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Martensite transforms to carbides after a sufficiently long time, and is very hard and brittle. To make it a more useful and tougher structure, it is tempered to control the distribution of carbides.

The meta-stable microstructure of martensite

In this column, we will discuss martensite and its formation.

Heat treating steel involves heating the component into the austenite range. Once the part is thoroughly heated into the austenite range and all the steel has transformed to austenite with the complete solution of carbides, the part is then cooled in a controlled fashion to achieve the desired microstructure. If the part is cooled slowly, the microstructure will consist of pearlite and ferrite; if cooled rapidly, the part will consist of martensite. If an intermediate cooling rate is achieved, bainite or a mixed microstructure will result. The required rates to achieve the desired microstructures are governed by the carbon and alloy content. This is shown schematically in Figure 1.

At fast quench rates, that is dependent upon the alloy composition, martensite is formed. It is arguably the most important microstructural constituent of steel. It is this microstructural phase that makes steel hard, and upon tempering, makes steel strong and impact-resistant.

MARTENSITE

Martensite is the name used to designate the hard phase in quenched carbon and alloy steel. Martensite was named after Adolf Martens by Floris Osmond in 1898 [1]. Martens was an early pioneer in metallurgical engineering. His interest in metallurgy led him to develop many of the basic techniques for metallography [2].

In iron-carbon alloys, austenite transforms to martensite on rapid cooling. Because of the rapid cooling, diffusion is suppressed, and carbon does not partition between ferrite and austenite. The composition of martensite is the same as the parent austenite.

Martensite forms a body-centered tetragonal structure (Figure 2). As the carbon level of the martensite is increased, the stretch of the tetragonal axis also increases as a function of the carbon content [3] [4] [5]. This stretch results in the volume expansion of the steel on fast quenching. As the carbon content is increased, the volume expansion also increases. This volume expansion is the major cause of distortion and warpage in steel parts. If the volume expansion is too large, or occurs at a stress concentration, cracking can occur.

Martensite is a meta-stable structure. That is, it will transform to carbides after a sufficiently long time. It is also very hard and brittle. To make this into a more useful and tougher structure, the martensite is tempered to control the distribution of carbides.

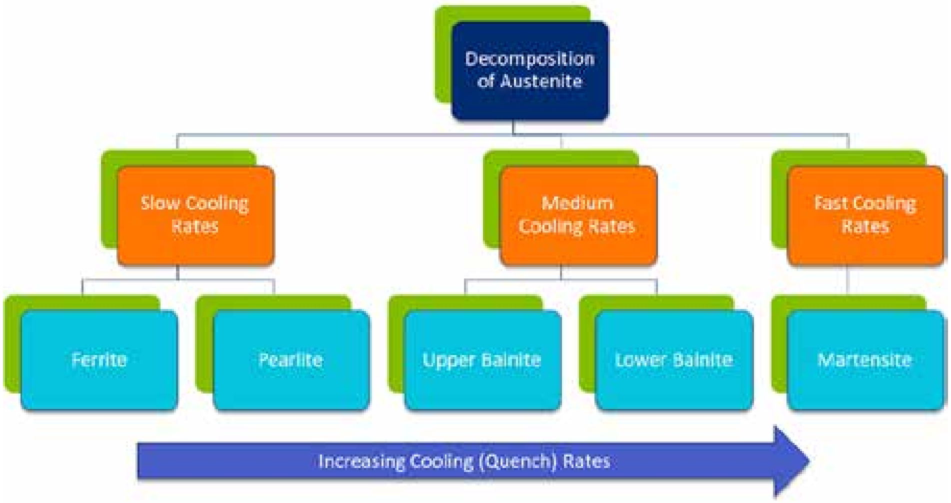

Figure 1: The decomposition of austenite as a function of cooling rates.

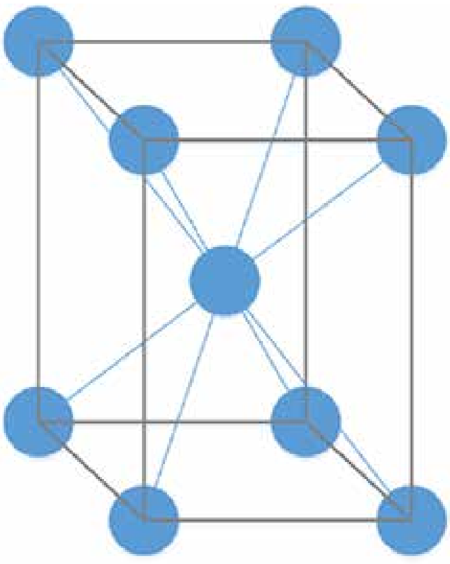

Figure 2: The body-center tetragonal structure of martensite.

The conversion of austenite to martensite takes place continuously while cooling. The mode of transformation is called athermal transformation (meaning without thermal activation). Martensite transformation starts to transform at the martensite transformation temperature, M_s, and ceases on reaching a given temperature. Only additional cooling can drive the transformation further. The martensite start transformation temperature, M_s, decreases with increasing carbon content, and can be changed with different alloying elements. The martensite finish temperature, M_f, is also a function of carbon content and alloying elements. For most steels above 0.30% carbon, the M_f temperature is above room temperature. This can cause significant amounts of retained austenite (austenite present at room temperature) to form. This retained austenite can transform to martensite upon application of lower temperatures, or by sudden shocks.

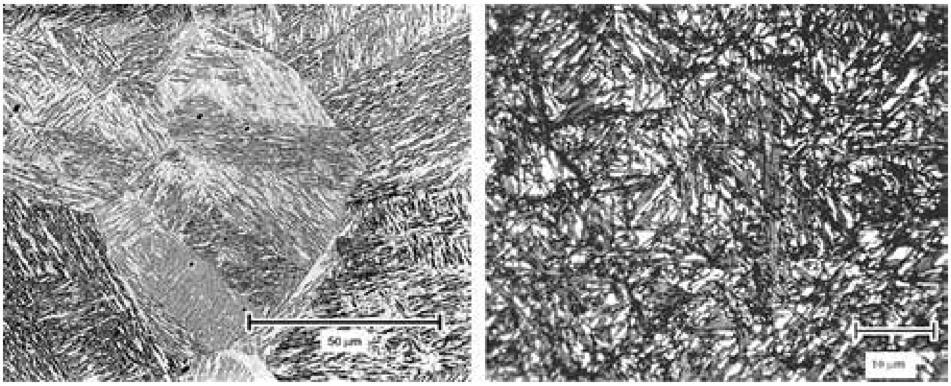

Figure 3: Microstructure of plate and lath martensite in steel. Left: Water quenched AISI 1080 steel showing plate martensite. 10% sodium metabisulfite etch; Right: Microstructure of a water quenched low-alloy steel showing lath martensite. 2% Nital etch.

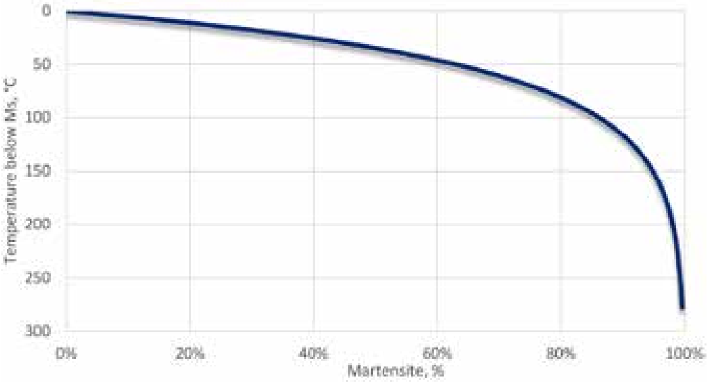

Figure 4: The effect of cooling below the martensite start temperature (Ms) on the percentage of martensite formed.

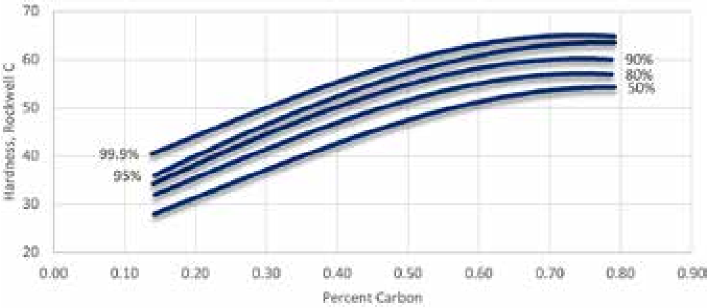

Figure 5: Average relationship between carbon content, hardness, and the percentage of martensite present "as-quenched" [7].

This can contribute to cracking before tempering.

In general, the M_s and M_f temperatures can be calculated from the following equations [6]:

$$M_S(°C) = 499 - 308[\%C] – 32.4[\%Mn] – 10.8[\%Si] - 27[\%Cr] – 16.2[\%Ni] – 10.8[\%Mo] – 10.8[\%W] \quad M_f(°C) = M_S – 215$$

Martensite has the appearance of sharp needles. There are two different types — plate and lath — related to the carbon content (Figure 3). If the carbon content is below 0.6%, the martensite present will have the appearance as laths. If the carbon content is greater than 1%, then the martensite will have the appearance of plates. In intermediate carbon concentrations, mixtures of plate and lath martensite will be present.

If the martensite start temperature (M_s) is known, the amount of martensite formed on quenching can be determined. The effect of under cooling on the percent of martensite is shown in Figure 4. This is important, as it shows that not all martensite is converted by the quench. To completely convert all the austenite to martensite, the quenchant temperature must be approximately 215°C below the martensite start temperature.

For many of the alloys, the M_f temperature is below room temperature. This indicates that there is residual retained austenite. This residual retained austenite must be converted to martensite or tempered martensite either by cryogenic processing or by tempering (or both).

An additional thing to notice for the core and carburized materials, like AISI 8620. The core, with 0.20% C will convert from austenite first, and then the core will transform. This can result in the beneficial compressive stresses of carburized products.

Martensite is hard and brittle. The hardness is only dependent on the amount of carbon present. Alloying does not change the achievable hardness of martensite, but only the depth of hardening. This is because the alloying elements slow the kinetics of pearlite formation and promote the formation of martensite. The hardness increases with carbon content up to approximately 0.70%. This is shown in Figure 5. At the higher carbon contents, some residual austenite remains which must be converted to martensite through cryogenic processing, or by subsequent tempering.

CONCLUSIONS

In this short article, we very briefly described the meta-stable microstructure of martensite.

Should there be any questions regarding this article, or suggestions for additional columns, please contact the writer or editor.

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