

Ultra-high Strength Hot-rolled Steel

超高强度热轧结构钢

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前言 Preface

宝钢于2008年在国内率先开始超高强度热轧结构钢板卷产品开发，已形成屈服强度800MPa-1300MPa级别的BS系列超高强钢产品。该系列超高强结构钢采用宝钢先进的炼钢、轧制以及热处理工艺，产品不仅具有超高的强度，而且具有良好的低温韧性、可焊接性和冷成形性能。该系列产品性能稳定均匀，板形、表面等质量良好。

该系列产品可广泛应用于起重机、泵车等工程机械及车辆结构等制造行业。

Ultra-high strength steel (UHSS) with 800MPa yield strength for construction machinery was first developed in China by Baosteel in 2008. Now 800MPa-1300MPa of BS series of UHSS products have been available. These products are manufactured with advanced steel making, rolling, and heat treatment processes. They have stable excellent properties such as ultra high strength, good toughness at low temperature, good welding performance and cold formability. This series of products have stable performances, good plate shape and excellent surface quality.

These products have been widely used in vehicles and engineering machinery such as cranes, pump trucks.



制造工艺及交货状态

Manufacturing process and delivery condition

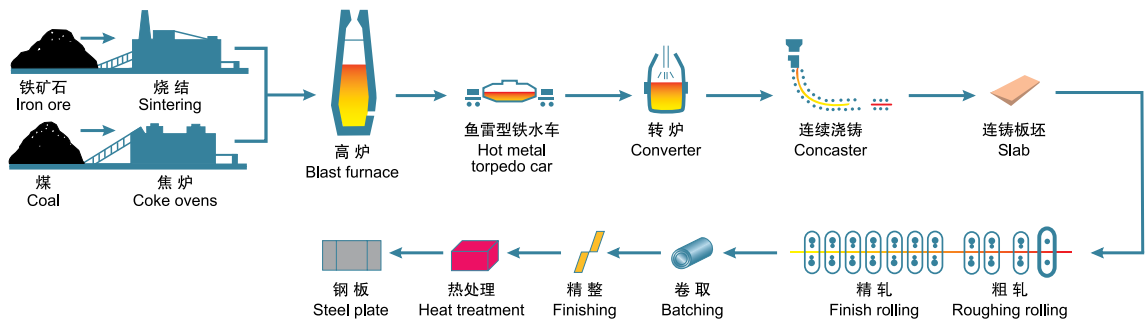
生产工艺流程：BS系列超高强钢采用氧气转炉冶炼镇静钢，经过炉外精炼后进行连续浇铸，连铸坯送热轧厂再加热并采用控轧控冷工艺轧制成卷，精整矫直切板，根据性能要求选择合适的热处理工艺，以热处理状态交货。(见图1)

交货状态：BS系列超高强钢采用热处理状态交货。

Manufacturing process: The BS series UHSS steel is killed in oxygen converter. After secondary refining and continuous casting, the slabs are reheated, rolled in TMCP rolling process, leveling and cutting process. Then, they will be heat-treated.

Delivery condition: The BS series UHSS steel is delivered in heat-treatment condition.

图1生产工艺流程
Fig.1 Manufacture process

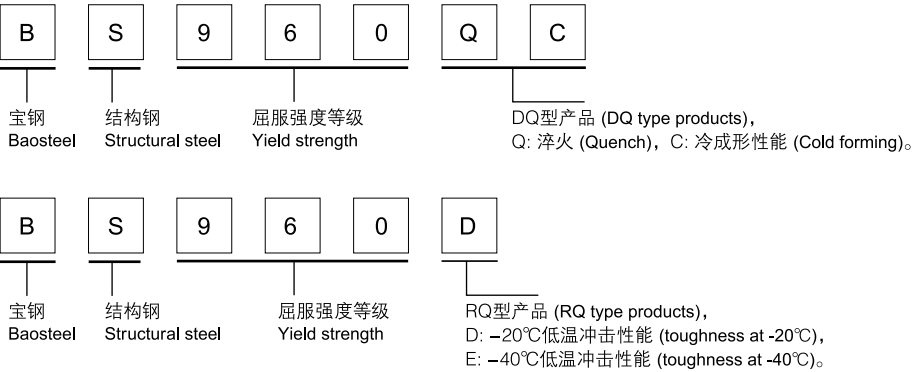


牌号及可供规格范围

Product range of dimensions

牌号意义

Designation



供货规格

Products available

宝钢BS系列超高强钢可供规格如表1所示，超出规格范围可与宝钢热轧高强钢产销研小组联系。

The available gauges of BS series UHSS steels are as shown in the table 1. Contact us if the required size is out of range.

表1 宝钢热轧超高强钢供货规格范围
Tab. 1 Gauge of Baosteel Hot-rolled UHSS

产品大类 Category	牌号 Grade	成品厚度 Thickness, mm	成品宽度 Width, mm	成品长度 Length, mm	交货状态 Delivery condition
DQ型 DQ type	BS800QC	3-4	850-1400	2000-12000	DQ+T (在线淬火+回火) (Direct quenching and tempering)
	BS900QC BS960QC	>4-8	850-1600		
RQ型 RQ type	BS900D(E) BS960D(E)	3-4	850-1650	2000-12800	Q+T (离线淬火+回火) (Reheating, quenching and tempering)
	BS1100D(E) BS1300D	>4-12	850-1850		

供货技术条件

Technical supply conditions

表2 供货技术条件—DQ型产品化学成分(wt%)

Tab. 2 Chemical composition of DQ type products

牌号 Grade	C	Si	Mn	P	S	Al _t
BS800QC	≤0.12	≤0.50	≤2.00	≤0.020	≤0.010	≥0.015
BS900QC	≤0.12	≤0.50	≤2.00	≤0.020	≤0.010	≥0.015
BS960QC	≤0.12	≤0.50	≤2.00	≤0.020	≤0.010	≥0.015

注：根据强度要求，可以加入Nb、V、Ti、Mo、B等合金元素。

Note: Nb, V, Ti, Mo, B may be added according to requirement

表3 供货技术条件—RQ型产品化学成分(wt%)

Tab. 3 Chemical composition of RQ type products

牌号 Grade	C	Si	Mn	Cr	Mo	P	S	Al _t	B
BS900 D(E)	≤0.20	≤0.50	≤2.00	≤1.0	≤1.0	≤0.015	≤0.005	≥0.015	≤0.005
BS960D(E)	≤0.20	≤0.50	≤2.00	≤1.0	≤1.0	≤0.015	≤0.005	≥0.015	≤0.005
BS1100D(E)	≤0.22	≤0.50	≤2.00	≤1.0	≤1.0	≤0.015	≤0.005	≥0.015	≤0.005
BS1300D	≤0.30	≤0.50	≤2.00	≤1.0	≤1.0	≤0.015	≤0.005	≥0.015	≤0.005

注：根据强度要求，可以加入Nb、V、Ti等合金元素。

Note: Nb, V, Ti may be added according to requirement

表4 供货技术条件—DQ型产品力学性能

Tab. 4 Mechanical properties of DQ type products

牌号 Grade	厚度 Thickness mm	拉伸试验 ⁽¹⁾ Tensile test				弯曲试验 ⁽²⁾ Bending test	冲击试验 ⁽³⁾ Impact test	
		方向 Direction	屈服强度 Yield strength ReH, MPa	抗拉强度 Tensile strength Rm, MPa	延伸率 Elongation A, %	弯曲内径 Bending diameter d	温度 Temperature	冲击值 ⁽⁴⁾ Charp impact, J
BS800QC	3-8	L	≥800	≥850	≥10	d=4a, 90°	-40°C	≥27
BS900QC	3-8	L	≥900	≥950	≥10	d=5a, 90°	-40°C	≥27
BS960QC	3-8	L	≥960	≥980	≥8	d=6a, 90°	-40°C	≥27

1) 拉伸试样方向T=横向，L=纵向。试样采用短比例标距， $l_0 = 5.65\sqrt{S_0}$ 。

2) 弯曲试验取横向试样，d=弯心直径，a=钢板公称厚度。

3) 冲击试验采用夏比V型缺口试样，取样方向平行于轧制方向（纵向试样），表中冲击值为全试样（10×10×55，mm）冲击值，采用1/2试样或3/4试样时，该值等比例减小；板厚<6mm时不做冲击性能检测。

4) 冲击功值为三个试样试验结果的平均值，允许其中一个试样的试验结果小于规定值，但不得小于规定值的70%。

1) Tensile test sample T=transverse direction, L=longitudinal direction. A short gauge length sample ($l_0 = 5.65\sqrt{S_0}$) is used in tensile test.

2) Transverse sample is used in bending test. d=bending diameter, a=thickness of steel sheet.

3) Charp V-notch longitudinal sample is used in impact test. The values in Tab. 4 are required from full sizes (10×10×55, mm).

The values are reduced proportionally when 1/2 samples or 3/4 samples are used. Impact test will not processed with sheet thickness <6mm.

4) Impact value is the average value of 3 test results. One result lower than criterion but not lower than 70% of criterion is permitted.

表5 供货技术条件—RQ型产品力学性能
Tab. 5 Mechanical properties of RQ type products

牌号 Grade	厚度 Thickness mm	拉伸试验 ⁽¹⁾ Tensile test				弯曲试验 ⁽²⁾ Bending test	冲击试验 ⁽³⁾ Impact test	
		方向 Direction	屈服强度 Yield strength ReH, MPa	抗拉强度 Tensile strength Rm, MPa	延伸率 Elongation A, %	弯曲内径 Bending diameter d	温度 Temperature	冲击值 ⁽⁴⁾ Charp impact, J
BS900D	3-12	L	≥900	≥950	≥12	d=5a, 90°	-20°C	≥27
BS900E							-40°C	≥27
BS960D	3-12	L	≥960	≥980	≥10	d=6a, 90°	-20°C	≥27
BS960E							-40°C	≥27
BS1100D	3-12	L	≥1100	≥1250	≥8	d=6a, 90°	-20°C	≥27
BS1100E							-40°C	≥27
BS1300D	3-12	L	≥1300	≥1350	≥8	d=8a, 90°	-20°C	≥27

1) 拉伸试样方向T=横向, L=纵向。试样采用短比例标距, $l_0 = 5.65\sqrt{S_0}$ 。
2) 弯曲试验取横向试样, d=弯心直径, a=钢板公称厚度。
3) 冲击试验采用夏比V型缺口试样, 取样方向平行于轧制方向(纵向试样), 表中冲击值为全试样(10×10×55, mm)冲击值, 采用1/2试样或3/4试样时, 该值等比例减小; 板厚<6mm时不做冲击性能检测。
4) 冲击功值为—组三个试样试验结果的平均值, 允许其中一个试样的试验结果小于规定值, 但不得小于规定值的70%。
1) Tensile test sample T=transverse direction, L=longitudinal direction. A short gauge length sample ($l_0 = 5.65\sqrt{S_0}$) is used in tensile test.
2) Transverse sample is used in bending test. d=bending diameter, a = thickness of steel sheet.
3) Charp V-notch longitudinal sample is used in impact test. The values in Tab. 5 are required from full sizes (10×10×55, mm).
The values are reduced proportionally when 1/2 samples or 3/4 samples are used. Impact test will not processed with sheet thickness <6mm.
4) Impact value is the average value of 3 test results. One result lower than criterion but not lower than 70% of criterion is permitted.

用户使用技术

Application technology

焊接工艺

Welding technology

1 预热和层间温度

Preheating and interpass temperature

宝钢BS系列高强钢通过合理的化学成分设计及先进的生产工艺制造, 保证其拥有优良综合力学性能及优良的焊接性。其典型的碳当量Ceq及冷裂纹敏感性指数Pcm见表6。为了避免出现焊接冷裂纹, 表6同时给出了不同产品、不同规格的预热及层间温度推荐值。

Baosteel BS series steel is developed with reasonable chemical composition and advanced manufacture process to ensure excellent mechanical properties and weldability. Typical values of carbon equivalents (Ceq) and cold cracking sensitivity indexes (Pcm) are given in table 6. The recommended preheat temperature and interpass temperature of steel with different types and thickness are also given in table 6 to minimize the risk of welding cold cracking.

表6 BS系列超高强钢产品典型碳当量、冷裂纹敏感性指数及预热、层间温度推荐

Tab. 6 Typical Ceq, Pcm and cold cracking sensitivity index of BS series UHSS and recommended preheating and interpass temperatures

牌号 Grade	Ceq (IIW)	Pcm	最低预热温度 Minimum preheat temperature				最高层间温度 Maximum interpass temperature	
			< 5mm	5~10mm	10~12mm	12~14mm		
BS800QC	0.39	0.17	室温 Room temperature (20℃)				150℃	
BS900QC	0.48	0.21	室温 (20℃) Room temperature					75℃
BS960QC	0.48	0.21						
BS900D	0.50	0.28						
BS900E	0.50	0.28						
BS960D	0.50	0.28						
BS960E	0.50	0.28						
BS1100D	0.56	0.30	室温 (20℃) Room temperature		75℃			
BS1100E	0.56	0.30						
BS1300D	0.64	0.37						

$$Ceq(IIW) = C + \frac{Mn}{6} + \frac{(Mo+Cr+V)}{5} + \frac{(Ni+Cu)}{15}$$

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

同种钢不等厚焊接时，应采取的预热和层间温度取决于最大板厚；同一板厚不同强度钢焊接时，应采取的预热和层间温度取决于强度较高钢种；异种钢焊接时，应采取的预热和层间温度取决于焊接工艺要求较高钢种。

如果环境湿度大，或者温度低于5℃，最低推荐预热温度应再增加25℃

2 焊接热输入

Welding heat input

钢板受到焊接热输入作用，其力学性能及微观组织产生相应的变化，因此焊接热输入对整个焊接接头区域性能起到至关重要的作用。

焊接热输入取决于焊接电流、焊接电压及焊接速度，通常，我们用如下公式计算焊接过程热输入。

$$Q = \frac{U \times I}{V}$$

宝钢BS系列高强结构钢系列产品推荐焊接热输入见表7所示。

$$Ceq(IIW) = C + \frac{Mn}{6} + \frac{(Mo+Cr+V)}{5} + \frac{(Ni+Cu)}{15}$$

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

When welding same steel with different thickness, the preheating and interpass temperatures depend on the thicker one. When welding same steel with different strength, the preheating and interpass temperatures depend on the stronger one. When welding different steel, the temperatures depend on the steel requiring higher welding process demands.

If the ambient humidity is high or the temperature is below +5℃, another 25℃ should be added to the recommended lowest preheating temperature.

The mechanical properties and microstructure of steel sheets will be changed by the welding heat input, which is critical to properties of entire welded joints.

The heat input depends on current, voltage, and welding speed with the formula as following

$$Q = \frac{U \times I}{V}$$

The recommended heat input of Baosteel BS series steels is shown in Table 7

表7 宝钢BS系列产品在最低预热温度下GMAW热输入推荐
Tab. 7 recommended GMAW heat input at minimum preheating temperature








强度级别 Grade	热输入 (Q) kJ/cm Heat input		
	t ≤ 6mm	6 < t ≤ 10mm	10 < t ≤ 14mm
BS800	≤ 8	≤ 12	≤ 15
BS900	≤ 8	≤ 10	≤ 12
BS960			3-12
BS1100			
BS1300			

3 焊材选择与推荐
Matched welding consumables

为了最大程度的减少焊接冷裂纹的产生，在焊接BS系列产品时，建议采用实心焊丝气体保护焊（GMAW），与钢种匹配的焊接材料推荐表如下。

In order to minimize the risk of welding cold cracking, GMAW method is recommended and matched welding consumables are shown in table 8.

表8 宝钢BS产品焊材匹配推荐
Tab. 8 Recommended matched welding consumables for Baosteel BS steels

Rp0.2 MPa	500	600	700	800	900	
EN标准 EN standard	EN12534 G62X EN440 G50X	EN12534 G62X	EN12534 G69X	EN12534 G79X	EN12534 G89X	
AWS标准 AWS standard	AWS A5.28 ER80S-X ER90S-X	AWS A5.28 ER100S-X	AWS A5.28 ER110S-X	AWS A5.28 ER120S-X	AWS A5.28 ER140S-X	
宝钢产品 Baosteel products	BH600-II	BH700-II	BH800-II	BH900-II	BH1000-II	
BS800						
BS900						
BS960						
BS1100						
BS1300						

 等强匹配 (Equal strength matching)  低强匹配 (lower strength matching)

对于BS系列产品，在选择焊材时，应根据实际需求选择匹配形式。等强匹配形式多用于承载焊缝，要求焊接接头有强度保证，焊缝服役在高应力环境；低强匹配形式用于联系焊缝等其他形式，焊缝服役在低应力环境。

For BS series steels, the matched welding consumable should be selected in accordance with the actual requirement. Consumables with equal strength are recommended in load-bearing joints. And consumables with lower strength are recommended in other working situations such as welded joints enduring low stresses.

4 接头疲劳性能

Fatigue in welded joints

疲劳断裂是焊接结构失效的主要方式，占焊接结构总断裂事故的70-80%以上。焊接接头疲劳强度并不会随静载强度的大幅度提高而明显提高，有时甚至会降低。工程机械的工况大多承受动载荷及重载荷，因此从保证结构安全可靠的角度，需要评价高强钢接头的疲劳性能。

本手册以8mm厚BS960QC的气保焊为例，评价了对接接头和十字接头（图2）的疲劳性能，焊材使用BH900-II。疲劳载荷类型为恒幅轴向拉-拉应力，应力循环比0.1，循环次数为 2×10^6 。试验评价标准BS7608。疲劳性能见表9所示。

Fatigue is a very important consideration for welded structures that are subjected to variable loads. Up to 70%~80% of failures in welded structures are believed to be related to fatigue. The importance is even greater when using high strength steel because the fatigue strength of a welded joint is almost the same. Engineering machines are usually subjected to variable loads and high stress loads. In order to ensure the safety of welded structures, it is necessary to assess the fatigue performance of high strength welded joints.

For instance, the fatigue performance of both butt and cruciform joints of BS960 with the thickness of 8mm, which is obtained by GMAW using solid welding wire BH900-II, is given in table 9. Both joints are shown in Fig. 2. The samples are tested under constant amplitude loading at an axial tensile stress state with a stress ratio 0.1 and cycle index 2×10^6 , according to the British Standard BS7608.

图2 疲劳接头试样

Fig. 2 welded Joints samples for fatigue test



对接接头 (Butt joint)



十字接头 (Cruciform joint)

表9 宝钢BS960QC匹配BH900-II接头疲劳性能

Tab. 9 The fatigue performance of GMAW welded joints BS960/BH900-II

接头形式 Joint type	2×10 ⁶ 循环下的疲劳极限 (MPa) Fatigue strength at 2×10 ⁶ cycles		BS7608标准要求 Requirement in Standard BS7608
	基于疲劳极限试验 based on fatigue limit test	基于拟合的均值S-N曲线 Based on S-N curve	
BS960 对接接头 Butt joint	140	128.8	118 (Class E)
BS960 横向十字接头 Cruciform joint	135	106.9	95.2 (Class F)

切割

Cutting

BS系列超高强钢推荐采用热切割方式，如激光切割或等离子切割，切割表面平滑，热影响区小，对钢板的力学性能影响可忽略不计。

BS超高强钢不推荐机械方式进行切割下料（包括剪切、冲裁、圆盘剪切等）。

Thermal cutting is recommended to BS series UHSS, such as Laser cutting and plasma cutting, in order to obtain smooth surface and narrowest heat affected zone. The reduction of mechanical properties can be ignored.

Mechanical cutting of BS UHSS is highly not recommended, such as shearing, blanking, disc shearing, etc.

冷弯加工

Cold forming

BS系列超高强钢具有良好的塑性，适合冷弯加工。折弯时，弯曲半径应大于技术条件中的规定值。除了折弯半径和折弯角，钢板表面质量、切边质量、折弯方向都可能影响折弯质量。

超高强钢的回弹较大，成型时应通过适当的过弯曲来保证获得所需的折弯角度。

With high strength and good formability, BS series steel is suitable for cold forming. It is suggested the actual bending diameter should be no less than the diameter specified in the delivery condition. Also to note, the rebounding of high strength steels is greater than conventional steel and might result in the deviation of the shape. Suitable over-bending could be applied to get the required angle.

矫形

Leveling

BS系列超高强钢如需矫形时，建议采用冷矫形方式。如特殊情况下需要采用热矫形时，BS800、BS900和BS960级别超高强钢的热矫形温度建议不超过500℃，BS1100和BS1300级别超高强钢不建议进行热矫形。

Cold leveling is recommended when deviation occurs after the forming of BS series steel. If heat leveling must be used in exceptional situation, the heat leveling temperature of BS800, BS900, BS960 is suggested not to be greater than 550℃ in order to avoid changes in properties. Heat leveling of BS1100, BS1300 is not recommended.



用户技术支持

Technical customer service

如您在选择、使用BS超高强结构钢时存在疑问或需要帮助，请洽：

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【销售管理】**温夏玲** 薄板销售部热轧室 021-26648124 wenxl@baosteel.com

If you need any help in using BS UHSS steels, please contact following telephone numbers

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【Customer service】**Li Fengbin** Customer and product service department 021-26642663 lifengbin@baosteel.com

【Sales management】**Wen Xialing** Sheet sales department 021-26648124 wenxl@baosteel.com

结束语

Our vision

宝钢一贯秉持“要善于学习，更要善于创新”的创业精神，在热轧高强钢的开发征程上勇于开拓进取，产品不断升级换代，技术不断突破创新，我们愿以更好的产品和服务全心全意地效力于国内外工程机械行业的进步发展。

Following the creed, “Good at learning and good at innovation”, Baosteel is pioneering in the development of high strength hot-rolled steel, continuing the upgrade of products and breakthrough of technology. With high quality products and full-hearted service, Baosteel will contribute to the development of domestic and foreign construction machinery industry.

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东北亚及澳洲大区 Northeast Asia and Oceania Region

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