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Boron in Steel

Boron addition to steel is a complex subject, and it does not always make our lives as heat treaters easier. Let's learn more.

The Boron Hardenability Effect

An outstanding feature of boron steels is the improvement in hardenability produced by the addition of even a minute quantity of boron. It is generally accepted that a hardenability peak is reached when the quantity of boron is between 3 and 15 ppm[1]. If an excessive amount of boron (>30 ppm) is present, the boron constituents become segregated in the austenite grain boundaries, which not only lowers hardenability, but also may decrease toughness, cause embrittlement and produce hot shortness. The affect of boron on hardenability also depends on the amount of carbon in the steel. The effect of boron increases in inverse proportion to the percentage of carbon present.

Boron must be in its atomic state to improve hardenability, which means that care must be taken during steel production for the boron to be effective. Boron may also become ineffective if its state is changed by incorrect heat treatment. For example, high austenitizing temperatures must be avoided as well as temperature ranges where certain boron precipitates occur.

Hardenability is highly dependent on the behavior of oxygen, carbon and nitrogen present in the steel. Boron reacts with oxygen to form boron oxide (B_2O_3); with carbon to form iron borocementite ($Fe_3(CB)$) and iron borocarbide ($Fe_{23}(CB)_6$); and with nitrogen to form boron nitride (BN). Loss of boron by oxygen is prevented by making the boron addition to silicon-aluminum killed steels and by using good ladle and mold practices. Strong nitride formers (titanium, aluminum, zirconium) protect the boron from reaction with nitrogen. For example, if nitrogen is fixed by using titanium, satisfactory hardenability is obtained in the temperature range up to 1830°F (1000°C) provided that the steel contains about 5-20 ppm of boron.

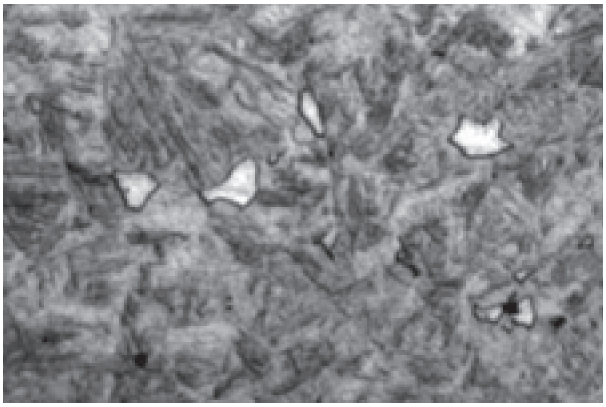

Fig. 1. Core ferrite (500X)

The hardenability of boron steel is also closely related to austenitizing conditions and is generally said to decrease by heating above 1830°F (1000°C). Boron steel must also be tempered at a lower temperature than other alloy element steels of the same hardenability.

Case History 1 – Commercial Heat Treater

Problem description: A commercial heat treater reported low core hardness and localized core ferrite (Fig. 1) after routine inspection of sample lots of steel parts carburized in separate loads. Inspection of subsequent loads using the same cycle failed to show a recurrence of the ferrite condition.

Background: Parts were carburized in a batch integral quench furnace – in one case at a temperature of 1675°F (915°C) and in the other at 1700°F (925°C). Either temperature should have been sufficient to completely dissolve ferrite into austenite (per the iron-carbon phase diagram).

Attempted solutions: The first step was to send parts out for chemical analysis and to compare the chemistry to customer specification and to the material certification. The material chemistry was found to be within specification.

Next, the furnace temperature and temperature uniformity were checked and found to be within acceptable limits. No unusual variation in case depth was found, which would be indicative of austenitizing temperature variation in the carburizing chamber. Additional steps involved increasing load sample size to nine pieces/load and complete microstructural checks. Loading patterns and load weight were monitored.

As an added precaution, carburizing temperature was increased to 1725°F (940°C), necessitating additional checks to look for dimensional changes associated with this higher temperature. Careful monitoring of case depth was also needed because quite often increasing diffusion temperature can add variation in shallow case depths.

Samples containing core ferrite were reheated in a vacuum furnace at temperatures of 1675°F (915°C) and 1800°F (980°C). Core ferrite did not dissolve completely at 1675°F (915°C), but austenitizing at 1800°F (980°C) finally put the ferrite back into solution.

Case History 2 – Captive Heat Treater

Problem description: Ferrite was observed in the core microstructure of 15B21 parts along with variations in core hardness from 93 HRB to 40 HRC.

Background: Parts were initially carburized at 1725°F (940°C) and oil quenched from 1550°F (840°C). A surface hardness of 58–61 HRC was obtained with an effective case depth (50 HRC) of approximately 0.055 inch (1.40 mm). Microstructural examination of parts at 93 HRB (Fig. 2) revealed the presence of ferrite in the core.

Attempted solutions: The first step was to send parts out for chemical analysis (Table 1) and to compare the chemistry to customer specification and to the material certification. The material chemistry was found to be within specification.

The next step was to run parts in different furnaces. A total of seven batch integral-quench and pusher furnaces were used in an attempt to rule out such variables as temperature, temperature uniformity, carburizing uniformity, furnace atmosphere, atmosphere control, quenchant and quench severity. All parts run produced similar results.

Finally, material from a different steel lot was processed to the same set of heat-treatment parameters. The result was consistent core hardness in the range of 34 HRC (Fig. 3).

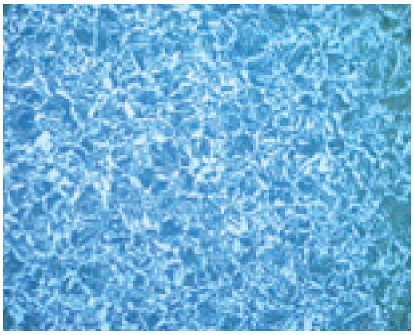

Fig. 2. Core microstructure (500X)

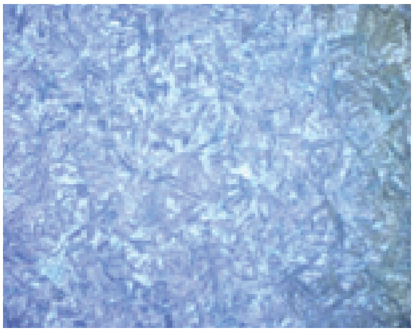

Fig. 3. Core microstructure (500X)

Table 1 Chemistry Comparison

Element	Specification	Part 1	Part 2	Ladle Analysis
Carbon	0.19 – 0.23	0.17	0.19	0.20
Manganese	0.8 – 1.10	0.90	0.94	0.91
Phosphorous	0.040 max	0.021	0.022	0.009
Sulfur	0.050 max	0.012	0.014	0.015
Silicon	0.15 – 0.35	0.22	0.24	0.24
Nickel	-	0.10	0.13	0.10
Chromium	-	0.16	0.19	0.16
Molybdenum	-	0.016	0.024	0.02
Copper	-	0.21	0.17	0.28
Aluminum	-	< 0.01	< 0.01	0.0019
Boron	0.0005 – 0.003	0.0016	0.0023	0.0017
Titanium	-	0.023	0.043	0.035
Niobium	-	< 0.01	< 0.01	-
Vanadium	-	< 0.01	< 0.01	-
Lead	-	< 0.01	< 0.01	-

Note: Nitrogen content was not specified.

Lessons Learned

The heat treater can control many of his process and equipment variables. He/she can design robust boost/diffuse carburizing cycles, minimize retained austenite and intergranular oxidation as well as control carbide distribution. The heat treater can also ensure that the equipment is operating properly, is well maintained and has good temperature uniformity. He/she can load parts in a manner as to maximize heat transfer and aid uniformity of quenching. Sometimes all of this is not enough, however, since the heat treater has limited control over material properties (e.g. alloy segregation, as-received grain size, steel cleanliness).

Both the commercial and captive heat treater in these case studies spent considerable resources and countless hours in an attempt to rule out a process or equipment problem and to find the root cause of the phenomenon. While most heat-treating problems are not material issues, these case studies clearly pointed to the material as the root cause of the problem. Despite the fact that the Jominy readings were within an acceptable range for the steels in question, parts would not harden.

As it turns out, the titanium to nitrogen (Ti:N) ratio in the steel heat is a critical factor. When specifying boron steels, many companies believe a 4:1 ratio (or greater) is needed to avoid the problem of "ineffective" boron. In many cases the effective boron content is not the total boron content. **IH**

References

1. Kobe Steel Technical Bulletin, *Features and Properties of Boron Steel.*
2. Banerji, S. K. and J. E. Morral, "Boron in Steel", Conference Proceeds, The Metallurgical Society of AIME, 1980.

Additional related information may be found by searching for these (and other) key words/terms via BNP Media SEARCH at www.industrialheating.com: hardenability, embrittlement, hot shortness, diffusion, case depth, retained austenite, intergranular, oxidation