

# **Quality Assurance of High Strength Steel**

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## **General**

Steel has been used for decades as a popular construction material in Hong Kong and the advent of high strength steel is conducive to the local construction industry. The high strength steel herein referred to possesses yield strength ranging from 460 to 690 MPa. They are generally manufactured by Quenching and Tempering and grain size gives excellent properties combined with good weldability.

The high strength steel products shall meet all the requirements for technical delivery and welding aspects. To facilitate better control, quality assurance processes are given to the following aspects: -

1. Welding Electrode and Consumable
2. High Strength Steel material
3. Welding Process
4. Welded Joint
5. Fabrication, Assembly and Erection of Steelwork

### **1. Quality Assurance of Welding Electrode and Consumable**

Depending on the exact high strength steel grade to be used, the welding electrode or consumable shall comply with the relevant applicable standards such as the ISO standards. The use of applicable standards for welding electrode or consumables shall be compatible in terms of mechanical properties and chemical composition conforming to reference material standard for the parent high strength steel being welded.

All welding electrodes and consumables delivered to construction sites in Hong Kong shall be sampled and tested by the end purchaser. All tests shall be performed by a HOKLAS (i.e. Hong Kong Laboratory Accreditation Scheme) accredited laboratory or other laboratory accredited under the mutual recognition agreement/arrangement with HOKLAS. The test certificates shall be endorsed by HOKLAS or equivalent.

For the purpose of testing, the welding electrode or consumable is to be divided into batches. Each batch shall consist of welding electrodes or consumables of the same strength grade and diameter. Welding electrodes and consumables shall be classified into 2 quality classes: -

Class 1 is defined as welding electrode or consumable produced by a quality assured manufacturer certified by a third party certification body to ISO 9001:2000 under a relevant scope and with full batch traceability. A copy of the welding electrode or consumable certificate for the batch shall be produced by the quality assured manufacturer for evidence. No end purchaser test is necessary for

class 1 welding electrode unless the requirement for testing is stipulated in the project specification.

Class 2 is defined as the welding electrodes or consumables produced by a manufacturer other than class 1. Test electrodes shall be taken from each batch and the testing rate shall be in accordance with the Table 1 below. The welding electrode or consumables used should be at least the same strength grade as the high strength steel.

**Table 1 Purchaser’s Test requirements of Quality Class 2 electrodes**

<b>Amount of electrodes</b>	<b>Test requirements</b>
0- 20 tonnes for each batch of welding electrode or consumables	1 set of all-weld mechanical tensile test, impact test for the weld metal and chemical composition analysis for the welding electrode or filler wire
Additional 10 tonnes or part of 10 tonnes for the same batch of welding electrode or consumables	1 set of all-weld mechanical tensile test, impact test for the weld metal and chemical composition analysis for the welding electrode or filler wire

Note: The welding electrodes or consumables mentioned above apply for various types of welding. The steel manufacturer would normally supply information on the recommended use of welding electrode or consumable for that particular grade of steel.

## **2. Quality Assurance of Material (High Strength Structural Steel)**

### **Quality Classification**

All high strength steel used in Hong Kong must be adopted strictly in accordance with the reference standards to which the material is manufactured. These standards may be BS EN or any other national or international standards such as the ISO, etc.

The high strength steel shall be supplied by quality assured manufacturers with full lot traceability and handled by a quality assured stockist.

Quality assured manufacturers mean that they are certified to ISO 9001 for their manufacturing process to a scope of “Manufacturing of Structural Steel to BS EN or other similar steel product standards”. A copy of this certificate should be produced by the manufacturer for evidence.

Quality assured stockists mean that they are also certified to ISO 9001 for trading of steel materials. A copy of this certificate should also be produced by the stockist for evidence.

Full lot traceability means any cast or heat of steel products labeled with sufficient identification of its production details in order to ensure the steel material fabricated into the final shape can still be identified to the respective cast or heat.

A series of end purchaser tests is required for high strength steel upon delivery to site before it is used in the construction works. The frequency of testing shall be set at every 40 tonnes of each batch consisting of same steel grade, same cast/heat, same form or section, and of the same range of thickness and diameter.

#### **End purchaser test of high strength steel**

All high strength steel arrived on site shall be sampled and tested by the end purchaser. All tests shall be performed by a HOKLAS accredited laboratory or other laboratory accredited under the mutual recognition agreement/arrangement with HOKLAS and the test certificates shall be endorsed by HOKLAS or equivalent. For the purpose of testing, the steel shall be divided into batches. Each batch shall consist of same steel grade, same product form, of the same range of thickness or diameter, and of the same cast. When the steel is shipped to Hong Kong, additional end purchaser test shall be carried out to ensure the steel complied with the following requisite requirements.

##### **a) Strength:**

The minimum ultimate tensile strength shall be at least 1.2 times the minimum yield strength (normally taken as the upper yield strength of the material). The yield strength divided by the partial material factor  $\gamma_{m1}$ , which is taken as 1.0, gives the design strength of steel material. Such derived design strength shall not be greater than that stipulated in the reference standard or product standard.

##### **b) Resistance to brittle fracture**

The minimum average Charpy V-notch impact test energy of 27 Joules at the required testing temperature for the strength of steel, thickness involved and minimum design service temperature as required by the structural application code should be provided in order to possess adequate notch toughness.

##### **c) Ductility:**

The elongation on a gauge length of  $5.65\sqrt{S_o}$  is not to be less than 15%, where  $S_o$  is the cross sectional area of the section. The 15% elongation is solely necessary in plastic analysis requiring a higher degree of ductility for the formation of plastic hinges.

##### **d) Weldability:**

By ladle analysis, the maximum carbon equivalent value shall not exceed 0.48%. The maximum carbon content shall not exceed 0.20%. Chromium content shall not exceed 0.70% while the maximum Sulphur content shall not exceed 0.025% and the maximum Phosphorus contents shall not exceed 0.025%.

The chemical compositions of various grades of steel shall either conform to the requirements stipulated in the national materials standards to which they are manufactured, or to the above minimum basic requirements, whichever is the more stringent.

### **3. Quality Assurance of Welding Process**

#### **Welding procedures**

All welded connections shall be conducted in strict adherence to the welding procedure specification of a particular project, the content of which shall be prepared in accordance with BSEN 288 -1 or ENISO 15609-1.

As for the welding procedure specification, it shall be qualified by welding procedure tests. These welding procedure tests shall be carried out in accordance with BS EN 1011-1, BS EN 288-3, EN ISO 15614-1:2004 or other applicable standards relevant to the specific project.

A qualified welding inspector for the approval of welding procedure tests is defined as welding inspection personnel, who is usually employed by the supervisory party such as the RSE and holds valid certificates issued by recognized authorities such as The Welding Institute or the American Welding Society.

#### **Mitigation of hydrogen-induced cracking**

The occurrence of hydrogen cracking depends on a number of factors, such as the composition of the steel, the welding procedure, the welding consumables and the stress involved. Welding conditions should be selected to avoid cracking by several means: -

- ensuring that the heat-affected zone cools sufficiently slowly,
- control of weld run dimensions in relation to metal thickness,
- and if necessary, applying preheat and inter-pass temperature in the range from 100°C to 300°C hence beneficially influencing the dispersion of hydrogen from the welded joint. In particular, this can also be achieved by post-heat treatment on completion of welding for up to 24 hours..

The hydrogen content of the weld shall be controlled by using hydrogen controlled welding processes and low hydrogen consumables (grade D or better).

#### **Quality Control of Welded Strength Steel**

The quality of welded high strength steel can be verified by the Hardness survey along the welded joint, i.e. from the weld metal through the HAZ to the parent metal. Insofar as the variation of the hardness value does not exceed 30 HV, the quality of welded high strength steel can be considered as acceptable. The variation of such hardness can be offset by the application of preheat as well as post heat treatment.

#### **Qualified Welders**

All welders shall be approved in accordance with BS EN 287-1 or other applicable standards relevant to the specific project. The welder shall be inspected and examined by a certified welding inspector affiliated to a welding inspection body. The welder certificate shall be issued and signed by an approved signatory of the welding inspection body. The welding inspection body shall be accredited

under HKIAS (i.e. Hong Kong Inspection Body Accreditation Scheme) for the relevant scope on welders testing approval or equivalent.

#### 4. Quality Assurance of Welded Joints

##### Non-destructive testing of welds

Upon the completion of the welding process, all welds shall be subject to tests by relevant non-destructive testing (NDT) methods as given in table 2 below. All NDT on welds shall be performed by a HOKLAS accredited laboratory or other laboratory accredited under the mutual recognition agreement/arrangement with HOKLAS. The test certificates shall be endorsed by HOKLAS or equivalent. Sufficient hold times for performing the non-destructive test shall be maintained.

**Table 2 NDT of weld test requirements**

Type of Weld	Type of Test	Frequency of Test
All welds	VT	100 %
Fillet Weld, leg length $\geq$ 4 mm (Shop & Site)	UT	100 %
	MT or PT	100 %
Fillet Weld, leg length $<$ 4 mm (Shop & Site)		N/A
	MT or PT	50 %
Lap Fillet (For all thickness)		N/A
	MT or PT	50 %
Full Penetration Butt Weld (Shop & Site)	UT or RT	100 %
	MT or PT	100 %
Partial Penetration Butt Weld (Shop & Site)	UT	100 %
	MT or PT	50%

Remark: the requirements of UT and/or RT and MT and/or PT may be imposed at the discretion of the RSE and the feasibility of carrying out these NDTs may be dependent upon the actual configuration of a particular weld or structural steel connection.

Visual, ultrasonic, radiographic, magnetic and/or penetrant tests shall be carried out in accordance with the above table.

Visual tests (VT) shall be carried out in accordance with BS 5289, BS EN 970 or other applicable standards relevant to the specific project.

Ultrasonic tests (UT) shall be carried out in accordance with BS 3923: Part 1, BS EN 1714 or other applicable standards relevant to the specific project.

Radiographic tests (RT) shall be carried out in accordance with BS 2600: Part 1, BS EN 1435 or other applicable standards relevant to the specific project. Radiographic tests shall not be used on site unless required by the project specification.

Magnetic tests (MT) shall be carried out in accordance with BS 6072, BS EN 1290 or other applicable

standards relevant to the specific project.

Penetrant tests (PT) shall be carried out in accordance with BS 6443, BS EN 571-1 or other applicable standards relevant to the specific project.

#### **Acceptance criteria and corrective actions of welds**

All welds shall conform to the quality requirements of Table A3 and A4 of BS 5950-2:2001 for structural steelworks in buildings and Clause 5.5.2.4 of BS 5400-6 for structural steelwork in bridges, which also provides requirements for corrective measures in the event of non-conformance. (Note: the acceptance criteria adopted in BS5950-2 and Annex C of NSSS are essentially the same, see Annex A.)

#### **Non-destructive Testing of Welds - Hold time**

The requirement of hold time is the period allowed after completion of welding before commencement of final VT, UT, RT, MT, and/or PT. It is recommended to have the hold time of 24 hours.

In high restraint situations (e.g. cruciform welds) the hold time might need to be increased; with evidence of continual satisfactory production hold times might be reduced. Should there be any doubt, the advice of a welding specialist should be sought.

### **5. Quality Assurance of the Fabrication, Assembly and Erection of Steelwork**

The contractor for the fabrication, assembly and erection of structural steelworks shall be carried out a Registered General Building Contractor (RGBC) registered under the Building Authority.

The supervisory party such as the RSE should employ on behalf of the Client qualified and competent welding inspection personnel to supervise and oversee the full operation during fabrication and erection of structural steelworks. The welding inspection personnel shall be responsible for the following duties: -

- i) Implementation of a quality system and such system should be documented in a quality manual.
- ii) Project quality plans and quality procedures as set out for the assembly and erection processes. A mechanism should be in place to control each welding process.
- iii) Sufficient quality records should be kept for the traceability of each steel sectional component and defects of materials and workmanship to enable the carrying out of subsequent remedial works.
- iv) All necessary documentation records should be properly controlled.
- v) Performing supervisory and technical tasks that are competent for the job assigned. Organization chart, job responsibility description and training records should be established.
- vi) Prior to initiating procurement of sub-contractors service and/or materials supply, contract reviews should be carried out to ensure the procured services comply with the applicable requirements.
- vii) Sufficient quality inspection and testing should be conducted at various points of the assembly

and during the course erection processes. Appropriate equipment and calibrated measuring devices to be used.

viii) Non-conforming products should be controlled and corrective and preventive actions to be performed if necessary.

ix) Internal audits should be conducted by competent auditors at regular intervals of assembly and erection processes. Management reviews should be held by the supervisory and management staff to review the overall steelworks project.

x) A statistical control technique should be established by the RGBC and endorsed by the RSE for the relevant works.

xi) When the RGBC utilizes sub-contractors to carry out parts of the assembly and erection works, similar quality systems should be implemented by the respective subcontractors.

### Annex A Comparison of acceptance requirements and measurement definitions of welds between BS5950-2:2001 and NSSS for structural steelworks in buildings

Table A1 Acceptance requirements & measurement definitions of welds in Annex C of NSSS						
<i>(Requirements in BS5950-2 are shown in brackets and underlined; notes (a) to (g) should be referred to at the end of this Annex)</i>						
	Parameter	Weld Type	Particular Conditions <sup>(a)</sup>	Figure reference in Table A2	Acceptance criteria normal quality All dimensions in mm <sup>(b,c)</sup> (Notes 1 & 5)	Remedial action for non-conforming welds Table A2 (Note 2) <sup>(d)</sup>
Weld Geometry	Location <sup>(e)</sup>	All	-	-	$D \pm 10$	Repair <i>(Refer to Engineer)</i>
	Weld type	All	-	-	$D$	Refer to Engineer
	Length	All	-	-	$D + 10 - 0$	Repair <i>(Refer to Engineer)</i>
Profile discontinuities	<u>(Actual)</u> Throat thickness	All	-	(i), (ii), (iii)	$a, s \geq D(Av.50)$ $a, s \leq D + 5$	Repair and dress smooth
	Leg length	Fillet	-	(i)	$z \geq D(Av.50)$	Repair <i>(Refer to Engineer)</i>
	Toe angle	All	Transverse or Longitudinal	(i), (ii)	$\theta \geq 90^\circ$	Repair and dress smooth
	Excess weld metal	Butt	Transverse or Longitudinal	(ii)	$h \leq 6$	Repair and dress smooth
	Incomplete groove or concave root	Butt	Transverse	(ii)	$h \leq 0(Av.50)$	Repair <i>(Repair by welding to approved procedure)</i>
			Longitudinal	(ii)	$h \leq 0.1 t$	
Linear misalignment	Butt	Butt Joint	(iv)	$h \leq D + 0.2t$	Refer to Engineer	
	All	Transverse cruciform	(v)	$h \leq D + 0.4t$		

			Longitudinal	(iv), (v)	$h \leq D + 0.4t$		
Surface breaking discontinuities	Undercut <sup>(d)</sup>	All	Transverse (Not lap joint)	(iv), (v)	$h_1 + h_2 \leq 0.05t$ $l$ – No limit	Repair  <i>(Repair by welding to approved procedure)</i>	
		Fillet	Transverse (Lap joint)	(v)	$h_1 + h_2 \leq 0.03t$ $l \leq 10$		
		All	Longitudinal	(iv), (v)	$h_1 + h_2 \leq 0.1t$		
	Lack of root penetration	S/S Butt	Transverse		(iii)	$h \leq D + 0.05t(Av.50)$	Repair  <i>(Repair by welding to approved procedure)</i>
			Longitudinal		(iii)	$h \leq D + 0.1t(Av.50)$	
	Porosity	All	Transverse		(vi)	$d \leq 2$ $\Sigma d \leq 10[100]$	Repair  <i>(Repair by welding to approved procedure)</i>
		All	Longitudinal		(vi)	$d \leq 2$ $\Sigma d \leq 20[100]$	
Lack of fusion	All			(vii)	No permitted	Repair  <i>(Repair by welding to approved procedure)</i>	
Cracks	All		<i>(At crater Not at crater)</i>	(vii)	No permitted	Repair  <i>(Repair by welding to approved procedure)</i>	
Sub-surface discontinuities	Lack of fusion/  Root penetration,  slag lines	Butt	All		(vii)	$h \leq 3$	Repair  <i>(Repair by welding to approved procedure)</i>
			Transverse	Full depth $h_1 < 6$ $h_1 > 6$	(vii)	$\Sigma l \leq 1.5t[100]$ $l \leq 10$ $l' \geq 10$ $l$ – No limit $l'$ – No limit	
			Longitudinal	Full depth $h_1 < 6$ $h_1 > 6$	(vii)	$\Sigma l \leq 3t[100]$ $l$ – No limit $l'$ – No limit $l$ – No limit $l'$ – No limit	
	Root gap	Fillet,  P/P Butt			(i), (v)	$r_g \leq 2(Av.100)$  $r_g \leq 3$	Repair  <i>(Repair by welding to approved procedure)</i>
	Cracks	All				No permitted	Repair  <i>(Repair by welding to approved procedure)</i>
Lamellar tears	All		Transverse Longitudinal		No permitted <sup>(d)</sup>	Refer to Engineer	

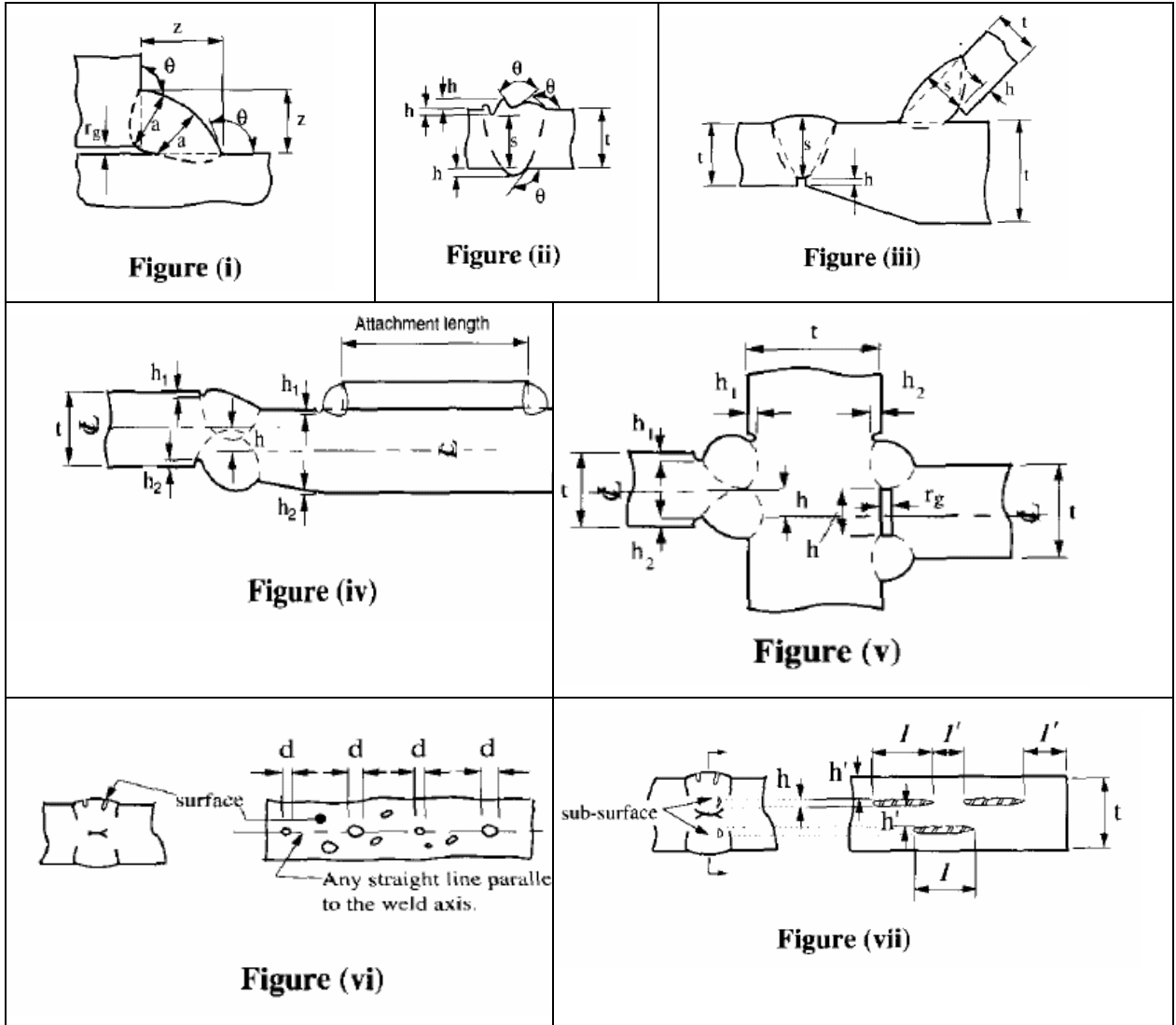


Table A2 Definition of measuring production welds in steel structures

<b>Abbreviated terms and notes applicable to NSSS (extracted from Table C.1)</b>			
D	As specified on drawing	Note 1	For definition of orientation see Table A2.
P/P	Partial Penetration	Note 2	Thickness applies to minimum member thickness at weld in question. For thicknesses greater than 20 mm 't' shall be taken as 20 mm.
Repair	Repair by welding to approved procedure		
S/S	Single sided		
$\geq$	(including butt weld in hollow section) Greater than or equal to (i.e. Not less than)	Note 3	"Lap" shall apply to any fillet welded attachment whose length in the longitudinal direction exceeds 50 mm.
$\leq$	Less than or equal to (i.e. Not greater than)	Note 4	Subject to any other locational requirements
$\Sigma$	Sum of	Note 5	Where more than one requirement is given both shall apply
(Av50)	Length of weld over which measurement may be averaged (mm)	Note 6	Where a repair is necessary an approved procedure shall be used. If on increasing the scope of inspection, further non-conformances are found, the scope shall further non-conformances are found, the scope shall be increased to 100% for the joint type in question.
[100]	Length of weld over which summation is made (mm)		
/	Length parallel to the weld axis-	Note 7	Lamellar tears may be accepted in the longitudinal welds only if extent does not exceed limits for lack of fusion in transverse welds.

<b>Notes applicable to BS5950-2:2001 (extracted from Table A.3)</b>			
<b>Abbreviated terms:</b>			
E	Refer to Engineer	a	For definition of orientation see Table A2.
NL	No limit	b	Thickness applies to minimum member thickness at weld in question. For thicknesses greater than 20 mm 't' shall be taken as 20 mm. Where permitted, size 'h' of a discontinuity is related to 't', the maximum permitted value shall not be less than 0.3 mm in any case.
NP	Not permitted (applies to discontinuities which are detectable by NDT methods in Table A1)	c	Where more than one requirement is given both shall apply
P/P	Partial Penetration	d	Where a repair is necessary an approved procedure shall be used.
R	Repair by welding to approved procedure	e	If on increasing the scope of inspection, further non-conformances are found, the scope shall further non-conformances are found, the scope shall be increased to 100% for the joint type in question. Subject to any other locational requirements
$\geq$	Greater than or equal to (i.e. Not less than)	f	"Lap" shall apply to any fillet welded attachment whose length in the longitudinal direction exceeds 50 mm.
$\leq$	Less than or equal to (i.e. Not greater than)	g	Lamellar tears may be accepted in the longitudinal welds only if extent does not exceed limits for lack of fusion in transverse welds.
$\Sigma$	Sum of		
( )	Length of weld over which measurement may be averaged (mm)		
[ ]	Length of weld over which the summation is made (mm)		
l	Length parallel to the weld axis		

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