

Metallurgical insights for induction heat treaters

PART 4: OBTAINING FULLY MARTENSITIC STRUCTURES USING WATER SPRAY QUENCHING

Entries in the “Metallurgical insights for induction heat treaters” series alternate with those in the “Systematic analysis of induction coil failures” series.

In induction hardening of steel, the ability to obtain a certain degree of martensitic structure is often the measure of the success of the process. Martensite is a supersaturated solid solution of carbon in ferrite with a body-centered tetragonal (BCT) structure. Upon rapid cooling, carbon is trapped in the crystal structure. The high hardness developed in the steel is due to the distortion that occurs during the transformation from face-centered cubic (FCC) austenite to BCT martensite.¹⁻⁴

Martensite 101

Martensite formation is governed by shear-type (diffusionless) transformation of austenite; that is, the transformation occurs almost instantaneously upon reaching a certain temperature. Since the transformation is diffusionless, the initially created martensite plates do not grow in size with time. Instead, new plates continue to form upon further cooling.²⁻⁴

If the continuous cooling transformation (CCT) diagram of steel is shifted far to the left, the cooling curve will enter the upper transformation-start region practically regardless of quench severity, preventing the formation of an entirely martensitic microstructure.^{1,5,6} In such cases, the final microstructure of the hardened layer will consist of a combination of martensite and upper transformation products (such as pearlite and bainite). Although a fully martensitic structure might not be obtained, the amount of upper transformation products can be appreciably small and, depending on the application, might not noticeably affect component mechanical properties.

Temperature range: Martensitic transformation occurs over a temperature range between the M_s (martensite start) and M_f (martensite finish) temperatures. The range depends on the steel’s chemical composition and, from a practical perspective, cannot

be changed by varying quench severity. If quenching is interrupted at a certain temperature within the martensite transformation range, no further transformation to martensite will occur. However, the transformation will resume upon further cooling.

In plain carbon steels, the M_s to M_f temperature range is directly related to the carbon content (Fig. 1). The carbon content and amount of martensite formed directly determine the maximum hardness of a given steel. In the range of 0.2 to 0.65% carbon, the hardness of the steel is proportional to the carbon content.

Retained austenite: M_f temperatures for plain

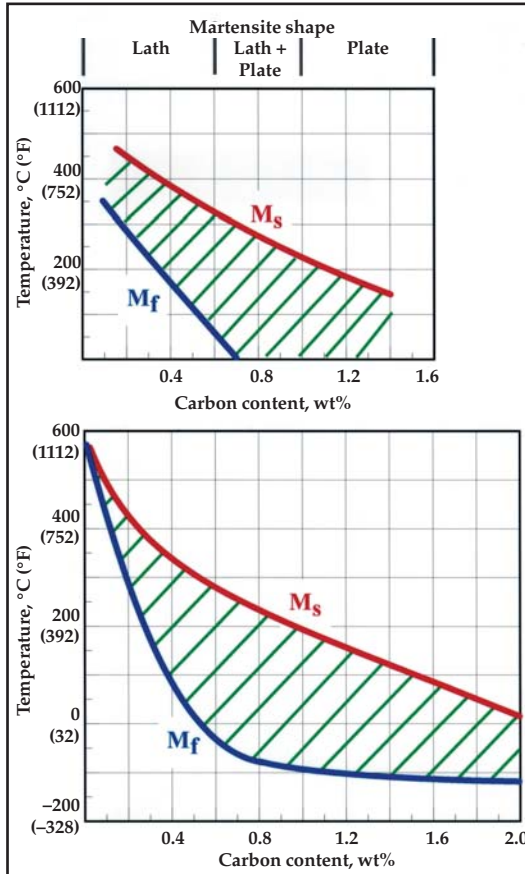


Fig. 1 — M_s and M_f temperatures as a function of carbon content, according to References 7 and 8, top, and Ref. 9, bottom.



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carbon steels with high carbon content, cast irons, and some alloy steels are well below room temperature. Thus, even if quench severity is sufficient to miss the upper transformation region of the CCT diagram, a fully martensitic structure will not be obtained within the hardened layer.¹⁰ The existence of a noticeable amount of untransformed austenite — retained austenite — will be unavoidable (Fig. 2).

In plain carbon steels having a carbon content below 0.5%, the retained austenite is typically less than 2%. As carbon content increases, so does retained austenite, rising to around 6% in steels with 0.8% C and to more than 30% for steels with 1.25% C.⁴

The amount of retained austenite also increases with increasing hardening temperatures. Alloying elements that lower the M_s temperature typically increase the amount of retained austenite. Besides carbon content and alloying elements, the temperature of the quenchant can also affect the amount of retained austenite. Several relationships — the Harris-Cohen correlation for one — have been developed for calculating the amount of retained austenite in a given steel based on the difference between the M_s and quench temperatures.

Two notes: Cryogenic treatment can transform retained austenite into martensite. An untempered fully martensitic structure has low ductility.¹

Induction Case History

In the past, some heat treaters have been confused by observing the presence of nonmartensitic structures in induction hardened parts where, based on conventional metallurgical practice and widely used heat treating diagrams, a fully martensitic structure should have been obtained.

An example follows:

- *Fact 1:* After induction heating and quenching of a steel component there was no evidence of ferrite/pearlite networking. This led the heat treater to conclude that austenitization of the steel had been completed.

- *Fact 2:* Metallographic examination revealed no evidence of excessive grain growth, scale formation, or decarburization, which supported the idea that the final temperature had not been too high. This was verified by measuring the surface temperature of the heated component.

- *Fact 3:* Based on data provided by the steel's manufacturer, the M_f temperature was above the temperature of the quenchant. Quench time and concentration were sufficient to cool the heated component below the M_f temperature and miss the "nose" of the CCT curve.

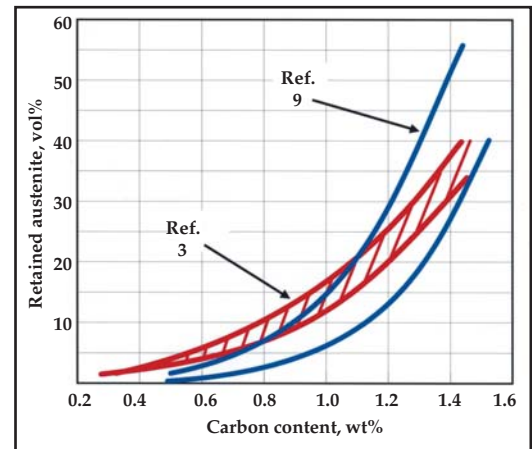


Fig. 2 — Volume percent retained austenite as a function of carbon content. In plain carbon steels with less than 0.5% C, retained austenite content is typically less than 2%. As carbon content increases, so does retained austenite, rising to more than 30% for steels with 1.25% C.

Analysis: These conditions explain why the heat treater expected a fully martensitic structure after quenching. However, metallography revealed a small amount of nonmartensitic upper transformation products.

An improper assumption had been made: The absence of ferrite/pearlite networking in martensite does not mean that homogeneous austenite had been obtained. One characteristic of inhomogeneous austenite is a nonuniform distribution of carbon.

After fast heating, ferrite/pearlite networking may not exist, but there might still be an inhomogeneous distribution of carbon in the austenite. Instead of ferrite/pearlite networking, there could be some localized carbon-enriched areas and regions where the carbon concentration is noticeably reduced. Since both the M_s and M_f temperatures depend upon carbon content, the high- and low-carbon areas of a part having inhomogeneous austenite will have different CCT curves upon quenching. As a result, these areas have different critical cooling rates, and other, nonmartensitic transformation products may appear in the predominantly martensitic structure. A longer time at austenitizing temperature is required to reduce the heterogeneity of the austenite and fix this problem.

Carbon content not only influences the maximum achievable surface hardness and case depth, but also the transition zone. For example, eutectoid steels always have a shorter transition zone compared with that of hypoeutectoid steels (assuming thermal conditions upon heating and quenching are the same).

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