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Heat Treatment of Large Components

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Large gear components can be offered in many applications such as in marine, wind power, steel rolling mills, power plants, transportation, railroad, aircraft, cement crushers, mining and oil industry applications.

There are three important surface hardening methods used to improve and expand the technical use of gear components. Design and material engineers must decide which hardening method to use. Case hardening is normally the first choice because of the highest load capacity. But, case hardening also poses challenges that must be acknowledged. Therefore, it is good to know that there are three options for very large components.

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Introduction

Large gear components can be offered in many applications such as in marine, wind power, steel rolling mills, power plants, transportation, railroad, aircraft, cement crushers, mining and oil industry applications.

There are three important surface hardening methods, as seen in Figure 1, used to improve and expand the technical use of gear components. Design and material engineers must decide which hardening method to use. Case hardening is normally the first choice because of the highest load capacity. But, case hardening also poses challenges that must be acknowledged. Therefore, it is good to know that there are three options for very large components. So first, let's compare these methods.

Three methods compared

Case hardening is normally carried out at temperatures between 880°C to 980°C for carburizing, and 780°C - 860°C for hardening. The standard or normal procedure is gas carburizing. By diffusion of carbon into the surface and quench hardening, the process produces a strong hard surface layer of martensite of up to 10 millimeters. This thermochemical method adds defined quantities of carbon to the workpiece by using a carbon enriched gas (i.e. methane (CH₄) or propane (C₄H₈)). After carburization, the components are hardened and tempered to the required surface hardness and to relieve internal stresses. In addition to a high surface hardness (max 850 HV) and abrasion resistance, the heat-treated workpieces exhibit good reverse bending and fatigue strengths due to residual compressive stress. Specific time and temperature variations in the carburizing, hardening, and tempering processes can be introduced to optimize the material properties and minimize the changes in dimensions associated with the respective charging techniques - hereto lies the art of hardening.

Nitriding treating temperatures range from 500°C - 580°C for gas nitriding and from 400°C and up for plasma nitriding and plasma nitrocarburizing. Nitriding is a method for enriching the surface layer of ferrous materials with defined quantities of nitrogen or, in the case of nitrocarburizing, of nitrogen and carbon. This not only enhances the hardness, but also the abrasion resistance, fatigue strength, corrosion resistance and antifrictional properties. Furthermore, there are no microstructural transformations from austenite to martensite, so high dimensional stability is ensured.

Normally, nitriding penetrates to a maximum depth of 0.8 mm. "Profundinieren", a deep nitriding method developed by Dr.-Ing. Helmut Reese, penetrates to depths exceeding 1.0 mm, depending on the material. Provided that the corresponding steels are used, non-deforming nitriding is in many instances a viable alternative to case and surface hardening. Nitriding steels are listed under DIN 17211 and EN 10085.

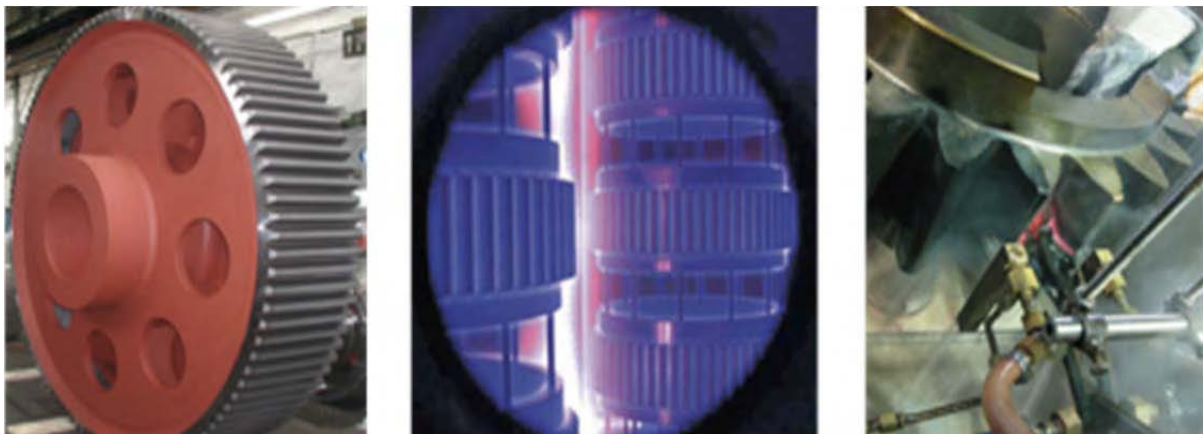


Figure 1. The three important surface hardening methods from left to right are case hardening, nitriding, and induction-flame-hardening respectively

Surface hardening is carried out at treating temperatures 50°C – 100°C above the material-specific hardening temperature. The heating can be done by flame, induction, laser- or electron beam. These processes produce a hard surface layer of martensite. These methods can also be used to harden large components or complex geometries. Induction or flame heating is applied to the heavily loaded areas (specific surfaces) of the workpiece until the respective hardening temperature is reached, after which the workpiece is quenched. Much experience is necessary for optimizing the methods and finding component-based solutions for both flame and induction hardening. Much experience is necessary for optimizing the methods and finding component-based solutions for both flame and induction hardening. Therefore the evaluation and consistency of test samples is essential and is greatly enhanced by specific definitions of machine parameters. In summary, surface hardening is a technical and economical alternative to conventional case hardening in many instances.

A side-by-side comparison of the three surface hardening methods can be seen in Table 1.

The choice and selection of the hardening method

For the load capacity of a component, the important factors are hardness, case depth and core strength:

- If the load capacity of the gear is vital, case hardening is the first choice, even if the hardening distortion during nitriding is less.
- If Hertzian pressures are low, as in hydraulic cylinder applications, and low hardness depths are sufficient, nitriding is the first choice.
- Large hardness depths in a short time, partial hardening of large components, and flexibility are assets of the surface layer hardening

The load capacities of the three hardening methods can be compared using Figure 2 where fatigue strength is measured against hardness.

Because of the highest load capacity, case hardening is the first choice for the treatment of large transmission components.

Table 1. Comparison of three surface hardening methods (pros and cons)

	Case hardening	Surface hardening	Nitriding
Pros	• Large case-hardening depths (CHD) of up to 10 mm, which can be achieved within treatment times of 10 to 200 h • Very hard surface layer • Very tough core • Excellent fatigue resistance by surface compressive stresses • Good under impact stresses • High surface pressure	• High surface hardness depths (SHD): 2≥30 mm is possible, which can be reached in a short time of treatment with a relatively low energy consumption. • Hard surface layer • Tough core • Good fatigue strength • Good bending and torsion resistance	• Low treatment temperatures result in minimal dimensional and shape changes and therefore rework is seldom necessary • Limited accessible areas can be hardened • very hard surface layer, depending on the material • Tough core • Good fatigue properties • Improved corrosion resistance • Very thermostable • Improved sliding properties
Cons	• Due to the high processing temperatures, martensitic transformation and quenching, considerable dimensional changes and hardening distortions can occur. • Not to be used above tempering temperature • Little corrosion resistance	• Hardness depths below 2 mm difficult • Only with inductor or flame can easily accessible areas be hardened • Increased risk of cracking • Expensive sample hardenings for reproducible results	• Low nitriding depths with a relatively long treatment time, • NHD by definition only 50 HV above core hardness => 1mm NHD is considerably less than 1mm in CHD • Under excessive stress, crack and fracture risk due to high surface hardness

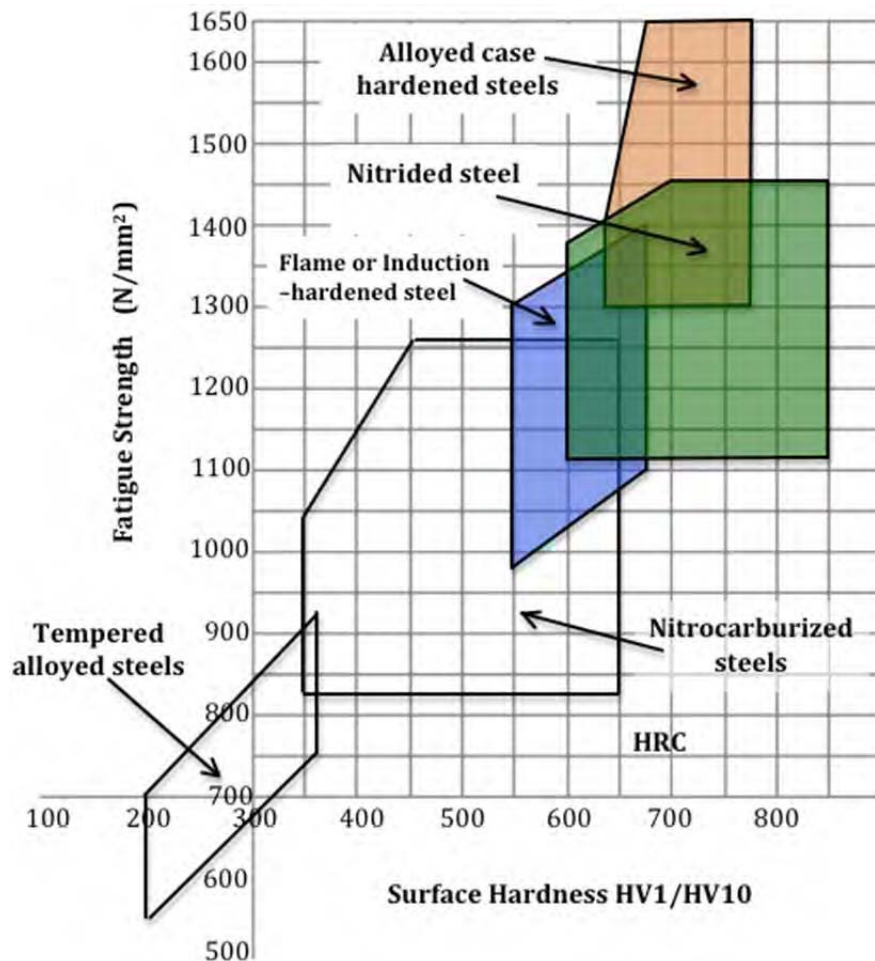


Figure 2. Load capacities of the three hardening methods: fatigue strength vs. hardness
(Niemann/Winter Maschinenelemente)

The main aspects for case hardening of big gear components

Three main aspects have to be considered:

- Hardenability (material selection and geometrical influence)
- Weight (as much as necessary, as little as possible)
- Dimensional changes and distortion

Hardenability

Large components are normally quenched in oil. Cooling below the alloy M_s temperature through to the core often takes longer than 1 hour depending on the size of the cross sections. During this time, the heat is conducting through the surface. Therefore, a steel must be selected, with its ferrite/pearlite nose as far to the right as possible. Otherwise, there will be a significant decrease of the surface hardness and case depth. The larger the cross-sections, the more it is necessary to utilize high alloyed steels.

According to the experience at Reese, for large components with a cross section more than 100 mm, 18CrNiMo7-6 or 18CrNi8, or similar steel qualities with HH-alloying-scatter-band, must be chosen. The two time-temperature-transformation diagrams, Figures 3 and 4, exhibit the differences between a high alloyed and low alloyed case hardening steel.

The alloying elements Cr, Ni, Mo, Mn and V increase the hardenability, and V, Ni and Mo additions increase toughness. If a steel is selected with insufficient hardenability, regardless of intensive quenching in oil with very good cooling and circulation, the result will be an unacceptable drop of hardness and hardness depth of large components. This hardness reduction is evident in gear parts especially below

the pitch circle down to the tooth base to a hardness of partially well below 52 HRC. The components can fail after a short period of time by pitting, flank fractures and tooth root fractures. Using the same alloyed steels from Figures 3, 4, 6 and 7, display the relationship of hardness as a function of the distance from the quenched end. As seen, there is an obviously much larger decrease in hardness as the distance between the quenched end grows with the low alloyed case hardening steel. The graphs created are a result of the Jominy hardenability test (Figure 5).

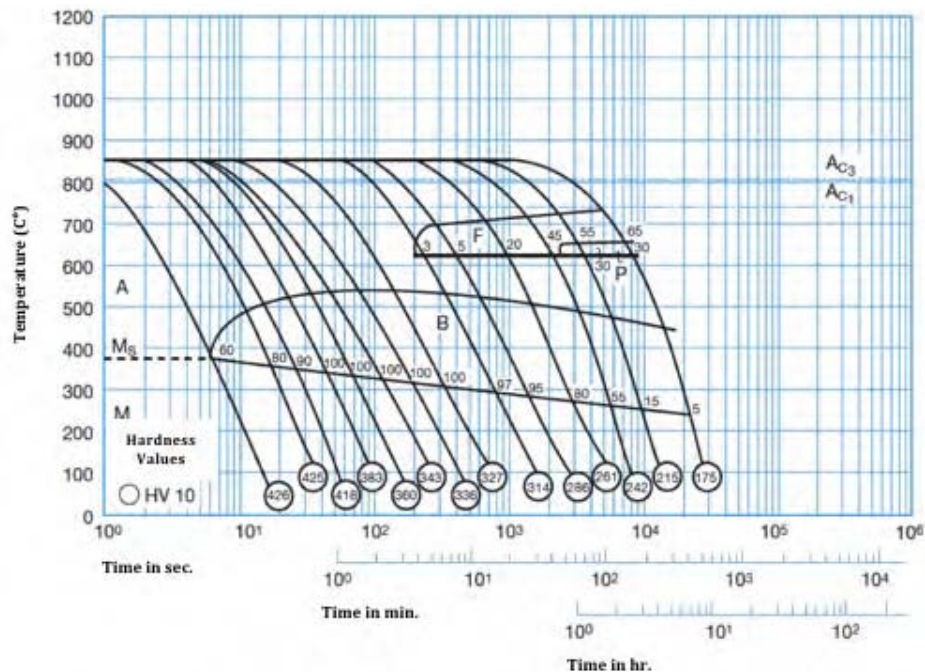


Figure 3. Time-temperature-transformation (TTT) diagram for the high alloyed case hardening steel 18CrNiMo7-6

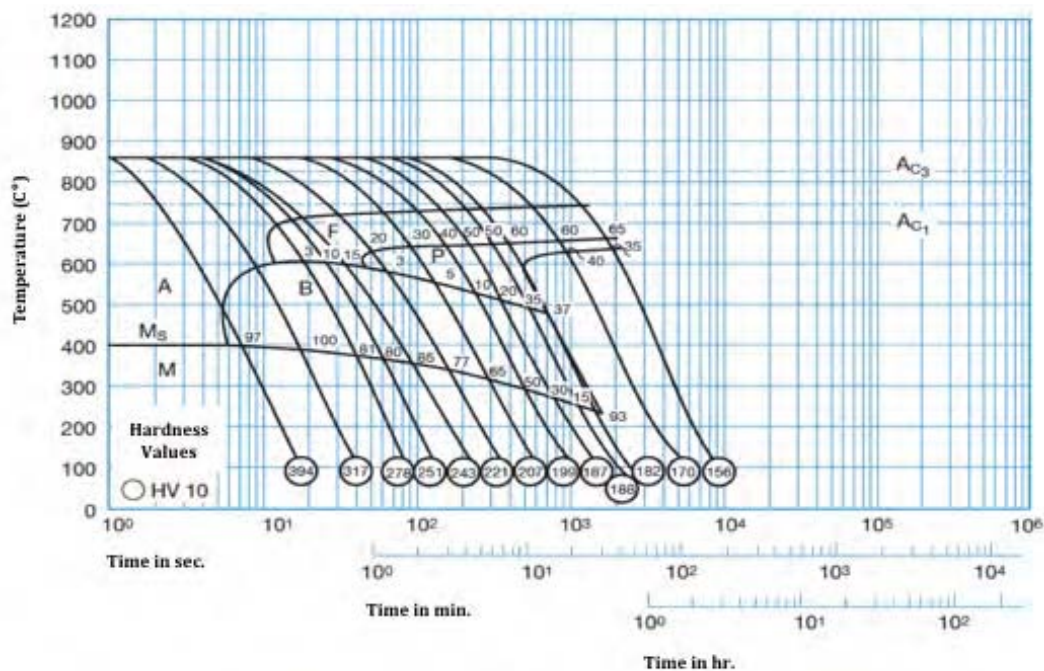


Figure 4. TTT diagram for the low alloyed case hardening steel 16MnCr5.

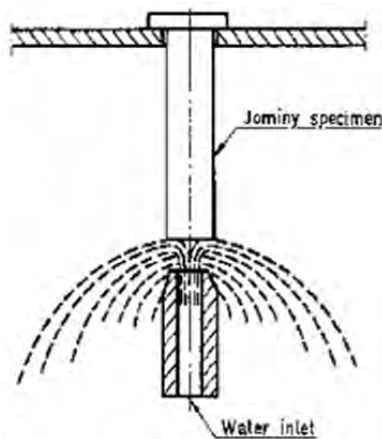


Figure 5. Jominy hardenability test

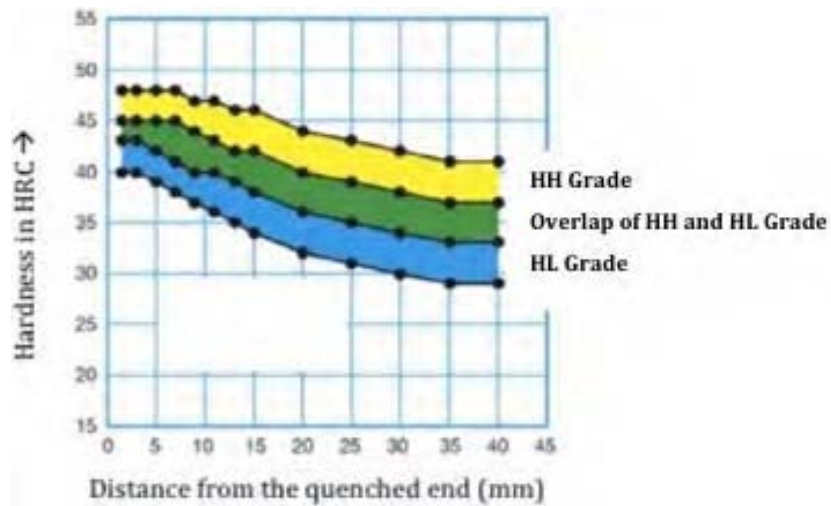


Figure 6. Hardness as a function of distance from the quenched end for 18CrNiMo7-6

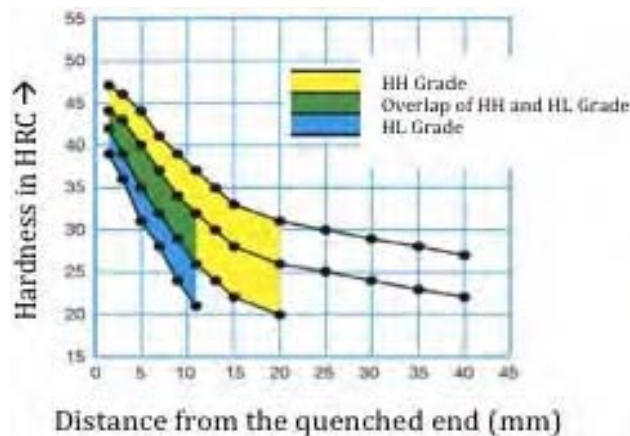


Figure 7. Hardness as a function of distance from the quenched end for 16MnCr5

In the area of decreasing hardness to the tooth root, the CHD cannot be adequately modeled by the cylindrical geometry of a sample coupon. In particular, the geometric conditions and their influence on the cooling rates in massive components cannot be compared with small cylindrical test pieces. Case hardening results of the tooth base and tooth flank in comparison with a small cylindrical sample coupon are not a sufficient match of the carbon depth profile. The coupon sample should therefore be shaped such that it, in addition to a custom size, also has a greater geometrical resemblance to the tooth base. A