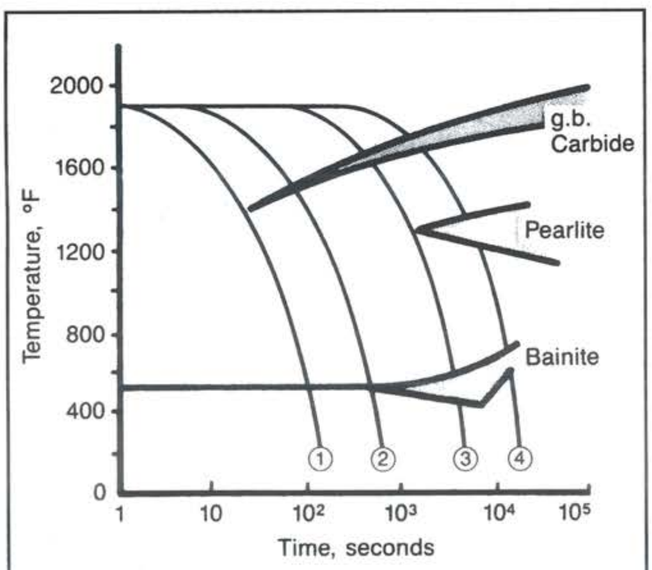

Fig. 1. Continuous Cooling Transformation diagram for Premium H-13 die steel.

Specifications

Only a few of the largest die casters, end users and tool builders have the engineering and metallurgical resources to write meaningful heat treating specifications. Unfortunately, without an industry standard for heat treating, there is no clear mandate for commercial heat treaters to modernize their hardening furnaces and lab facilities. The high capital expenditure for modern, fast quenching furnaces poses a double risk. In addition to high cost, an increased potential for die distortion and possible quench cracks exists when hardening a die steel for maximum mechanical properties.

As long as hardness is the only requirement placed on the heat treater, outdated, less costly methods of heat treating will prevail with die casters and tool shops suffering the consequences. While many in the industry have heard or read something about how fast quenching in heat treating can improve die life, few understand how to specify it. In an attempt to improve their standards, tooling engineers and purchasing agents are beginning to add to their heat treating hardness specification terms such as, "fast quench," "two-bar quench," "five bar quench," "cool at 30°F per min," "heat treat to the NADCA spec," or another well-known automotive specification.

What do these terms mean to the average heat treating shop? What type of equipment, technology, and know-how is required to meet the objectives of the industry and reach the metallurgical and mechanical potential that premium die steel was designed to meet? The objective of this article is to answer these questions. In doing so, this author intends to demonstrate that one of the easiest and most cost effective methods of improving die life and reducing die related downtime is to understand and specify what will henceforth be known as "Premium Heat Treating" for premium grade die casting steels. These new specifications are now being finalized for publication as a new standard for heating treating premium H-13 by the Heat Treating Task Group of the NADCA Die Materials Committee. The standard is being readied for publication in early 1997 (see accompanying article).

Review of Metallurgical Objectives

The quenching process is the most important of all the processing steps involved in tool steel heat treating. In order to understand how to achieve the greatest possible thermal fatigue resistance and impact strength, which resists heat checking and gross die failure, one must review the CCT (Continuous Cooling Transformation) diagram (Fig. 1). For H-13 the required quench rate, which eliminates the formation of undesirable microstructures such as bainite and carbide precipitation, is in excess of 100°F per min from austenitizing temperature to below 550°F. This quench rate is used as the standard when measuring the impact strength capability of a steel, as in NADCA 207-90, which specifies an oil quench of charpy specimens.

Quenching massive, complex die shapes at this rate is not wise, however. Quench cracks, excessive distortion and center bulging occur when surface cooling rates greatly exceed the thermal coefficient of heat transfer for a die

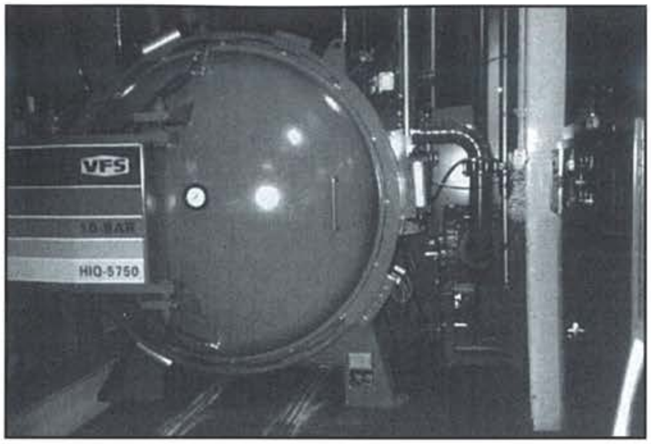

Fig. 2. Shown is a typical high pressure gas quenching furnace.

steel. If the surface of a die hardens unevenly, and rapidly approaches room temperature (where its toughness is low) while the core is still hot, not fully transformed, and is volumetrically expanding as it does transform . . . then quench cracks and/or severe deformation will occur.

The contrary is equally undesirable. Slow quenching below 30°F per min will form high percentages of bainite and massive carbide precipitation in the grain boundaries. This will ultimately result in a die detail that has low impact strength and little thermal fatigue resistance. It will most likely crack in use or heat check prematurely.

The ultimate challenge to a heat treater is how to achieve minimal carbide precipitation at the grain boundaries, minimal bainite formation and as close to 100% martensitic transformation as possible without quench cracking or severely deforming the die.

Required Furnace Equipment

The 1990s answer is a sophisticated computer controlled vacuum furnace (Fig. 2) with a positive pressure quench that has the ability to cool the surfaces of die steels at rates approaching or exceeding 100°F per min, while monitoring and controlling the rate of cooling based on the temperature differential between the surface and core of the die. The furnace must also be able to isothermally hold or maintain a surface temperature just above the Martensite start (Ms) of transformation when the core temperature exceeds the surface temperature by more than 200-300°F.

Today, the best method of achieving this goal is with a 5-10 bar positive pressure gas quenching furnace (Note: 1 bar = 14.7 psi [760mm Hg]). The modern high pressure vacuum furnace is environmentally friendly with a cold wall, water jacketed, high pressure vessel surrounding the hot zone. With no flame or exterior heat it can be operated in a lab like environment by an experienced tooling technician. The electrically heated, computer controlled hot zone provides an oxygen or scale free environment for the heated tool load. Quenching is facilitated by use of a several hundred horse power blower that circulates the compressed or pressurized gas atmosphere through a series of evenly spaced cooling vanes. Load thermocouples, placed within parts in the load, monitor and control the heat treating cycle.

Years ago, the best metallurgical properties were achieved in salt baths using numerous salt pots to pre-heat, austenitize and step quench the tool (Fig. 3). The process was messy and dangerous to the operator, and lacked an accurate method of measuring temperature differentials or actual die cooling rate. Surface decarburization also was a problem. Further, die water lines would often fill with salt, which solidified when cooled below 500°F.

With the introduction of vacuum furnaces some 25 years ago a cleaner and more controlled environment was available. Yet these early vacuums were limited in quenching capability. In the '80s, two-bar pressurized quenching with more powerful blowers and larger heat exchangers improved quench rates for small tools.

As the die casting industry grew in the late '80s and early '90s, so did the size of the inserts, cavities, and cores required to produce transmission cases, aluminum wheels and die cast engine blocks. During that time, five-bar pressure seemed to fill the bill. With computerized controllers becoming more advanced, heat treating cycles were actually controlled from load thermocouples inserted in the dies.

Today, with proper thermocouple placement, and the avoidance of unradiused sharp corners from machining, dies can now be quenched relatively safely, at rates approaching 50-100°F per min on the die surface.

Other Factors Impacting Successful Modern Heat Treating

While the quench rate is the major factor in improving impact toughness and thermal fatigue resistance, other factors contribute to overall quality of the heat treating process. Distortion generally is increased when cooling rates accelerate because of the uneven cooling of complex die shapes. Thin sections cool and transform before heavy cross sections do, causing movement in may directions. While the geometry of complex die shapes cannot be changed, several things can be done by the heat treater to minimize distortion.

Proper load configuration is a significant factor in assuring the uniform heating and cooling of complex die shapes. Dies should be spaced and positioned on the furnace grid, or hearth, in such way as to provide the best possible gas circulation to all die surfaces, and to allow the maximum support at high temperatures (Fig. 4).

Thermocouple placement is also critical, since it tells the furnace and operator the difference in temperature between the surface and core, as well as heating and cooling rates. A surface couple placed in a thin section near a corner will often cause the quench cycle to be interrupted prematurely, causing undesirable grain boundary transformation and high bainite concentrations. A thermocouple placed too deep will cause the interruption of quench, or isothermal hold to take place too late, creating a greater risk of quench cracking.

Tempering temperature uniformity and accuracy is critical when attempting to consistently hit a two-to-three-point hardness range. On larger details with radical differences in cross section, it is safer to increase soak time at a more conservative temperature than to temper for a shorter time at a higher temperature. A minimum of two tempers are required.

Hardness is best checked by measuring details over 100 lb. on a calibrated Brinell tester. A second verification can

Fig. 3. The salt pot heat treating process is shown.

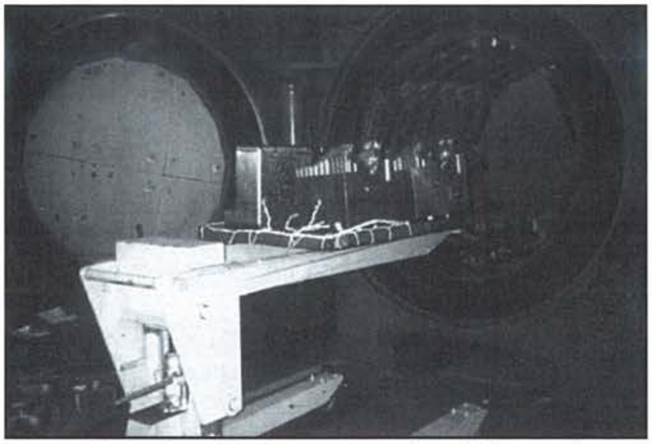

Fig. 4. Optimal positioning and spacing of dies on furnace grid is shown.

be performed in the metallurgical lab after carefully cutting a specimen from the back corner of the die. A wet saw is advisable to prevent burning the test piece.

Capable heat treaters should have a metallurgical lab with a qualified lab technician and staff metallurgist. A minimal lab inspection should include a metallographic examination of a specimen cut from the back corner of all details over 200 lb. The microstructure should be examined at 500X for grain boundary carbides, primary carbides, upper transformation products, and bainite. The current standard for acceptance is Chrysler's NP2080 specification. Furnace quench charts should also be reviewed by the lab technician to correlate quench rate versus structure (Fig. 5).

On large details, usually over 500 lb., where extreme loading is expected or a history of gross cracking has prevailed, Charpy V-notch impact testing is advisable. Since few heat treaters have this capability, the use of an independent metallurgical laboratory is required. Charpy specimens are to be taken from the short transverse direction of the die block. They are usually tack welded to the die detail before heat treating. The results of the heat treated impact toughness are then compared with the steel capability results as a measure of the heat treatment quality. Impact toughness values after heat treatment should be within 80% of the original capability test.

Conclusions

The demands of the die casting and squeeze casting industry today have created a large market for premium grade die steels. Today's Premium H-13 has the potential to resist heat checking and gross die failure significantly better than steels produced five years ago. It is now the grade of choice.

A proper heat treatment is critical for these premium steels to reach their mechanical potential. Significant cost saving and reduced die related downtime will be realized by the die casting industry when the standard for heat treatment is expanded beyond Rockwell hardness to include quench rate and measurements of toughness and microstructure.

Conscientious die casting engineers and tool builders should audit their heat treaters' capabilities and avoid sources that lack laboratory facilities and controlled fast quenching furnaces. The steel companies that produce Premium H-13 to the NADCA 207-90 specification are a good source for heat treating recommendations. A die steel's performance is dependent on the quality of the heat treatment it receives after rough machining. It is in the best interest of the steel producers to suggest sources and processing specifications that will optimize their steel's performance. The new NADCA heat treating standard has been endorsed by the top producers of Premium H-13.

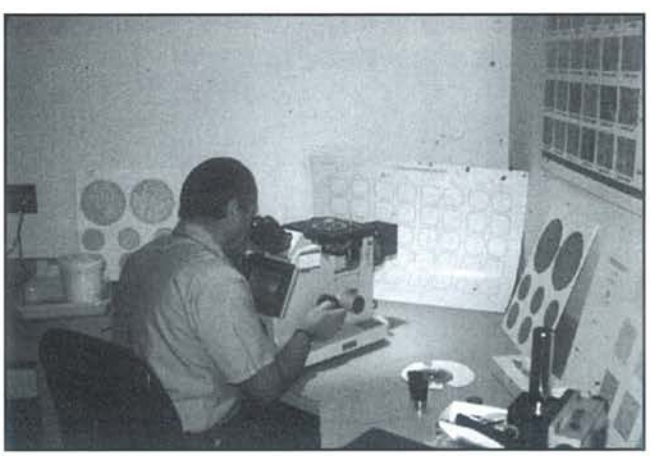

Fig. 5. A technician in a typical metallurgical lab examines a die specimen's microstructure, comparing it with furnace quench charts.

New NADCA Heat Treating Standard for Premium H-13 Complements NADCA 207-90 Steel Acceptance Criteria

One of the easiest and most cost effective methods of improving die life and reducing die related downtime is to understand and specify "Premium Heat Treating" for premium grade die casting steels. These new specifications are now being finalized for publication as a new standard for heating treating premium H-13 by the Heat Treating Task Group of the NADCA Die Materials Committee. The new standard is being readied for early 1997 publication by NADCA.

Today's Premium H-13 has the potential to resist heat checking and gross die failure significantly better than steels produced just five years ago. It is now the grade of choice.

But a die steel's performance is dependent on the quality of the heat treatment it receives after rough machining. A proper heat treatment is critical for these premium steels to reach their mechanical potential. The new standard complements the existing steel acceptance criteria by emphasizing this crucial relationship.

Significant cost saving and reduced die related downtime will be realized by the die casting industry when the standard for heat treatment is expanded beyond Rockwell hardness to include quench rate and measurements of toughness and microstructure. Standards for these processes and properties have been formulated by the Heat Treating Task Group and will become an important, consistent standard for utilization by the entire die casting, die steel and heating industries upon publication. The ultimate value will be to the die caster, who will be able to use them to realize the great benefits of increased die life.

The industry professionals who serve on the Heat Treating Task Group and who made their knowledge and expertise available to put together this important new document are: Terry Bachmeier, Thyssen Marathon; Kjell Bengsson, Uddeholm; Corwyn Berger, Bodycote Taussig; Guy Brada, A. Finkl & Sons; Herb Brucher, Howmet; Carl Dorsch, Crucible Steels; John Fitzgerald, F.P.M. Heat Treating; Rod Pressey, Thyssen Marathon; Patrick Roche, Uddeholm; Mark McCormick, Paulo Heat Treating. John Worbye, Thyssen Specialty Steels, who passed away in September 1996, also contributed to the project.