

REPORT FOR THE ANTI-DUMPING COMMISSION ON THE EFFECT OF BORON IN STEELS

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1. Advice sought by the Anti-Dumping Commission

The Anti-Dumping Commission has requested the University to provide scientific advice on practical impacts of boron in steel products to assist with their anti-circumvention inquiries. Specifically, the University was requested to address the following questions.

1. What effect does the addition of boron have on HSS and galvanized (flat rolled) steel?
2. At what point, or in what proportion does the addition of boron have a measurable impact on the performance characteristics of HSS and galvanized steel? What are these effects?
3. To what extent do these effects differ according to the processes used to manufacture the product (such as quench and tempering)?
4. Are there any end-use applications of HSS and galvanized steel that contain boron above 0.0008% concentration where the end use is different before and after the addition of boron (i.e. where non-boron goods would not be suitable)?
5. What are these applications, and what are the physical characteristics of the steel necessary to meet the requirements of these applications? For example, can these be determined by the level of boron, the particular production process required (such as quenched and tempered), or by reference to some other characteristic not present in the non-alloyed steel (such as an improved tensile strength)?
6. *Are there any other factors which the Anti-Dumping Commission ought to consider to achieve its objective of not disrupting legitimate trade in alloyed HSS or alloyed galvanized steel?*

The responses to these questions are given in Section 9, following a review of the effects of boron-alloying on the microstructures and properties of steels.

2. Defining an alloy steel

In effect, all steels are alloyed. The principal elements are Fe and C, but even for plain carbon steels, Mn and Si are normally present, together with small concentrations of other elements, deliberately added or present as impurities.

Despite the multi-component nature of most steels, a distinction is made between “unalloyed” and “alloy” steels. However, categorisation into one of these two groups is not always straightforward and in an attempt to resolve this ambiguity, ISO – the International Organisation for Standardization, developed International Standard ISO 4948/1 in 1982 to classify steels into unalloyed and alloy steels based on composition. Table 1 lists boundary values for 19 possible alloying elements (excepting C, N, P and S), and bases the definition of an alloy steel as one containing one or more elements in concentrations equal to, or in excess of, the relevant value in the table. The boundary values were proposed by the Technical Committee ISO/TC 17, “Steel”, and were circulated to member bodies for endorsement. Although twenty five countries, including Australia, approved the International Standard, disapproval on technical grounds was registered by the UK and USA. This outcome indicates that the selection of boundary values is somewhat arbitrary and, in some cases, contentious.

In 2000, the European Standard EN 10020 was prepared by the Technical Committee ECISS/TC 6 “Steels - Definition and classification”. The intention was to align the Standard “as far as possible” with ISO 4948-1 and ISO 4948-2; and with the Harmonised System Nomenclature of the World Custom Organisation (WCO). A few of the composition values defining the unalloyed/alloyed steel boundary differ from those of ISO 4948-1 (Table 1). Specifically, the Al and Si boundary values are higher, 0.3 wt% and 0.6 wt%, compared with 0.1 wt% and 0.5 wt% in ISO 4948-1. This European Standard has the status of the British Standard and has been widely accepted. Moreover, the boundary values are mostly the same as those listed in Chapter 72 (iron and steel) of Schedule 3 of the Customs Tariff Act of 1995. These lists of alloy boundary values all specify that 8 ppm or more of boron qualifies steel as alloy steel.

ISO 4948/1-1982 (E)

Table 1. Unalloyed/alloy steel boundary

| Constituent | Percentage |
|---|------------|
| Aluminium | 0,10 |
| Boron | 0,000 8 |
| Bismuth | 0,10 |
| Chromium | 0,30 |
| Cobalt | 0,10 |
| Copper | 0,40 |
| Manganese | 1,65* |
| Molybdenum | 0,08 |
| Nickel | 0,30 |
| Niobium | 0,06 |
| Lead | 0,40 |
| Selenium | 0,10 |
| Silicon | 0,50 |
| Tellurium | 0,10 |
| Titanium | 0,05 |
| Tungsten | 0,10 |
| Vanadium | 0,10 |
| Zirconium | 0,05 |
| Lanthanides (each) | 0,05 |
| Other specified elements (except S, P, C and N) | 0,05 |

* If only a maximum is specified for the manganese content of the steel, the boundary shall be at 1,80 %.

3. Steel microstructures and basic metallurgical terms

The two primary elements of steel are iron and carbon. The versatility of steel as an engineering material stems from the **polymorphic** nature of iron (the capacity to exist in more than one crystal structure) and the significant strengthening effect produced by carbon. The polymorphism of iron makes steel amenable to heat treatment. At elevated temperatures the stable phase, called **austenite**, has a face-centred cubic (FCC) crystal structure. However, on *slow cooling* of steels containing less than 0.8% C, austenite initially undergoes transformation to a body-centred cubic (BCC) phase, called **ferrite**. A second bi-phase constituent, called **pearlite**, which consists of fine alternating plates or lamellae of ferrite and iron carbide, also forms from the remaining austenite.

The average C content of pearlite is 0.8% and an alloy of this composition has a microstructure of 100 volume % pearlite on cooling to room temperature. For C contents < 0.8%, the microstructure is a mixture of ferrite and pearlite, with the volume fraction of pearlite decreasing with decreasing C content.

The vast majority of commercial steels have C contents much lower than 0.8% and therefore the microstructure that evolves in these steels on slow cooling, by **annealing** (furnace cooling) or **normalising** (air cooling), is a mixture of ferrite and pearlite. Ferrite is typically the dominant phase because the trend in steel design since the 1970s has been to lower the carbon content to facilitate welding.

If steels of this kind are subjected to *fast cooling*, the formation of ferrite and pearlite is suppressed and different ferritic-type microstructures can form: **bainite** – a product composed mainly of ferrite laths and residual interlath “islands” of various C-rich constituents [1]; **martensite** - a phase which has a lath/plate morphology and is supersaturated with carbon; and **acicular ferrite** – which consists of fine multi-variant ferrite laths nucleated from small particles within the austenite grains. The last type of transformation product is common in weld metals [1].

Bainite forms over a higher temperature range than martensite and therefore cooling by rapid quenching in oil or water is usually required to produce martensite. Steels that can readily form bainite or martensite on cooling are said to have a high **hardenability**. Since both of these products have high strength and hardness, heat treatment by **tempering** at intermediate temperatures (200 – 600°C) is frequently employed to increase toughness, with controlled loss of strength.

4. Boron as an alloying element in steel

The outstanding element in Table 1 is boron, which is considered to qualify steel as “alloyed” for a concentration that is at least an order of magnitude **lower** than the boundary concentration of any other element in the table.

This extraordinarily low boundary value arises from the potency of boron in increasing the hardenability of steel by suppressing the transformation of austenite to ferrite and pearlite on cooling from elevated temperatures (above about 850°C) and promoting the formation of bainitic or martensitic microstructures over lower temperature ranges. These latter transformation products significantly increase the strength and hardness at the expense of ductility.

In order for boron to be effective as a hardenability-promoter, it must be present at high temperature as solute atoms that can diffuse to, and segregate at, austenite grain boundaries, thereby reducing their effectiveness as nucleation sites for ferrite grain formation on cooling [2, 3]. Since boron is a reactive element, other elements are required during steelmaking to prevent the formation of nitride, oxide and carbide compounds (BN , B_2O_3 and $\text{Fe}_{23}(\text{BC})_6$). The formation of these compounds reduces the B solute content and the efficacy of B as a hardenability agent [3].

Boron, in combination with Mo, can result in the formation of a bainitic microstructure on cooling of low carbon steel (0.10-0.15%C) over a wide range of rates after hot rolling [3], resulting in a yield strength higher than about 450 MPa. More typically however, boron-containing low alloy steels are designed for use in the quenched and tempered (QT) martensitic condition. Both hot rolled bainitic steels and QT martensitic steels are normally Al-killed to lower the oxygen content and Ti-treated to tie-up N. Although B can increase hardenability at concentrations as low as 5 ppm, the optimum concentration range is 15-25 ppm, because a higher concentration promotes formation of $\text{Fe}_{23}(\text{BC})_6$, decreasing the effectiveness of boron as a hardenability enhancer and reducing the toughness of the steel [2, 3].

Boron promotes hardenability most strongly in low carbon steels and its effectiveness diminishes with increasing carbon content [4].

The addition of B to low alloy steels has become more common in recent decades because of its capacity to strongly increase the hardenability *per se*, as well as enhancing the effectiveness of traditional hardenability-promoting elements such as C, Cr, Mo and V. Moreover, the use of boron allows reductions of the concentrations of other alloying elements, thereby reducing the alloy cost without compromising the alloy hardenability.

5. Welding of steel

Whether the base microstructure of a structural steel is ferrite + pearlitic or bainite/martensite, it is likely to be fabricated by welding in the construction of engineering components and assemblies. Since welding subjects the base steel to high temperatures adjacent to the molten weld pool (in the so-called **heat affected zone**, HAZ), followed by relatively rapid cooling, the austenite present in the HAZ at elevated temperatures has the potential to transform to martensite on cooling, particularly if the carbon and alloy contents of the parent plate are relatively high. This possibility is a serious welding issue because the presence of a martensitic structure with high hardness and low toughness, together with small concentrations of H absorbed in the welding process, can result in **hydrogen assisted cold cracking** (HACC) of the weldment [5].

Welding researchers have proposed a number of empirical formulae for calculation of an index called the Carbon Equivalent (CE). This index is effectively a hardenability predictor based on the parent or weld metal composition. One of most widely used formulas for CE is that proposed by the International Institute for Welding (IIW) [6]:

$$\text{CE (IIW)} = C + \text{Mn}/6 + (\text{Cr}+\text{Mo}+\text{V})/5 + (\text{Cu}+\text{Ni})/15 \quad (1)$$

This formula covers a wide range of C contents and its usefulness is reflected in its incorporation into a British Standard in 1974 [7]. **CE(IIW)** values higher than 0.40 are considered to require welding procedures that ensure that the cooling rate is low enough to prevent excessive hardening of the HAZ. An “excessive” HAZ hardness in relation to susceptibility to HACC is generally considered to be about 350 HV [8], but both lower and higher limits have been proposed. The limiting CE and the maximum hardness are empirically based and a range of carbon equivalent formulas and maximum HAZ hardness values have been proposed in attempting to account for different steel designs.

However, CE is an imprecise predictor of hardenability, particularly of weld metal, as it does not take into account the variables of prior austenite grain size; type, quantity and size distribution of non-metallic inclusions; and the weld cooling rate. These factors, together with the alloy composition, determine the transformation behaviour of the austenite on cooling. Nevertheless, **CE(IIW)** is widely used to provide guidance in the control of the weld heat input and the preheat appropriate for a particular welding process, weld configuration and effective thickness of the plates being welded. These factors control the cooling rate and can be used to reduce hardening of the weld metal and HAZ and to avoid cracking of the weldment.

Early CE formulae did not take into account boron, but the strong effect of B on hardenability is well recognised by the welding industry and modified formulae have been proposed to overcome this shortcoming.

6. Welding of B-containing steels

The following formula for B-containing, low carbon, microalloyed steels was proposed by Ito and Bessyo [9] and was adopted by the Japanese Welding Engineering Society in 1983:

$$\text{Pcm} = C + \text{Si}/30 + \text{Mn}/20 + \text{Cu}/20 + \text{Ni}/60 + \text{Cr}/20 + \text{Mo}/15 + \text{V}/10 + 5B \quad (2)$$

Compared to Equation (1), the effects of the substitutional alloying elements are downgraded relative to C and the strong contribution of B is recognised.

A more recent formula by Yurioka *et al.* [10] is a combined version of Equations (1) and (2) for which the carbon equivalent, **CEN**, approaches **CE(IIW)** given by Equation (1) for C levels higher than 0.18%, and is close to the values given by **Pcm** for C contents lower than 0.16%.

Because of its strong effect on hardenability, the presence of B in steels introduces the requirement of stricter weld procedure control to avoid cracking. This issue has been pointed out repeatedly by various steel industry bodies. One example is a Customer Information guide from Dillinger Hutte, a major German plate steel producer, published in 2014 [11] which points out that adding 8 ppm or more of boron to normally non-alloyed S235JR and S355J2 (EN 10025) hot rolled structural steels can raise the HAZ hardness above the specified maximum of 380 HV, particularly for tack welding, oxy-cutting and welding of temporary assembly aids. The risks of HACC are therefore increased. A similar "Industry Alert" was issued recently by the Welding Technology Institute of Australia (WTIA) [12].

The European Standard EN 10025 is referred to above and it should be recognised, as pointed out in Ref. [13], that steel standards (e.g. for non-alloyed structural steel plate) are likely to differ for different countries across the world. The various standards can be comparable but are rarely equivalent, because of at least small differences in steel compositions and mechanical properties. Therefore, although imported steels may be comparable (or a close match) to steel standards specified in relevant AS/NZS standards, they will not normally be equivalent.

7. Types of B-alloyed steels

7.1 Hot rolled bainitic steels and tempered martensitic (QT) steel

As discussed in Section 4, about 20 ppm of B can promote bainite formation during cooling of controlled-rolled steels. The pioneer steel design was developed in the 1950s by Irvine and Pickering [14] and the main components were 0.1-0.15% C, 1.25 Mn, 0.5 % Mo and 20 ppm B. Since the design of this steel, more advanced B-alloyed designs have been developed to produce hot rolled bainitic steels with outstanding toughness, strength and weldability. To achieve these properties an ultra-low C content of 0.02-0.03% is used, together with controlled rolling and carefully adjusted concentrations of Ti and Nb [15].

Notwithstanding the attractive properties of controlled-rolled bainitic steels, the most widely used type of B-alloyed steel is a low carbon, low alloy steel designed for use in the quenched and tempered condition. Yield strengths are typically above about 700 MPa and can be 1800 MPa or higher. Restricting the carbon content to below about 0.25 wt% ensures that the CE remains relatively low, facilitating fabrication by welding. BISPlate 80 is an Australian-produced tempered

martensitic plate steel (Bisalloy Steels) with a 690 MPa minimum yield strength that is used in applications where a high strength to weight ratio is important, such as building frames, dumper truck bodies, bins, cranes and mining equipment. EM812 steel, which was used for construction of the hull of the Collins Class submarine, is another example of a 690 MPa, B-alloyed, QT martensitic steel.

Many of the traditional higher strength QT alloy steels have higher carbon contents of 0.3 to 0.5 wt% and are used to manufacture components which may not involve welding, such as highly stressed shafts and gears. An example of the American Iron and Steel Institute (AISI) designation for an alloy steel of this type is AISI 4340, where the first two digits show the presence of Ni, Cr and Mo and the last two digits indicate the average C content (0.40%). Yield strengths in the range 850 to 1850 MPa can be obtained by adjusting the tempering temperature of the as-quenched martensite. In recent years boron-alloyed alternatives to these alloys have become available, including lower carbon, high strength alloys (< 0.25% C) with improved weldability.

If the first two digits of the AISI designation are 10 or 15, a Mn content lower than 1% (10) or higher than 1% (15) is indicated. For example, AISI 15B20H indicates a hardenable alloy (H) containing boron (B), an average C content of 0.20% and more than 1% Mn. The B content is typically in the range 5-30 ppm and alloys are available with a wide range of C contents to produce tensile properties in the QT condition that are similar to those for traditional B-free low alloy steels. A boron content of 30 ppm is approximately equivalent to 0.5%C or 1%Ni or 0.3%Mo in terms of hardenability effect [16]. These C-Mn-B steels can be used as replacements for more expensive steels of equivalent hardenability in applications such as drive sprockets, axle components, crankshafts, cutting and punching tools and spades [16].

The European automotive industry, in particular, has embraced these types of alloys for improved crash-worthiness and durability of vehicle components such as pillar reinforcements, roof rails, side-wall members and beams for crash management [17]. The B-alloyed steels are typically low in C and alloy content (e.g. AISI 15B20H or EN 10083 alloy 22MnB5) and can be hot stamped and quenched to produce martensite in a single operation [17]. A tensile strength of about 1500 MPa is typical and allows manufacture of thin lightweight components that result in significant vehicle weight savings. These alloys are also suitable for joining by spot welding.

7.2 Weld filler metals

Another area in which B alloying has been adopted is in the manufacture of welding consumables for producing higher strength weld metals designed for strength-matching with high strength plate or

strip steel components. Boron-alloying of welding consumables has not, however, been universally welcome. In 2008, the Research and Standards Committee (RSC) of the Australian Pipeline Industry Association (APIA) issued a "Boron Alert" about the largely undisclosed use of boron in EXX10 cellulosic electrodes designed for field girth welding of pipelines [18]. Almost universally, maximum boron levels of 5 ppm have been specified by pipeline fabricators because of past experience of serious welding problems for boron-alloyed steels. These concerns apply to high hydrogen cellulosic consumables and increased susceptibility to HACC for weld metal containing more than 5 ppm B. However, other types of consumables do contain boron and have been successfully used. For example, Ti-B consumables can be used for submerged arc welding (SAW) and commercially available, B-containing flux-cored arc (FCA) consumables are used to provide increased weld metal strength with reduced levels of more expensive alloy additions (such as Mn, Cr, Mo and Ni) [19].

However, the effect of boron on weld metal structure and properties is more complex than for wrought steels. Research work by Devletian and Heine [20] established that weld metals produced by gas metal arc (GMA) and gas tungsten arc (GTA) welding were substantially refined in the presence of a B content as low as 6 ppm and C contents of 0.05-0.45%. Grain refinement was found to result from the formation of ferrite allotriomorphs along both cell and columnar grain boundaries that are enriched in Mn and decorated by fine precipitates of borocarbides. Refinement was maximised for Mn > 0.5%, C > 0.18% and intermediate weld cooling rates. These authors subsequently reported [5] that B in the filler is effectively transferred across the arc for GTA and GMA welding using Ar gas shielding and also for the submerged arc (SA) welding process. Using AISI 1020 and AISI 10B20 (17 ppm B) as the base steels and remelting to adjust the B content, Devletian and Heine [5] produced a series of seven 2.2 mm dia. weld filler wires with B contents in the range 0 to 240 ppm. Welding was performed on both B-free 1020 plate and 10B20 plate. They found that for B concentrations between 10 and 30 ppm the weld metal hardness was significantly increased and the tensile strength of notched cross-weld specimens peaked at about 20 ppm, 25% higher than for B-free weld metal. However, a B content of 30 ppm or higher resulted in significant borocarbide precipitation on grain and cell boundaries, and resulted in fracture at a lower tensile stress. Degradation of strength and toughness has also reported for wrought B-steels containing more than 25 ppm of boron [2, 3]. Devletian and Heine concluded that for a B concentration of 17 ppm, the hardness of weld metal was similar to that of the parent plate cooled at the same rate. Although the hardness values were similar, the microstructures were markedly different, implying that different transformation mechanisms occurred during cooling. Moreover, the soluble B content of the weld metal was only about 9 ppm compared with 17 ppm in the wrought 10B20 steel. Although 9 ppm of soluble B is likely to retard transformation of the austenite to a ferrite-pearlite microstructure,

undercooling would also have been promoted by the relatively coarse as-solidified grain size. Transformation of austenite is expected to have occurred over a low temperature range, forming a high proportion of acicular ferrite nucleated by non-metallic inclusions and boron-containing particles, instead of formation of the martensitic/bainitic microstructure of the AISI 10B20 plate.

A complication arising from the use of B-containing weld consumables is that even for 100% transfer across the arc, the boron content of the weld metal will depend on the extent of dilution by the base plate, which depends in turn on the welding process and the weld heat input. The weld metal composition is not known *a priori* and test welds are normally recommended to qualify the welding procedure. Boron content and the form in which it is present in the weld metal will depend on type and concentrations of co-elements in both the filler metal and the base plate.

Oh *et al.* [20] investigated a series of commercially produced Ti-B weld metals (AWS designation E71T-1) that are designed for flux cored arc welding (FCAW). The Ti and B were included in the consumable as compounds in the flux. The aim was to maximise the % acicular ferrite which is known to provide superior low temperature toughness compared to other possible weld metal microstructures. The 25 mm thick base plate was a 0.14% C structural steel (ASTM A663Gr) and the welds were produced by 4 passes into a 12.5 mm deep vee groove using heat inputs ranging from 1.07 to 2.13 kJ/mm and CO₂ shielding gas. The weld metal compositions ranged from 8-91 ppm B, 76-778 ppm Ti and 63-146 ppm N. The C, Mn, Si, Ni and O contents of the weld metals were approximately constant at 0.08%, 1.4%, 0.45%, 0.05% and 300 ppm, respectively. It was concluded that the optimum combination of B and Ti to achieve maximum acicular ferrite content and the highest toughness was 42 ppm B and 420 ppm Ti. However, B at this concentration level and a low Ti content did not promote acicular ferrite, presumably because of formation of BN. Further, high B and Ti contents enhanced transformation to upper bainite at the expense of acicular ferrite and reduced the toughness. The optimum B content of 42 ppm is considerably higher than that normally recommended for wrought steels in order to avoid a decrease in toughness and increased susceptibility to cracking. It is likely that only a proportion of the total B was available in the solute form necessary to retard formation of ferrite, with most of the remaining B being combined as B₂O₃ due to the high oxygen potential of CO₂ shielding gas. Although 420 ppm of Ti would be expected to tie up the N and prevent loss of solute B as BN, the formation of Fe₂₃(BC)₆ is also possible.

Special care should therefore be exercised in welding of B-containing steels and in the selection of B-alloyed filler metals to obtain the structures and properties required for the weld metal and the HAZ. Avoidance of welding conditions that increase the susceptibility to HACC is of paramount importance.

7.3 Extra deep drawing steels

The third class of steels for which B has become an accepted alloying element is highly formable sheet steels used, for example, in forming of automotive structural components. Extra deep drawing capacity can be obtained by using “interstitial-free” (IF) steels in which C and N atoms are removed from solution as carbides and nitrides formed as a result of addition of one or more of the elements Al, Ti and Nb. Boron is also an effective scavenger for C and N and can be used instead of, or in addition to, Ti and Al [21]. However, the main role of B in IF steels is as solute atoms, which segregate to ferrite grain boundaries, thereby displacing P which can cause secondary cold work embrittlement (SCWE) [21]. About 10-15 ppm of B is used for this purpose.

7.4 High alloy steels

Boron has been found to be a useful alloying element in a several types of high alloy steels in cases where hardenability is not the primary consideration [16]. For example, B can be added to tool steels such as 18W-4Cr-1V high speed steel to improve cutting performance. Up to 100 ppm B can also be added to austenitic steels to enhance high temperature strength and 5-50 ppm can be used in ferritic stainless steels (14-18% Cr) to improve surface quality of strip [16].

8. Discussion

Boron can be an extremely useful alloying addition to steels because of its potential to act either as a powerful hardenability-promoter or an effective scavenger of unwanted N, C and O from solid solution. However, the concentration of B has to be carefully limited to prevent formation of B-containing compounds that can degrade the strength and toughness of the steel. Moreover, when B is used to promote formation of martensite or bainite by heat treatment (QT) or thermomechanical controlled processing (TMCP), diligence is required during subsequent welding processes to avoid increased susceptibility to hydrogen assisted cold cracking of weldments. Care should also be exercised in using B-containing weld filler metals designed to increase weld metal strength and toughness by promoting formation of acicular ferrite. The distribution of boron between solute and compound forms can be variable, depending on the welding conditions, and excessive formation of boron-rich compounds can degrade strength and toughness, as well as increasing the susceptibility to hydrogen assisted cold cracking.

For normal structural steel applications, there is little need to use a hardenable alloy steel to boost the strength level. Boron in solute form in ferrite exerts no significant strengthening effect [16] and therefore the addition of B with no heat treatment, other than that locally imposed by welding, is likely to be counterproductive, especially if its presence in the steel is undeclared or is poorly

quantified. Alloying with boron is only a valid strategy if it leads to a verifiable improvement in the properties of the steel. This is unlikely to be the case for low C structural steels of moderate strength levels (yield strengths of 250-350 MPa), which exhibit excellent ductility and weldability. Addition of boron will not increase the strength unless a QT type heat treatment is applied [16], but it is likely to increase the potential for weldment cracking by promoting the formation of martensite in the HAZ. If the dangers of B-alloying are recognised, counteractive welding procedures can be employed, but these will probably add to manufacturing costs.

9. Responses to questions raised by AD Commission

1. The addition of B to HSS and galvanized sheet/plate products that are nominally low carbon structural steels would have no appreciable effect on the general mechanical properties of the steels unless they were subjected to a heat treatment that would allow the hardenability-promoting effect of B to come into play. In such a case the strength would be significantly increased with accompanying decrease in ductility/formability. However, QT heat treatment is not a normal practice for these types of steels. Whether heat treated or not, the presence of boron could adversely affect the localised HAZ microstructure and properties produced as a result of welding.
2. As little as 0.0005% (5 ppm) of B can affect hardenability, but 0.0008% (8 ppm) is usually recognised as the boundary value (Table 1) that can produce a significant increase in hardenability. The effects on mechanical properties are outlined in 1.
3. Processing of hollow structural sections and galvanized flat products by engineering manufacturers is likely to involve shape forming by cutting, shearing or stamping, followed by joining by arc or spot welding or mechanical fastening to produce assembled products or structures. Building frames, beams, columns, booms, towers, barriers and bridges are typical products constructed from low carbon structural steels in the form of HSS and/or galvanized flat products. Although the yield strengths of non-alloyed steels are usually lower than about 350 MPa, cold forming can be used to raise the strength. A relatively low yield strength and high ductility are advantageous for the forming of hollow steel sections and therefore higher strength alloy steels are less amenable to processing in this way. Although non-alloyed structural plate could be used in similar applications to those of alloyed structural plate, the latter would be superior in cases where a high strength to weight ratio is required.
4. The addition of 8 ppm or more of B to an otherwise low carbon non-alloyed structural plate steel could result in a similar steel product to BISPlate80 if it were subjected to a QT heat treatment. It would then be a genuine alloy steel (like AISI 10B20 or AISI 15B20) and its strength properties would not be matched by a non-alloyed steel (like AISI 1020 or AISI 1520).

5. Alloyed structural steels are used to provide the specified strength at reduced weight for a wide range of applications in the mining, agricultural and engineering industries. The essential processing step in producing these types of steels is QT heat treatment which requires a steel composition of adequate hardenability through the presence of boron and/or other alloying elements. Although alloyed structural steels exhibit markedly higher tensile strengths than non-alloyed structural steels, their formability and weldability are lower than those of non-alloyed steels. The relative importance of these sets of properties needs to be taken into account in the selection of a steel for a particular use.
6. The main processing feature that separates alloy and non-alloy versions of HSS and galvanized flat products is QT treatment. Other boron-containing alloys that can justifiably be classed as alloy steels are those discussed in Section 7 and include TMCP bainitic steels, weld filler consumables, high alloy steels and extra deep drawing steels. Hardenability is important for the first two types of alloys, but for the final two the boron serves other functions that enhance the properties of the steels.

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