USE OF ALTERNATIVE STRUCTURAL STEEL MATERIALS IN SINGAPORE

S.P. Chiew

Professor and Programme Director of Civil Engineering
SINGAPORE INSTITUTE OF TECHNOLOGY, SINGAPORE
(Email: singping.chiew@singaporetech.edu.sg)

ABSTRACT

While it is useful to implement a set of technically advanced structural design codes such as the Eurocodes from Western Europe, it is important to take cognizance of the fact that Singapore is not part of the European Union but a small island city state within ASEAN with an open market economy. Most of her structural materials for building and construction are from the Asia-Pacific region, and they are manufactured to a variety of international product standards. It is untenable to insist that only construction materials manufactured to European product standards can be used because of her unique geo-physical and geo-economical position within the region. This paper will provide the background and design framework on how alternative materials can be used with the aid of the Design Guide BC1: 2008 & 2012 published by the Building and Construction Authority of Singapore and will focus, in particular, on the use of the Chinese *Guobiao* steel materials in Singapore. The underlying concern has always been reliability and consistency, and the onus is on the manufacturers to exercise due diligence and care, and have in place stringent factory production control systems which can be audited by independent certification bodies to ensure safety and quality assurance to their users.

KEYWORDS

Alternative steel materials, factory production control certification, adequacy, reliability

INTRODUCTION

In Singapore, design of steel structures has predominantly been based on the BS5950 for a very long time until very recently when the Structural Eurocodes (EC3) is fully implemented with effect from 1 April 2015. In the local context, the need to look into the use of alternative steel materials which are manufactured to non BS EN product standards is understandable not just from the commercial and availability perspectives. Disruption in the supply of sand and granite from neighboring countries resulting in escalating costs and project delays have forced the Building and Construction Authority of Singapore (BCA) to move away from the more traditional form of concrete construction and look more seriously at the more sustainable form of steel and composite construction. BCA has set target and introduce new regulations such as Concrete Usage Index (CUI) to reduce concrete consumption. Compounded by the need to be less reliant and to reduce the number of imported migrant workers, BCA is pushing for more sustainable and productive form of construction in Singapore and the industry is recording greater market share of steel and composite construction over the years.

In recent years, China produced more than 500 million tonnes of steel and currently accounts for more than 50% of the total global steel production. Some of the surplus Chinese steel has naturally found its way into many countries outside China and Singapore is no exception. The availability of these steel materials which are manufactured to the Chinese *Guobiao* (GB) product standards has prompted an urgent study back in 2007 to look into the feasibility of using such materials to pave the way for more sustainable and productive steel construction in Singapore. It was recognized very early that it is neither tenable for Singapore to hold a position that only BS EN steel materials can be used nor realistic to insist that 'Made-in-China' materials cannot be used because it will go against the principles of free trade. Instead, a more pragmatic approach is to allow it but take the opportunity to tighten the quality control regime.

This set the stage for the development of the Design Guide BC1 which was first introduced to the industry in 2008. In addition to BS EN and GB materials, other alternative materials which are commonly found in Singapore such as ASTM, JIS and AS/NZS materials are also included in BC1. Essentially, the approach is to classify the materials into three different classes depending on whether they are adequate and reliable or not for design. Adequacy of the materials is met if they satisfy a set of essential material performance requirements which is largely based on equivalency study of the BS EN material requirements. A list of certified Chinese steel materials complying with such essential material performance requirements is drawn up and these certified materials are treated as per normal in design without any restriction if they are produced by manufacturers who can meet all the quality assurance requirements. Other non-certified materials from quality manufacturers can also be used as per normal if they can demonstrate compliance with the essential material performance requirements through material testing. The key intention is to highlight the need for consistently reliable and quality materials and manufacturers should always have in place stringent factory production control (FPC) system and certification to provide the necessary quality assurance to their purchasers and end users. Failure to meet these requirements will result in their materials being severely downgraded and their use limited to non-structural application.

OVERALL DESIGN FRAMEWORK IN BC1

The bottom line must be use of alternative steel materials should not compromise engineering resistance and safety in any way. Classification of the alternative steel materials is one way to determine whether these materials can be used in BS5950/EC3 design with or without any restriction. Two major concerns have been identified in BC1, namely how adequate and reliable are these materials. In this connection, the adequacy and reliability requirements should be met by checking the material performance and quality assurance of the alternative steel materials in the design process.

Material Performance Requirements

Material performance requirements are essential requirements for the mechanical, physical, chemical, dimensional tolerances and/or other relevant properties of alternative steel materials to ensure their adequacy in BS5950/EC3 design. It should be noted that material performance requirements are material-specific, i.e. different sets of requirements are applicable to different types of materials like steel plates, hot-rolled sections, hollow sections, bolts, etc.

The material performance indicators are derived by referring, with reasonable and appropriate adjustments, to the relevant clauses given in several parts of BS5950, for example, Part 2 (2001) provide information on the specifications of BS or EN steel plates, hot-rolled sections, hollow sections, bolts and welding consumables which are acceptable to BS5950 Part 1 (2000); whereas Part 7 (1992) provides information on the product standards of BS or EN steels acceptable for cold forming of thin gauge (Part 5, 1998) and light gauge (Part 6, 1995) steel sections. In addition, the relevant clauses pertaining to the material requirements given in the Eurocodes are also referenced. Adequacy of the alternative materials should be verified against the material performance requirements. Certification by rigorous evaluation and material testing are the two possible methods to ensure their adequacy.

Certification by rigorous evaluation

In this process, the material specifications given in the Chinese GB material product standards are evaluated rigorously against the essential material performance requirements. As a result, a list of certified steel materials for each product is produced and it is given in the Appendix of this paper. Only those materials which meet the essential material performance requirements are included. In other words, not all materials manufactured to the GB standards automatically qualifies as certified steel materials as not all of them are in compliance with the essential material performance requirements.

Material testing

On the other hand, material testing can also be used to verify the adequacy of the alternative materials which do not pass through the certification process and they are more applicable to those alternative materials not found in the list given in the Appendix of BC1, i.e. those alternative materials not covered by BC1. Material testing can be conducted to verify every aspect of the material performance requirements.

Quality Assurance Requirements

Quality assurance requirements are requirements for the manufacturers to comply to ensure reliability and compliance of the alternative steel materials with their nominal specifications, hence their reliability to be used in BS5950/EC3 design. The compliance of the actual performance of the alternative steel materials with the nominal specifications needs to be substantiated by an approved quality assurance system, which in this case, is an approved quality assurance system comprising a factory production control certification in addition to the traditional manufacturer or mill test certification.

Factory production control certification

The manufacturer shall establish, as a minimum, document and maintain a factory production control (FPC) system to ensure the conformity of the products to their nominal specifications. Such quality control system shall consist of written quality procedures (QP), regular inspection and test plans (ITP), and/or assessments and the use of the results to control six (6) key quality regimes, i.e. feedstock materials, equipment, personnel, product testing, product marking and non-conforming products. For independent audit or certification purpose, the following items shall be documented properly and made available for examination purpose by the third-party certification bodies or agencies recognized by the BCA only.

- **Feedstock materials** – the source of feedstock or raw materials shall be well-documented to ensure the full traceability of the products. The specifications of all incoming raw materials and the relevant inspection scheme to ensure their conformity shall be documented in accordance with the manufacturer's written procedures.

- **Equipment** – all equipment used in the manufacturing process shall be regularly inspected and maintained to ensure consistency in the manufacturing process and the product quality; all weighing, measuring and testing equipment for quality control shall be regularly inspected and calibrated to ensure the reliability and accuracy of results. Such inspections, maintenances and calibrations shall be carried out and documented in accordance with the manufacturer's written procedures.

- **Personnel** – qualifications of personnel involved in process affecting product quality and conformity based on relevant education, training, skills and experience, shall be assessed and documented in the manufacturer's written procedures. The responsibilities of personnel managing, performing or verifying work affecting product quality and conformity, and their inter-relationship, shall be clearly defined.

- **Product testing** – the manufacturer shall establish testing procedures to ensure conformity of the products to the nominal specifications.

- **Product marking** – the products shall be properly marked using methods like painting, stamping, laser marking, bar coding, durable adhesive labels or attached tags with the product specifications, particulars of manufacturer and any other essential information.

- **Non-conforming products** – the manufacturer shall establish appropriate actions to be taken against products not conforming to the nominal specifications. Occurrence of such non conformity shall be documented in accordance with the manufacturer's written procedures.

Manufacturer test certification

Traditionally, certification is required for testing, including inspections, which are carried out by the manufacturer. Certificates issued by a third party accredited inspection and testing agency shall also be produced upon the request of the purchasers. Different types of certification are required, depending on the nature of testing – routine or specific testing.

- Routine testing is carried out by the manufacturer in accordance with the manufacturer's written procedures.

- Specific testing, upon request at the time of order, shall be carried out by authorized inspection representative independent of the manufacturer prior to delivery to ensure the products conform to the nominal specifications and any other additional requirements made at the time of order.

To certify such testing, the manufacturer shall provide a validated certificate of compliance with the requirements made at the time of order and the requested test results. The documents shall also be validated by, if any, third party inspection agency authorized by the purchaser or inspector designated by the official regulations.

Classification of Alternative Steel Materials

The classification of alternative steel materials for design is represented schematically in Figure 1.

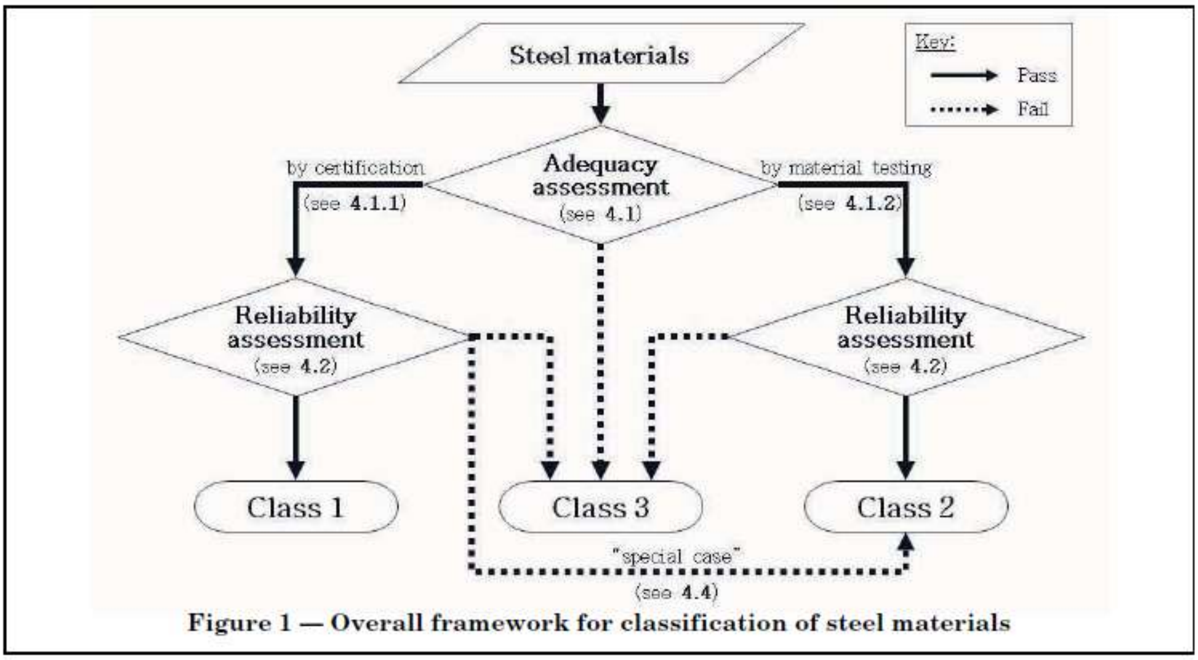

Figure 1: Classification of alternative steel materials

Depending on the verification against material performance (adequacy assessment) and quality assurance (reliability assessment) requirements, alternative steel materials can be classified into Class 1, Class 2 and Class 3 as described below.

Class 1 alternative steel materials

Class 1 materials are certified alternative steel materials which meet the material performance requirements through certification and are also manufactured with approved FPC quality assurance. Their use in BS5950/EC3 shall be as per normal without any restriction/imposition on their material safety factor. Only certified materials can qualify as Class 1 alternative steel materials depending on the quality assurance provided by the manufacturers.

Class 2 alternative steel materials

Class 2 materials are those certified steel materials but produced by non-audited manufacturers and they qualified under ‘Special Case’ at the moment. They can also be non-certified alternative steel materials which are not covered in BC1 at present, for example, Korean KS steel or Indian IS steel materials, They are also unlikely to be produced with an approved FPC quality system, these materials will have to have both their material performance and quality assurance requirements verified through material batch testing on a project basis. Their use shall be subjected to higher material safety factors as Class 2. It ought to be pointed out that these routes are counter-productive and work against achieving the goal using only Class 1 materials and they ought to be viewed as ‘interim’ measures to get the industry to move over completely in the near future.

Class 3 alternative steel materials

Class 3 alternative steel materials are steel materials which do not meet either or both the material performance and quality assurance requirements. Their use in BS5950/EC3 shall be restricted to non-structural members with severely downgraded design strength to 170 N/mm^2. It is important to note that failure to meet the quality assurance requirements will straightaway render the alternative steel materials as Class 3.

ADEQUACY OF CHINESE GB STEEL MATERIALS

To ensure the adequacy of Chinese steel materials to be used in accordance with the design clauses of BS5950/EC3, their technical specifications as given in the relevant GBs need to be verified against the essential material performance requirements. By referring to the relevant GBs, some of the major issues, from the technical point of view, regarding the use of Chinese steel materials as an alternative are highlighted in this section. Those certified steel materials complying with the material performance requirements are listed in the Appendix.

Commonly available structural steels from China are manufactured in accordance with GB/T 700 and GB/T 1591. Weathering steels with enhanced corrosion resistance are also manufactured in China according to GB/T 4171 and GB/T 4172. These Chinese steels are intended for the use as steel plates for steelwork fabrication as well as for the forming of structural sections, both open and hollow sections. It is noteworthy that not all the steels manufactured to these GBs are fit for use alongside BS5950/EC3.

Other than structural steels, there are also structural components like bolts and welding consumables manufactured to GBs. For examples, bolts, nuts and washers for non-preloaded use are manufactured to standards like GB/T 5780, GB/T 5781, GB/T 5782, GB/T 5783, GB/T 41, GB/T 6170, GB/T 6175 and GB/T 95. On the other hand, material standards like GB/T 1228, GB/T 1229, GB/T 1230 and GB/T 3632 govern the production of bolting components intended for preloading. Meanwhile, welding consumables are referred to standards like GB/T 5117, GB/T 5118, GB/T 8110, GB/T 5293, GB/T 12470, GB/T 10045 and GB/T 17493.

Mechanical properties

In structural design, mechanical properties are the most clear-cut performance indicators. Depending on the type of steel materials, mechanical properties include the yield strength, tensile strength, ductility, impact toughness, hardness and proof load stress. Table 1 summarizes the mechanical properties of some commonly used GB structural steel materials from GB/T 700 and GB/T 1591.

TABLE 1 MECHANICAL PROPERTIES OF COMMON GB STRUCTURAL STEELS

Grade	Thickness (mm)	Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Elongation after fracture (%)	Sub-grade and impact energy
Q235	≤ 16	235	370 ~ 500	26	A: Not specified B: 27 J at 20°C C: 27 J at 0°C D: 27 J at – 20°C
	> 16 ~ 40	225		26	
	> 40 ~ 60	215		25	
	> 60 ~ 100	215		24	
	> 100 ~ 150	195		22	
	>150 ~ 200	185		21	
Q345	≤ 16	345	470 ~ 630	21	A: Not specified B: 34 J at 20°C C: 34 J at 0°C D: 34 J at – 20°C E: 27 J at – 40°C
	> 16 ~ 35	325			
	> 35 ~ 50	295			
	> 50 ~ 100	275			
Q390	≤ 16	390	490 ~ 650	19	
	> 16 ~ 35	370			
	> 35 ~ 50	350			
	> 50 ~ 100	330			
Q420	≤ 16	420	520 ~ 680	18	
	> 16 ~ 35	400			
	> 35 ~ 50	380			
	> 50 ~ 100	360			

Yield strength

Adopted as the design strength on most occasions, yield strength is undoubtedly the most important design parameter. As a common practice, yield strength is taken as the stress at yield point or the 0.2 % proof strength without yield phenomenon. In general, only steel grades in the range of S235 to S460, which in fact corresponds to the yield strength of 235 N/mm^2 to 460 N/mm^2, are covered in BS5950/EC3. Minimum yield strength of 235 N/mm^2 implies that steel grades like Q195 and Q215 manufactured to GB/T 700 are to be eliminated from structural use.

As technology advances and material efficiency has become a key issue in promoting sustainable construction, use of high-strength steel materials shall be allowed. In view of this, the maximum yield strength of steel plates for structural use is to be increased to 690 N/mm^2 from the overly conservative 460 N/mm^2. Nonetheless, steels with yield strength beyond 460 N/mm^2 are not within the scope of GB/T 700 and GB/T 1591. Therefore, any high-strength steel materials with yield strength higher than 460 N/mm^2 but not more 690 N/mm^2 are considered non-certified.

On the other hand, formability tends to be another concern as strength increases and this explains why Chinese steels of grade Q420 and Q460 are not to be used in the cold forming of thin gauge sections.

Tensile strength

Although yield strength is usually taken as the design strength, under the circumstances when the yield strength of a steel material exceeds the tensile strength divided by 1.2, the later shall be assumed as the design strength, as represented by the mathematical expression below.

$$p_y = Y_s \leq \frac{U_s}{1.2} \qquad (1)$$

Therefore, it is a desirable, but not essential, criterion that the tensile strength of alternative steel materials is at least 1.2 times of the yield strength, to prevent unnecessary confusion over the choice of design strength.

Besides that, tensile strength is the main reference in the property class designation system of bolts as per ISO 898-1 (1999). Bolts with tensile strength in the range of 400 N/mm^2 to 1000 N/mm^2 are covered in BS5950/EC3. Hexagon bolts of grades 4.6, 8.8 and 10.9 according to the ISO naming system are recommended for non-preloaded bolted connections; whereas only those of grades 8.8 and 10.9 are recommended when preloading is required. Bolts of grades 4.6, 8.8 and 10.9 manufactured to a series of ISO-equivalent GBs – GB/T 5780, GB/T 5781, GB/T 5782 and GB/T 5783, are certified to be used in BS5950/EC3 non-preloaded bolted connections; whereas bolts of grades 8.8 and 10.9 covered by GB/T 1228 and GB/T 3632 are adequate for preloaded design in compliance with BS5950/EC3.

Ductility

Ductility is not just an important indicator to ensure the more preferred ductile mode of failure, but is also an essential material property of steel to facilitate a more economic plastic design. Clause 5.2.3 of BS5950-1 spells out ductility as one of the minimum requirements for plastic analysis, citing a minimum elongation at fracture on the proportional gauge length of $5.65\sqrt{A_0}$ shall be at least 15 %. In the context of bolts, however, a less stringent requirement on ductility can be imposed. Recognizing the fact that bolts are generally made from steels of higher strength and hardness, achieving an 8 % of elongation at fracture is considered adequate.

From the specifications given in the relevant product standards, Chinese steel materials are generally able to exhibit adequate ductility.

Impact toughness

Impact toughness serves as an indicator to gauge the resistance of stressed materials against fracture. As a minimum, structural steels for the fabrication of steel plates or sections shall be able to absorb at least 27 J of impact energy at 20 °C. According to GB/T 700 and GB/T 1591, steels of sub-grades A do not possess insured impact toughness. Chinese steels without tested impact toughness, including Q235A, Q275A, Q295A, Q345A, Q390A and Q420A, are not suitable for structural use although they are able to fulfill the yield strength requirement.

Hardness

Hardness is a measure of the resistance of materials against permanent deformation. It is of particular importance for components in bolting assembly to meet the required hardness range as they are susceptible to permanent deformation like indentation during the tightening process, resulting in difficulty to achieve the intended connection strength. Required hardness ranges are available in three different scales – Brinell, Rockwell and Vickers hardness scales. Bolts, nuts and washers to be used in BS5950/EC3 shall be able to meet the respective hardness ranges.

GB bolting components with certified hardness include, bolts of grades 4.6, 8.8 and 10.9 manufactured to GB/T 5780, GB/T 5781, GB/T 5782, GB/T 5783, GB/T 1228 and GB/T 3632; nuts of grades 4, 5, 8, 10 and 12 manufactured to GB/T 41, GB/T 6170, GB/T 6175, GB/T 1229 and GB/T 3632; and, washers manufactured to GB/T 95, GB/T 1230 and GB/T 3632.

Proof load stress

Proof load stress requirement is only specific to nuts used in bolting assembly. Under such requirement, the nuts shall be able to resist the intended load without failure by stripping or rupture. Referring to the designation system of ISO 898-2 (1992), nuts of property classes 4, 5, 8, 10 and 12 are recommended for bolting connections. These five classes of nuts are capable to withstand pulling forces equivalent to 400, 500, 800, 1000 and 1200 N/mm^2, respectively. Nuts manufactured to GB/T 41, GB/T 6170, GB/T 6175, GB/T 1229 and GB/T 3632 are verified to be adequate for structural use.

Chemical Compositions

Besides affecting certain mechanical properties of steel such as the strength, ductility and toughness, chemical compositions are also closely related to the weldability of steel materials. Weldability is an important technological property of steel materials to facilitate fabrication of welded sections and welded connections in structural steelwork. Welding both the weld and parent metals to form the all-weld metal is significantly influenced by the chemical compositions.

Unlike strength and ductility, quantification of weldability is relatively less straightforward. Toughness of the heat affected zone (HAZ) and tendency to cold cracking form the basis for the assessment of the weldability of steel materials. Carbon equivalent value (CEV) and impurity level are the two main parameters in the evaluation of weldability of steel materials.

Carbon equivalent value

CEV serves as an empirical measure of hardening tendency of the HAZ which promotes the crack formation. In general, increase in CEV will induce adverse effect on weldability. Weldability can be correlated to the CEV computed based on Eqn. 2 which is based on the IIW recommended equation.

$$CEV = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Cu + \%Ni}{15} \quad (2)$$

According to Eqn. 2, increasing the content of alloying elements in steel will increase the CEV and hence reduce the weldability. As weldability is not solely governed by the CEV, but also the metallurgical process, material strength, thickness, intended use and the welding procedures, it is therefore impossible to propose a single CEV limit applicable to all grades of structural steels. Instead, higher CEV limits are to be imposed on higher grades of steels realizing that weldability generally decreases with increasing strength which is related to the higher content of alloying elements in the higher strength steels.

For illustration purpose, Table 2 summarizes the proposed CEV requirements, derived from BS EN 10025 series, for different grades of steels used in the forming of hot rolled sections, based on ladle analysis. It should be noted that Table 2 is not applicable to other types of structural steels.

TABLE 2 MAXIMUM CEV FOR HOT ROLLED SECTIONS BASED ON LADLE ANALYSIS

Nominal yield strength (N/mm^2)	235	275	355	420	460
Maximum allowable CEV (% by mass)	0.40	0.44	0.49	0.52	0.55

Although CEV is a significant indicator of weldability, none of the Chinese steels are manufactured to a specified maximum CEV. Material standards like GB/T 700, GB/T 1591, GB/T 4171 and GB/T 4172 do not contain information about the maximum allowable CEV for their products. To enable the CEV evaluation of these Chinese steel products, the maximum allowable contents of carbon, manganese, chromium, molybdenum, vanadium, copper and nickel are retrieved from these material standards to compute the maximum possible CEV (see Eqn. 3). GB/T 13304 is the additional reference for the chemical content not provided by these four standards.

$$CEV_{max,\,possible} = \%C_{max} + \frac{\%Mn_{max}}{6} + \frac{\%Cr_{max} + \%Mo_{max} + \%V_{max}}{5} + \frac{\%Cu_{max} + \%Ni_{max}}{15} \quad (3)$$

By performing a simple correlation through Eqn. 4, the maximum allowable CEV of Chinese steels can be obtained.

$$CEV_{max} = 0.70 \cdot CEV_{max,possible} \quad (4)$$

It should be noted that the correlation factor of 0.70 in Eqn. 4 is obtained statistically by averaging the CEV_{max} to $CEV_{max,possible}$ ratios of all BS EN steels in the BS EN 10025 series. By using Eqn. 4 as a rough guide for evaluation, the CEV levels of Chinese steels manufactured to GB/T 700, GB/T 1591, GB/T 4171 and GB/T 4172 are found to be acceptable.

Impurity level

The presence of impurities, particularly non-metallic elements like sulphur and phosphorous, is a major contributing factor in crack formation during welding. Such non-metallic inclusions shall be observed by limiting the maximum sulphur and phosphorous contents in structural steels.

Compared to BS EN steels, Chinese steels generally contain higher percentages of sulphur and phosphorous. BS EN 10025 series rarely allow sulphur or phosphorous content of more than 0.035 % by mass, based on ladle analysis. Most Chinese steel products, on the other hand, have the difficulty in meeting such a stringent requirement. Considering the particular importance of impurity level towards the material performance of hollow sections and cold forming steels – as impurity level is also closely linked to the brittleness, more liberal yet reasonable constraints are given to Chinese steel plates and hot rolled sections. For instance, depending on steel grade, maximum allowable sulphur and phosphorous contents are raised to as high as 0.045 % for steel plates and hot rolled sections. For this reason, different sub-grades of GB/T 700 and GB/T 1591 steels are acceptable to different types of steel materials as shown in Table 3.

TABLE 3 ALLOWABLE GB STEEL SUB-GRADES

Type of steel materials	Allowable steel sub-grades	
	GB/T 700	GB/T 1591
Steel plates	B, C, D	B, C, D, E
Hot rolled sections	B, C, D	B, C, D, E
Hollow sections	C, D	C, D, E
Cold forming steels	D	C, D, E

Manufacturing Process

To a great extent, manufacturing process is decisive in determining the metallurgical behavior and hence the performance of steel products.

Deoxidation methods

To achieve certain mechanical properties, deoxidation methods adopted by manufacturers shall be complying with BS EN 10025 which specifies the technical delivery conditions of structural steel products to be used with BS5950/EC3. Rimming steel produced without the addition of deoxidation elements, shall not be used in the forming of structural steel plates and sections due to the low yield strength and impact toughness resulted from presence of internal voids. For this reason, products of rimming steel manufactured to GB/T 700 with an 'F' in the designation like Q235BF are considered unfit for structural application. Instead, products made of semi- or fully killed steel containing sufficient nitrogen binding elements are to be used.

Delivery conditions

In some cases, quenching and tempering are necessary to achieve higher strength, though at the expense of the ductility and hence the formability of steel sections. High strength steels Q420 and Q460 manufactured to GB/T 1591 may be quenched and tempered at the manufacturer's discretion. It is therefore the responsibility of purchasers to ensure the delivery conditions of steels Q420 and Q460 are suitable for the intended use, i.e. quenched and tempered steels are only usable as steel plates in steelwork, they are not permitted in the forming of steel sections.

Dimensional and Mass Tolerances

To ensure a steel product can function as intended, deviations from the nominal dimensions and mass shall be well within the manufacturing tolerances. Standards on manufacturing tolerances of BS, including EN, and GB steel products are summarized in Table 4.

TABLE 4 MANUFACTURING TOLERANCES OF BS EN AND GB STEEL PRODUCTS

Type of steel materials	Standards on dimensional and/or mass tolerances	
	BS EN	GB
Steel plates	BS EN 10029 BS EN 10051	GB/T 709
Universal beams and columns	BS EN 10034	GB/T 11263
Hollow sections	BS EN 10210-2 BS EN 10219-2	GB/T 6728
Joists	BS EN 10024	GB/T 706
T-sections	BS EN 10055	GB/T 11263
Channels	BS EN 10279	GB/T 707
Angles	BS EN 10056-2	GB/T 9787 GB/T 9946

Dimensional tolerances

For steel materials, physical dimensions are equally important as their mechanical properties because they affect sectional properties, hence the computation of structural resistance and safety. As a simple illustration, the axial capacity of a steel section is the product of its cross-sectional area with its design strength. Similar to their BS EN counterparts, Chinese steel products are also manufactured to specific dimensional tolerances. Table 5 shows the negative and positive dimensional tolerances of universal beams and columns given in BS EN 10034 and GB/T 11263.

TABLE 5 ACTUAL DIMENSIONAL TOLERANCES OF UNIVERSAL BEAMS AND COLUMNS

Dimensions	Tolerances (in mm) as according to:-	
	BS EN 10034	GB/T 11263
Overall depth D (mm)	$D \le 180$; – 2, + 3 $180 < D \le 400$; – 2, + 4 $400 < D \le 700$; – 3, + 5 $D > 700$; ± 5	$D \le 400$; ± 2 $400 < D \le 600$; ± 3 $D > 600$; ± 4
Flange width B (mm)	$B \le 110$; – 1, + 4 $110 < B \le 210$; – 2, + 4 $210 < B \le 325$; ± 4 $B > 325$; – 5, + 6	$B \le 100$; ± 2 $100 < B \le 200$; ± 2.5 $B > 200$; ± 3
Web thickness t (mm)	$t \le 7$; ± 0.7 $7 < t \le 10$; ± 1 $10 < t \le 20$; ± 1.5 $20 < t \le 40$; ± 2 $40 < t \le 60$; ± 2.5 $t > 60$; ± 3	$t \le 5$; ± 0.5 $5 < t \le 16$; ± 0.7 $16 < t \le 25$; ± 1 $25 < t \le 40$; ± 1.5 $t > 40$; ± 2
Flange thickness T (mm)	$T \le 6.5$; – 0.5, + 1.5 $6.5 < T \le 10$; – 1, + 2 $10 < T \le 20$; – 1.5, + 2.5 $20 < T \le 30$; – 2, + 2.5 $30 < T \le 40$; ± 2.5 $40 < T \le 60$; ± 3 $T > 60$; ± 4	$T \le 5$; ± 0.5 $5 < T \le 16$; ± 0.7 $16 < T \le 25$; ± 1 $25 < T \le 40$; ± 1.5 $T > 40$; ± 2

Table 6 compares the dimensional tolerances of BS EN and GB universal beams and columns based on the information extracted from Table 6.

TABLE 6 RELATIVE DIMENSIONAL TOLERANCES OF UNIVERSAL BEAMS AND COLUMNS

Dimensions		Negative and positive tolerances (in %) as according to:-			
		BS EN 10034		GB/T 11263	
Overall depth *D* (mm)	200	– 1.00 %	+ 2.00 %	– 1.00 %	+ 1.00 %
	400	– 0.50 %	+ 1.00 %	– 0.50 %	+ 0.50 %
	600	– 0.50 %	+ 0.83 %	– 0.50 %	+ 0.50 %
	700	– 0.43 %	+ 0.71 %	– 0.57 %	+ 0.57 %
	800	– 0.63 %	+ 0.63 %	– 0.50 %	+ 0.50 %
	Average	**– 0.61 %**	**+ 1.03 %**	**– 0.61 %**	**+ 0.61 %**
Flange width *B* (mm)	80	– 1.25 %	+ 5.00 %	– 2.50 %	+ 2.50 %
	150	– 1.33 %	+ 2.67 %	– 1.67 %	+ 1.67 %
	200	– 1.00 %	+ 2.00 %	– 1.25 %	+ 1.25 %
	300	– 1.33 %	+ 1.33 %	– 1.00 %	+ 1.00 %
	400	– 1.25 %	+ 1.50 %	– 0.75 %	+ 0.75 %
	Average	**– 1.23 %**	**+ 2.50 %**	**– 1.43 %**	**+ 1.43 %**
Web thickness *t* (mm)	5	– 14.00 %	+ 14.00 %	– 10.00 %	+ 10.00 %
	10	– 10.00 %	+ 10.00 %	– 7.00 %	+ 7.00 %
	15	– 10.00 %	+ 10.00 %	– 4.67 %	+ 4.67 %
	30	– 6.67 %	+ 6.67 %	– 5.00 %	+ 5.00 %
	50	– 5.00 %	+ 5.00 %	– 4.00 %	+ 4.00 %
	Average	**– 9.13 %**	**+ 9.13 %**	**– 6.13 %**	**+ 6.13 %**
Flange thickness *T* (mm)	5	– 10.00 %	+ 30.00 %	– 14.00 %	+ 14.00 %
	10	– 10.00 %	+ 20.00 %	– 10.00 %	+ 10.00 %
	15	– 10.00 %	+ 16.67 %	– 6.67 %	+ 6.67 %
	30	– 6.67 %	+ 8.33 %	– 5.67 %	+ 5.67 %
	50	– 6.00 %	+ 6.00 %	– 4.00 %	+ 4.00 %
	Average	**– 8.53 %**	**+ 16.20 %**	**– 8.07 %**	**+ 8.07 %**

Comparison in Table 6 indicates that the manufacturing tolerances of GB universal beams and columns are as good as those of BSs. Whenever necessary, similar method is applied to evaluate and compare the manufacturing tolerances of other types of steel materials manufactured to BS EN and GB.

The important results after comparison are summarized in Table 7.

TABLE 7 RELATIVE DIMENSIONAL TOLERANCES OF MAJOR BS EN AND GB STEEL MATERIALS

Steel materials	Dimensions	Negative and positive tolerances (in %) as according to:-			
		BS		GB	
Steel plates	Thickness *t*	– 4.16 % (Class A)	+ 9.10 % (Class A)	– 4.81 % (Class A)	+ 9.20 % (Class A)
		– 2.49 % (Class B)	+ 10.77 % (Class B)	– 2.49 % (Class B)	+ 11.52 % (Class B)
		0 (Class C)	+ 13.26 % (Class C)	0 (Class C)	+ 13.08 % (Class C)
		– 6.63 % (Class D)	+ 6.63 % (Class D)	– 6.54 % (Class N)	+ 6.54 % (Class N)
		– 8.61 % (Category A)	+ 8.61 % (Category A)	– 6.26 % (Class PT.B)	+ 6.26 % (Class PT.B)
		– 9.90 % (Category B)	+ 9.90 % (Category B)	– 8.21 % (Class PT.A)	+ 8.21 % (Class PT.A)
Universal beams and columns	Overall depth *D*	– 0.61 %	+ 1.03 %	– 0.61 %	+ 0.61 %
	Flange width *B*	– 1.23 %	+ 2.50 %	– 1.43 %	+ 1.43 %
	Web thickness *t*	– 9.13 %	+ 9.13 %	– 6.13 %	+ 6.13 %
	Flange thickness *T*	– 8.53 %	+ 16.20 %	– 8.07 %	+ 8.07 %
Hollow sections	Diameter *D*, depth *D* or width *B*	– 1 %	+ 1 %	– 1 %	+ 1 %
	Thickness *t*	– 10 %	+ 10 %	– 10 %	+ 10 %

From Table 7, it can be seen that the dimensional tolerances adopted in GBs are generally comparable to those in equivalent BSs.

Mass tolerances

The adequacy of structural steel to perform as intended also relies upon its mass, which is theoretically an indicator of the amount of material contained in the steel. The deviation in actual mass from mass computed using a density of 7850 kg/m^3 shall be within the allowable tolerances.

Table 8 compares the mass tolerances, by piece or batch, allowed by the relevant BSs and GBs given in Table 4.

TABLE 8 MASS TOLERANCES OF BS EN AND GB STEEL MATERIALS

Steel materials	Tolerances (in %) as according to:-	
	BS EN	GB
Steel plates	± 3 % to ± 21.5 %, depending on tolerance class, thickness and width	N/A
Universal beams and columns	± 4 % per piece or batch	± 6 % per piece; ± 4 % per batch
Hollow sections	± 6 % per piece	– 6 %, + 10 % (not specified)
Joists	± 4 % per piece or batch	– 5 %, + 3 % per meter
T-sections	– 8 % per piece for thickness ≤ 7 mm; – 6 % per piece for thickness > 7 mm	± 7 % per piece; ± 5 % per batch
Channels	± 6 % per meter for height ≤ 125 mm; ± 4 % per meter for height > 125 mm	– 5 %, + 3 % per meter
Angles	± 6 % per piece for thickness ≤ 4 mm; ± 4 % per piece for thickness > 4 mm	– 5 %, + 3 % per meter

Table 8 concludes that other than steel plates, Chinese steel materials are manufactured to reasonably stringent mass tolerances when compared to the equivalent BS EN steel materials.

CONCLUSIONS

The essential material performance requirements for adequate steel design to BS5950/EC3 are proposed and adopted in BC1. Alternative materials such as the Chinese GB materials can be rigorously evaluated against these essential material performance requirements to come up with a list of certified Chinese steel materials for different types of steel product category covered in BC1. These Class 1 certified materials are designed to BS5950/EC3 design without any restriction imposed on the material safety factor whatsoever if these materials are produced by audited steel manufacturers who can meet all the quality assurance requirements in terms of factory production control certification. However, certified materials produced from non-audited manufacturers are treated as Class 2 and they have to demonstrate compliance with quality assurance requirements through material batch testing. However, this is an interim measure and it will be removed as the intention is to source materials from audited manufacturers only. BCA has enforced the use of the Design Guide BC1 since 2008 and has put in place a material selection framework which is now widely accepted by the construction industry in Singapore. It is pro-business and forward looking; its success must certainly lies in the monitoring and enforcement of the international certification bodies which, at the moment, are restricted to only a few who are recognized for their work.

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