8

Construction Steel

This chapter focuses on the mechanical properties of construction steel, the cold working and strengthening of steel, and the standards and selection of steel. It introduces the corrosion reasons of steel and the measures to prevent corrosion. It simply introduces the fire protection of steel.

Steel consists mostly of iron, with a carbon content under 2% and various other elements.

Construction steel refers to various steel materials used in construction projects, including various materials used for steel structures (such as round steel, angle steel, joint steel, and steel pipe), plates, and steel bars, steel wires, and strands used in concrete structure.

Steel is the material produced under strict technical conditions, and it has the following advantages: even materials, stable properties, high strength, certain plasticity and toughness, and the properties to bear impacts and vibration loads, and can be welded, riveted, or screwed; the disadvantages are: easy to be corroded and high cost of repairs.

These characteristics determine that steel is one of the important materials needed by economic construction departments. In construction, the steel structures consisted by steel in various shapes have high security and light deadweight, used for large-span and high-rise structures. However, because every department needs a large amount of steel, the wide use of steel structure is limited to some extent. But though concrete structures have heavy deadweight, the usage of steel is decreased greatly, and it can overcome the corrosion and high cost of repairs of steel. Thus, steel is widely used in concrete structures.

8.1 Classifications of Steel

8.1.1 By Smelting Processes

Smelting is to oxidize the molten pig iron to reduce its carbon content to the scheduled range and to remove the other impurities to allowable range. During smelting, the removal degrees of impurities by different smelting methods are not the same, so the steel qualities are different. Recently, there are three kinds of steel, including Bessemer steel (converter steel), Siemens-Martin steel, and electric steel.

1. Bessemer Steel

The smelting process of this steel is to use the molten pig iron as the raw material without any fuel and to make steel with air being blown through the molten iron (the raw material) from the bottom or the sides of the converter, called pneumatic converter steel; if pure oxygen is used to replace the air, it is called the oxygen converter steel. The disadvantage of pneumatic converter steel is that the nitrogen, hydrogen and other impurities in the air will interfuse easily, the smelting time is short, and the impurity content is difficult to control, so the quality is poor; the quality of oxygen converter steel is high, but the cost is a little higher.

2. Siemens-Martin Steel

The process of Siemens-Martin steel is to use solid or fluid pig iron, ore or waste steel as the raw materials and coal gas or heavy oil as the fuel and to remove the impurities from the iron by oxidation with the oxygen in ore or waste steel or the oxygen being blown through the iron. Because the smelting time is long (4~12h), the impurities are removed clearly and the quality of steel is good. But the cost is higher than that of Bessemer steel.

3. Electric Steel

The process of electric steel is to make steel by electric heating. The heat source is high-tension arc, and the smelting temperature is high and can be adjusted freely, so the impurities can be removed clearly and the steel quality is good.

8.1.2 By Deoxidation Methods

Unavoidably, there will be part of ferric oxide left in molten steel during the smelting process, which reduce the steel quality. Thus, deoxidation is needed during the ingot casting. The steel made by different deoxidation methods has various properties. Therefore, there is rimmed steel, fully-killed steel, and semi-killed (or semi-deoxidized) steel.

1. Rimmed Steel

It is the unkilled steel which is deoxidized only by ferromanganese, a weak deoxidizer. Because the remained FeO in the molten steel can generate CO with C, there are a lot of foams in the process of casting ingot, like boil, known as rimmed steel. Its organization is not dense enough and contains foams, so the quality is poor; but the rate of finished products is high and the cost is low.

2. Fully-killed Steel

This kind of steel is deoxidized thoroughly with a certain amount of silicon, manganese, and aluminum deoxidizers. Because deoxidation is thorough, the molten steel can solidify calmly in ingot casting, known as fully-killed steel. Its organization is dense, chemical elements are even, and properties are stable, so its quality is good. However, the productivity is low, so the cost is high. It can be employed in the steel structures used to bear impacts, vibration or important welding.

3. Semi-killed Steel

Its deoxidation degree and quality are between the above two.

8.1.3 By Press-working Modes

In the process of smelting and ingot-casting, there will be uneven structures, foams or other defects happening to the steel, so the steel used in industry should be processed by press to eliminate the defects. Meanwhile, there is requirement for shapes. The press-working modes include hot working and cold working.

1. Hot-working Steel

Hot working is to heat the steel ingot to a certain temperature and to conduct press-working to the steel ingot in the plastic state, such as hot rolling and hot forging.

2. Cold-working Steel

The steel is processed under the normal temperature.

8.1.4 By Chemical Elements

Steel Classifications (GB/T13304-91), the Chinese standard, recommends two classification methods: one is to classify by chemical elements, and the other is to classify by quality degrees. By chemical elements, there is non-alloy steel, lean-alloy steel and alloy steel.

1) Non-alloy Steel: that is carbon steel with few alloy elements.

2) Lean-alloy Steel: that is the steel with low alloy elements.

3) Alloy Steel: that is the steel added with more alloy elements to improve some properties of the steel.

8.1.5 By Quality Degrees

According to quality degrees, the steel can be classified into: common steel, quality steel and advanced quality steel.

8.1.6 By Purposes

The steel can be classified by purposes, such as construction steel, railway steel, and pressure vessel steel. The construction steel can be classified by purposes into the steel for steel structures and that for concrete structures. At present, the steel commonly used in constructions includes carbon structural steel and lean-alloy and high-strength structural steel.

8.2 Characteristics of Steel

8.2.1 Characteristics of Steel

The characteristics of steel include strength, elasticity, plasticity, toughness and rigidity.

1. Tensile Strength

The tensile strength of construction steel includes: yield strength, ultimate tensile strength, and fatigue strength.

(1) Yield Strength or Yield Limit

Subjected to the dead load, steel starts to lose the ability to resist deformation and generates a great deal of stress in plastic deformation. As shown in Figure 8.1, at the yield stage, the corresponding stress of the highest point on the hackle is called the upper yield point (B_{up}); the corresponding stress of the lowest point is called the lower yield point (B_{down}). Because the yield points are unstable, the Chinese Standard regulates that the stress of the lower yield point is the yield strength of the steel, expressed by σ_s. Medium carbon steel and high carbon steel have no obvious yield points, so 0.2% of the stress of the residual deformation is the yield strength, expressed by $\sigma_{0.2}$, shown in Figure 8.2.

Yield strength is very important to the use of steel. When the actual stress of a structure reaches the yield point, there will be irretrievable deformation which is not allowed in constructions. Thus, yield strength is the main base to determine the allowable stress of the steel.

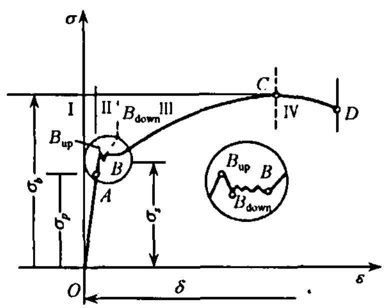


Figure 8.1 Stretching of Low Carbon Steel σ - ε

I The elastic stage, expressed by σ_p ; II The yield stage, expressed by σ_s

III The reinforcement stage, expressed by σ_b ;IV The necking stage.

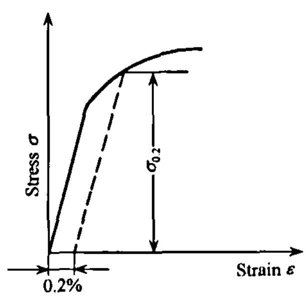


Figure 8.2 The Assigned Yield Point of Hard Steel

(2) Ultimate Tensile Strength (Simply Called Tensile Strength)

It is the ultimate tensile stress that the steel can bear under the role of tension, shown in Figure 8.1, the highest point of stage III. Tensile strength cannot be the calculated base directly, but the ratio of yield strength to tensile strength is the yield ratio, namely, $\frac{\sigma_s}{\sigma_b}$ which is very important in constructions. The smaller the yield ratio is, the more reliable the structure is, that is, the higher the potential to prevent the damage of the structure is; but if the ratio is too small, the available utilization ratio of the steel will be too low, and the reasonable yield ratio should lie between 0.6~0.75. Therefore, the yield strength and the tensile strength are the major test indexes of the mechanical properties of steel.

(3) Fatigue Strength

Under the role of alternating loads, steel will be damaged suddenly when the stress is far below the yield strength, and this damage is called fatigue failure. The value of stress at which failure occurs is called fatigue strength, or fatigue limit. The fatigue strength is the highest value of the stress at which the failure never occurs. Generally, the biggest stress that the steel bears alternating loads for 10^6~10^7 times and no failure occurs is called the fatigue strength.

2. Elasticity

Figure 8.1 shows that the steel is subjected to the dead load and the ratio of the stress to the strain at stage *OA* is the elastic stage. This deformation property is called elasticity. At this stage, the ratio of the stress to the strain is the modulus of elasticity, that is, $E=\frac{\sigma}{\varepsilon}$ with MPa as the unit.

The modulus of elasticity is the index to measure the ability of the steel to resist deformation. The bigger E is, the higher the stress that causes its deformation is; and under the certain stress, the smaller the elastic deformation will be. In projects, the modulus of elasticity reflects the rigidity of the steel which is an important value to calculate the deformation of a structure under stress. The elastic modulus of Q235, the carbon structural steel commonly used in constructions, is calculated as follows: E=(2.0~2.1) $\times 10^5$MPa.

3. Plasticity

The construction steel should have good plasticity. In projects, the plasticity of the steel is usually expressed by the elongation (or the reduction of cross-section area) and cold bending.

1) Elongation refers to the ratio of the increment of the gauge length to the original gauge length when the specimen is stretched off, expressed by δ (%), shown in Figure 8.3.

$$\delta = \frac{l_1 - l_0}{l_0} \times 100\%$$

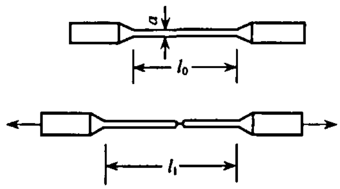


Figure 8.3 Elongation of Steel

2) Reduction of cross-section area is the percentage of the cross-section shrinkage quantity of the neck-shrinking part to the original cross-section area when the specimen is stretched off, expressed by ϕ (%).

For the sake of measurement, elongation is often used to express the plasticity of steel. Elongation is the important index to measure the plasticity of steel. The bigger the elongation is, the better the plasticity of steel is. The elongation is related to the gauge length, and usually δ_5 and δ_{10} are used to express the elongation when $l_0=5a$ and $l_0=10a$ respectively. For the same steel, $\delta_5 > \delta_{10}$.

3) Cold bending is the property that the steel bears the bending deformation under the normal conditions. The cold bending is tested by checking whether there are cracks, layers, squamous drops and ruptures on the bending part after the specimen goes through the regulated bending. Generally, it is expressed by the ratio of the bending angle α and the diameter of the bending heart d to the thickness of the steel or the diameter of the steel a. Figure 8.4 shows that the bigger the bending angle is, the smaller the ratio of d to a is, and the better the cold bending property is.

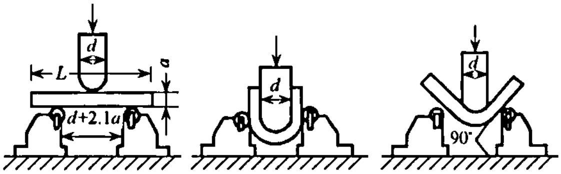


Figure 8.4 Cold Bending Test of Steel

d. diameter of the bending heart; *a*. the thickness or the diameter of the specimen; α . the cold bending angle (90°)

Cold bending is a method to check the plasticity of steel and is related to the elongation. The steel with bigger elongation has better cold bending property. But the cold bending test for the steel is more sensitive and strict than the tension test. Cold bending test is helpful to expose some defects of steel, such pores, impurities and cracks. In welding, the brittleness of parts and joints can be found by cold bending test, so the cold bending test is not only the index to check plasticity and processability, but also an important index to evaluate the welding quality. The cold bending test for the steel used in important structures or the bended steel should be qualified.

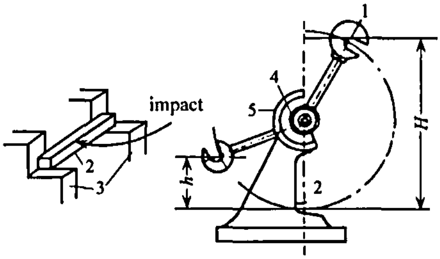
Plasticity is an important technical property for steel. Though the structures are used during the elastic stage, the part where the stress converges could be beyond the yield strength. And certain plasticity can guarantee the redistribution of the stress to avoid failure of structures.

4. Impact Durability

Impact durability refers to the property that the steel resist loads without being damaged. It is regulated that the impact durability is expressed by the work spent on the unit area of the damaged notch when the standard notched specimen is stricken by the pendulum of the impact test, with the sign α_K and the unit J, as shown in Figure 8.5. The bigger α_K is, the more work will be spent in damaging the specimen, or the more energy the steel will absorb before getting cracked, and the better the durability of the steel is.

The impact durability of the steel is related to its chemical elements, smelting, and processing. Generally, *P* and *S* contents in steel are high, and impurities and the tiny cracks forming in smelting will lower the impact durability.

In addition, the impact durability of the steel can be influenced by temperature and time. At the room temperature, the impact durability will decline little with the temperature falling, and the damaged steel structure reveals the ductile fracture; if the temperature falls into a range, α_K declines suddenly, as shown in Figure 8.6, the steel reveals the brittle fracture, and the temperature is very low when cold brittle fracture occurs. In north, especially the cold places, the brittle fracture of the steel should be tested when the steel is used. The critical temperature of its brittle fracture should be lower than the lowest temperature of the place. Because the measurement of the critical temperature is complicated, what is regulated in standards is the impact values at the negative temperature -20℃or -40℃.



(a) Test Device (b)Working Principle of Pendulum Tester

Figure 8.5 The Test Principle of Impact Durability

1. Pendulum; 2. Specimen; 3. Test-bed; 4. Dial; 5. Needle

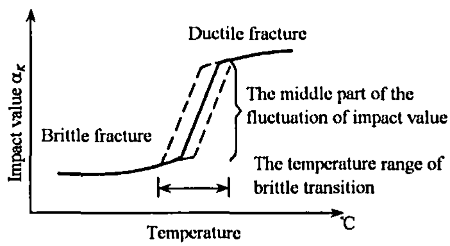


Figure 8.6 The Impact of Humidity on Impact Durability

5. Rigidity

Rigidity is the property to resist the plastic deformation when there is a hard object press into the steel within the partial volume of the surface, often related to the tensile strength. Recently, there are various methods to measure the rigidity of the steel, and the most common one is Brinell hardness, expressed by HB.

The yield strength, tensile strength, elongation, cold bending, and impact durability of the steel are usually used as the base for the evaluation mark.

8.2.2 Influences of the Steel Composition on Other Properties

1. Steel Composition

Steel is iron-carbon alloy. Besides iron and carbon, there are a large number of other elements left due to the raw materials, fuels, and smelting process, such as silicon, oxygen, sulfur, phosphor, nitrogen and others. Alloy steel is the modified steel added with some elements, like manganese, silicon, vanadium and titanium.

The combination of iron and carbon atoms in the steel has three basic modes: solid solution, compound, and mechanical mixture. Solid solution uses as the dissolvent and carbon as the solute, and the iron remains its original crystal lattice and carbon dissolves in it; compound is the chemical compound of Fe and C (that is, Fe_3C) whose crystal lattice is different from the original one; and mechanical mixture is the combination of the above solid solution and the compound. The so-called organization of the steel is composed by the above single combination mode or several combination modes. And it is a kind of polymer. The basic composition of the steel includes ferrite, cementite, and pearlite.

1) Ferrite is the solid solution of carbon in iron. Because the void between atoms is very small and C is hard to dissolve in the iron, it is just like pure iron, which renders the steel with good ductibility, plasticity and durability as well as low strength and rigidity.

2) Cementite is the compound of iron and carbon, Fe_3C, with the carbon content of 6.67%. It is hard and brittle and the major component of the strength of carbon steel.

3) Pearlite is the mixture of ferrite and cementite, with high strength and medium plasticity and durability (between the above two).

The mechanical properties of the three basic components are listed in Table 8.1.

Table 8.1 Elements and Mechanical Properties of the Basic Composition

Name	Element	Tensile Strength (MPa)	Elongation (%)	Brinell Hardness (HB)
Ferrite	A small amount of pure iron of carbon dissolving in the crystal texture of steel with	343	40	80
Pearlite	The mixture of ferrite and cementite in a certain proportion (carbon content is 0.80%)	833	10	200
Cementite	The grain of (Fe_3C) in the crystal texture of steel	Below 343	0	600

If C=0.8%, the steel with only pearlite is called eutectoid steel; if the carbon content is lower than 0.8%, the steel is called hypo-eutectoid steel; if the carbon content is higher than 0.8%, the steel is called hyper-eutectoid steel. The building steel is the hypo-eutectoid steel. The relations between the steel, carbon content and components are listed in Table 8.2.

Table 8.2 Relations between Steel, Carbon Content and Components

Name	Carbon Content	Components
Hypo-eutectoid Steel	<0.8	Pearlite + Ferrite
Eutectoid Steel	0.80	Pearlite
Hyper-eutectoid Steel	>0.80	Pearlite + Cementite

2. Influences of Chemical Elements on the Properties of Steel

(1) Carbon

Carbon is the major element that determines the properties of steel.

The influence of carbon on the mechanical properties of carbon is shown in Figure 8.7. With the increasing of carbon content, the rigidity and the trength of steel will increase, and its plasticity and toughness will decrease. If the carbon content is more than 1%, the ultimate strength of the steel begins to fall. In addition, if the carbon content is too high, the brittleness and aging sensitivity of the steel will rise, which reduce its ability to resist the corrosion of the atmosphere and weldability.

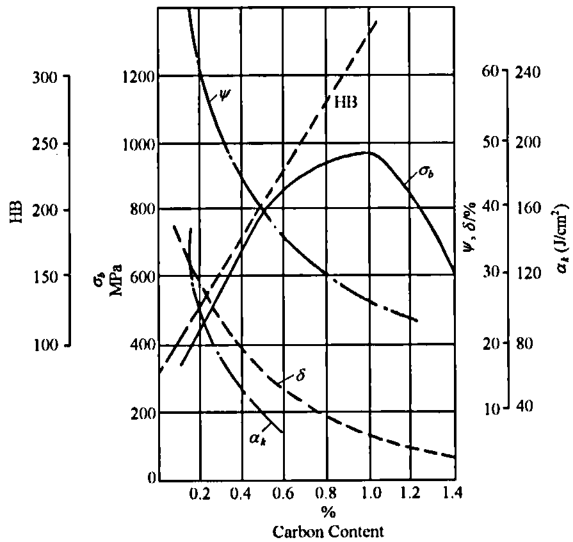


Figure 8.7 Influences of Carbon Content on Properties of Hot-rolled Carbon Steel

σ_b. Tensile Strength ; α_k .Impact Toughness; HB. Hardness; δ . Elongationl; φ . Shrinkage of Cross-section

(2) Phosphor and Sulfur

Phosphor is similar with carbon that can improve the yield point and bending strength of steel, lower its plasticity and toughness, and greatly increase its cold brittleness. But the segregation of phosphor is serious and there are cracks in welding, so phosphor is one of the elements that can lower the weldability of steel. Thus, in carbon steel, the phosphor content should be controlled strictly; but in alloy steel, it can improve the resistance to atmospheric corrosion of steel, and can also be the alloy element.

In steel, sulfur exists in the mode of FeS. FeS is a kind of low melting compound that has been melted when the steel is processed or welded in the state of glowing red and will lead to cracks inside the steel, called hot brittleness. The hot brittleness greatly reduces the processability and weldability of steel. In addition, the segregation of sulfur is serious that can reduce the impact-resistance, fatigue strength and anti-corrosion of steel. Thus, the sulfur content should also be controlled strictly.

(3) Oxygen and Nitrogen

Oxygen and nitrogen can partly dissolve in ferrite and most of them exist in the mode of compounds. These non-metals contain impurities that reduce the mechanical properties of steel, especially the toughness of steel, and can accelerate aging and lower weldability. Thus, the oxygen and nitrogen should be controlled strictly in steel.

(4) Silicon and Manganese

Silicon and manganese are the elements added purposely during steelmaking for deoxidation and desulphurization. Because silicon can combine with oxygen greatly, it can capture the oxygen in ferric oxide to generate silicon dioxide and stay in the steel slag. Most of the remaining silicon will dissolve in ferrite. And when the content is low (less than 1%), it can improve the strength of steel and has little influence on plasticity and toughness. Combining force of manganese with oxygen and sulfur is higher than that of iron, so manganese can change FeO and FeS into MnO and MnS respectively and stay in the steel slag. And the remaining manganese dissolves in ferrite and twists the crystal lattice to prevent slippage and deformation, greatly improving the strength of steel.

8.3 Cold Working, Ageing and Welding

8.3.1 Cold Working

Cold working is the process that steel is processed at the room temperature. The common cold working modes for construction steel include: cold stretching, cold drawing, cold rolling, cold twisting, notching.

At the room temperature, beyond the elastic range of the steel, the plastic deformation strength and rigidity of the steel have increased and its plasticity and toughness have decreased, which is called cold-working strengthening. As shown in Figure 8.8, the stress—strain curve of steel is $OBKCD$; if the steel is stretched to point K and release the tension, the steel will recover to point O'; and if it is stretched again, the stress—strain curve will be $O'KCD$, and the new yield point (K) is higher than the original yield point (B), but the elongation decreases. Within a certain range, the bigger the cold-working deformation is, the greater the yield strength increases, and the more the plasticity and the toughness decrease.

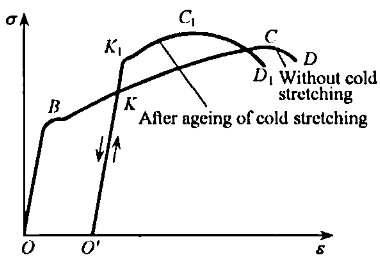


Figure 8.8 The Curve of Cold Stretching of Steel Bar

8.3.2 Ageing

With the extension of time, if the strength and the rigidity of steel increase and the plasticity and the rigidity of steel decrease, it is called ageing. The ageing process of steel under the natural state is very slow. If the steel often suffers vibrating and impact loads in cold working or use, the ageing will develop fast. After cold working, the yield strength, tensile strength and rigidity of steel will increase but the plasticity and the toughness keep decreasing, if the steel stay at room temperature for 15~20 days or is heated to 100~200℃ for 2h. The former is called natural ageing, and the latter is called artificial ageing. As shown in Figure 8.8, after cold working and ageing, the stress—strain curve is $O'K_1C_1D_1$; and the yield strength (K_1) and the tensile strength (C_1) are higher than those before ageing. Generally, the steel with lower strength adopts natural ageing, and the steel with higher strength adopts artificial ageing.

The degree to which the properties of steel have been changed by ageing is called ageing sensitivity. The bigger the sensitivity is, the greater the plasticity and the toughness have been changed. Thus, the important structures bearing vibrating and impact loads (such as crane beam and bridge) should use the steel with small ageing sensitivity.

Cold working and ageing are often used to improve the strength of building steel, increase the varieties and dimensions of steel and save steel.

8.3.3 Welding

Welding is the major mode for the combination of steel. The quality of welding depends on the welding techniques, welding materials and the weldability of steel.

Weldability refers to the property that under a certain welding condition, there is no crack or hard rupture in or around welding seams and the mechanical property after welding, especially the strength, should be not lower than the original one.

Weldabiltiy is often impacted by chemical components and the contents. The weldability will decrease, if the carbon content is more than 0.3%, or there is more sulfur, or the impurity content is high, and the alloy elements content is high.

Usually, the steel used for welding is the oxygen converter or the Siemens-Martin fully-killed steel with lower carbon content. For the high carbon steel and alloy steel, preheating and heat treatment should be adopted respectively before and after welding in order to improve the hard brittleness of the steel after welding.

8.4 Standards and Selection of Building Steel

8.4.1 The Steel Used for Steel Structures

Recently, the steel used for steel structures includes carbon structural steel and low-alloy high-strength structural steel.

1. Carbon Structural Steel

(1) Grade and Representation

Carbon Structural Steel (GB700-88), the national standard, regulates that grade consists of the letter of yield point, the value of yield point, the quality level, and the deoxidation method, the four parts in order. And, "Q" represents the yield point; the value of yield point includes 195MPa, 215MPa, 235MPa, 255MPa and 275 MPa; the quality level is expressed by the content of sulfur and phosphor: A, B, C, and D, in decreasing order; the deoxidation method is expressed as follows: F represents rimmed steel, b represents semi-killed steel, Z and TZ represents fully-killed steel and special fully-killed steel, and Z and TZ can be omitted in the grades of steel.

For example, Q235-A·F represents A-grade rimmed steel with the yield point of 235MPa.

(2) Technical Requirements

The chemical components of each steel grade should accord with Table 8.3. The mechanical properties and technological characteristics should be in line with Table 8.4 and Table 8.5.

Table 8.3 Chemical Components of Carbon Structural Steel (GB700-88)

Grade	Level	Chemical Component (%)					Deoxidation
		C	Mn	Si	S	P	
				≤			
Q195	—	0.06~0.12	0.25~0.50	0.30	0.050	0.045	F, b, Z
Q215	A	0.09~0.15	0.25~0.55	0.30	0.050	0.045	F, b, Z
	B				0.045		
Q235	A	0.14~0.22	0.30~0.65[1)]	0.30	0.050	0.045	F, b, Z
	B	0.12~0.20	0.30~0.70[1)]		0.045		
	C	≤0.18	0.35~0.80		0.040	0.040	Z
	D	≤0.17			0.035	0.035	TZ
Q255	A	0.18~0.28	0.40~0.70	0.30	0.050	0.045	F, b, Z
	B				0.045		
Q275	—	0.28~0.38	0.50~0.80	0.35	0.050	0.045	b, Z

1) The upper limit of manganese content of rimmed steel Q235 A and Q235B is 0.60%

Table 8.4 Mechanical Properties of Carbon Structural Steel (GB700-88)

Grade	level	Tensile Test: Yield Point σ_s (N/mm²), Thickness of Steel (Diameter) (mm)						Tensile Strength σ_b (N/mm²)	Elongation δ_5 (%), Thickness of Steel (Diameter) (mm)						Impact Test	
		≤16	>16~40	>40~60	>60~100	>100~140	>150		≤16	>16~40	>40~60	>60~100	>100~140	>150	Temperature (℃)	V Impact Work (Vertical) (J)
		≤							≤							≥
Q195	—	(195)	(185)	—	—	—	—	315~430	33	32	—	—	—	—	—	—
Q215	A	215	205	195	185	175	165	335~450	31	30	29	28	27	26	—	—
	B														20	27
Q235	A	235	225	215	205	195	185	375~00	26	25	24	23	22	21	—	—
	B														20	27
	C														0	
	D														-20	
Q275	A	255	245	235	225	215	205	410~550	24	23	22	21	20	19	—	—
	B														20	27
Q275	—	275	265	255	245	235	225	490~630	20	19	18	17	16	15	—	—

Table 8.5 Technological Characteristics of Carbon Structural Steel (GB700-88)

Grade	Direction of Samples	Cold Bending Test B=2a, 180°		
		Thickness of Steel(Diameter) (mm)		
		60	>60~100	>100~200
		Diameter of Bending Heart d		
Q195	Vertical	0	—	—
	Horizontal	0.5a		
Q215	Vertical	0.5a	1.5a	2a
	Horizontal	a	2a	2.5a
Q235	Vertical	a	2a	2.5a
	Horizontal	1.5a	2.5a	3a
Q255	—	2a	3a	3.5a
Q275a	—	3a	4a	4.5a

Note: B is the width of sample; a is the thickness of steel (diameter).

(3) Selection

The selection of steel depends on the quality, properties and the corresponding standards of steel on one side; on the other side, it depends on the requirements of the projects for the properties of steel.

In national standards, carbon structural steel includes five grades, and each grade has different quality levels. Generally, the bigger the grade is, the higher the carbon content is, and the higher the strength and the rigidity are, but the lower the plasticity and the toughness are. The martin steel and oxygen converter steel have good quality, and steel grade D and grade C with lower sulfur and phosphor contents are better than steel grade B and grade A. Special fully-killed steel and fully-killed steel are better than rimmed steel. And the better the steel, the higher the cost.

The load types, welding, and temperatures of the projects have different requirements for the properties of steel. And the demands should be met in the selection of steel. Usually, the rimmed steel is restricted under the following conditions: ①it is a welding structure directly bearing the dynamic loads; ②it is a non-welding structure and the calculating temperature is equal to or lower than –20℃; ③it is a welding structure bearing static loads and indirect dynamic loads and the calculating temperature is equal to or lower than –30℃.

In the construction steel structures, carbon steel Q235 is mainly used, namely, various profiles, steel boards and coffins made of Q235. Steel Q235 has good strength, toughness, plasticity, and processability, and is easy to be smelted and has lower cost. Because Q235-D has enough elements to form fine-particle structures and controls the contents of sulfur and phosphor strictly, it has better impact toughness to resist vibrating and impact loads than other grades, especially at negative temperature. Steel grade A is often used for the structures bearing static loads.

Steel Q215 has low strength and high plasticity, and deforms a lot under stress. It can replace Q235 after cold working.

Steel Q275 has high strength but low plasticity, and sometimes is rolled to ribbed bars used in concrete.

2. Low-alloy High-strength Structural Steel

(1) Representation of Grades

According to *Low-alloy High-strength Structural Steel* (GB1591-94), the national standard, there are five grades. The known elements are manganese, silicon, barium, titanium, niobium, chromium, nickel and lanthanon. The representation of grades consists of the letter of the yield point, the value of the yield point, and the quality level (including A, B, C, D, E, the five levels).

(2) Standards and Properties

Table 8.6 and Table 8.7 show the chemical elements and mechanical properties of the low-alloy high-strength structural steel.

Table 8.6 Chemical Components of Low-alloy High-strength Structural Steel (GB1591-94)

Grade	Quality Level	Chemical Components(%)										
		C (≤)	Mn	Si	P (≤)	S (≤)	V	Nb	Ti	Al (≥)	Cr ≤	Ni (≤)
Q295	A	0.16	0.80~1.50	0.55	0.045	0.045	0.02~0.15	0.015~0.060	0.02~0.20	—		
	B	0.16	0.80~1.50	0.55	0.040	0.040	0.02~0.15	0.015~0.060	0.02~0.20	—		
Q345	A	0.20	1.00~1.60	0.55	0.045	0.045	0.02~0.15	0.015~0.060	0.02~0.20	—		
	B	0.20	1.00~ 1.60	0.55	0.040	0.040	0.02~0.15	0.015~0.060	0.02~0.20	—		
	C	0.20	1.00~ 1.60	0.55	0.035	0.035	0.02~0.15	0.015~0.060	0.02~0.20	0.015		
	D	0.18	1.00~ 1.60	0.55	0.030	0.030	0.02~0.15	0.015~0.060	0.02~0.20	0.015		
	E	0.18	1.00~ 1.60	0.55	0.025	0.025	0.02~0.15	0.015~0.060	0.02~0.20	0.015		
Q390	A	0.20	1.00~ 1.60	0.55	0.045	0.045	0.02~0.20	0.015~0.060	0.02~0.20	—	0.30	0.70
	B	0.20	1.00~ 1.60	0.55	0.040	0.040	0.02~0.20	0.015~0.060	0.02~0.20	—	0.30	0.70
	C	0.20	1.00~ 1.60	0.55	0.035	0.035	0.02~0.20	0.015~0.060	0.02~0.20	0.015	0.30	0.70
	D	0.20	1.00~ 1.60	0.55	0.030	0.030	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.30	0.70
	E	0.20	1.00~ 1.60	0.55	0.025	0.025	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.30	0.70
Q420	A	0.20	1.00~ 1.70	0.55	0.045	0.045	0.02~ 0.20	0.015~ 0.060	0.02~0.20	—	0.40	0.70
	B	0.20	1.00~ 1.70	0.55	0.040	0.040	0.02~ 0.20	0.015~ 0.060	0.02~0.20	—	0.40	0.70
	C	0.20	1.00~ 1.70	0.55	0.035	0.035	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.40	0.70
	D	0.20	1.00~ 1.70	0.55	0.030	0.030	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.40	0.70
	E	0.20	1.00~ 1.70	0.55	0.025	0.025	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.40	0.70
Q460	C	0.20	1.00~ 1.70	0.55	0.035	0.035	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.70	0.70
	D	0.20	1.00~ 1.70	0.55	0.030	0.030	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.70	0.70
	E	0.20	1.00~ 1.70	0.55	0.025	0.025	0.02~ 0.20	0.015~ 0.060	0.02~0.20	0.015	0.70	0.70

Note: Al in the table is the total aluminum content. If the acid-soluble aluminum is tested, the content should be no less than 0.010%.

Table 8.7 Mechanical Properties of Low-alloy High-strength Structural Steel (GB1591-94)

Grade	Level	Yield Point σ_s (MPa) Thickness(diameter、side length)(mm) ≤15 ≥	> 16~35 ≥	>35~50 ≥	>50~100 ≥	Tensile Strength σ_b (MPa) ≥	Elongation δ_5 (%) ≥	Impact work(A_{kv})(Vertical) (J) +20℃ ≥	0℃ ≥	-20℃ ≥	-40℃ ≥	180°Bending Test d— diameter of bending heart; a— thickness of specimen(diameter) Thickness of steel(diameter)(mm) ≤16	>16~100
Q295	A	295	275	255	235	390~570	23					d=2 a	d=3 a
	B	295	275	255	235	390~570	23	34				d=2a	d=3 a
Q345	A	345	325	295	275	470~630	21					d=2 a	d=3 a
	B	345	325	295	275	470~630	21	34				d=2 a	d=3 a
	C	345	325	295	275	470~630	22		34			d=2a	d=3 a
	D	345	325	295	275	470~630	22			34		d=2 a	d=3 a
	E	345	325	295	275	470~630	22				27	d=2 a	d=3 a
Q390	A	390	370	350	330	490~650	19					d=2 a	d=3 a
	B	390	370	350	330	490~650	19	34				d=2 a	d=3 a
	C	390	370	350	330	490~650	20		34			d=2 a	d=3 a
	D	390	370	350	330	490~650	20			34		d=2 a	d=3 a
	E	390	370	350	330	490~650	20				27	d=2 a	d=3 a
Q420	A	420	400	380	360	520~680	18					d=2 a	d=3 a
	B	420	400	380	360	520~680	18	34				d=2 a	d=3 a
	C	420	400	380	360	520~680	19		34			d=2 a	d=3 a
	D	420	400	380	360	520~680	19			34		d=2 a	d=3 a
	E	420	400	380	360	520~680	19				27	d=2 a	d=3 a
Q460	C	460	440	420	360	550~720	17		34			d=2 a	d=3 a
	D	460	440	420	360	550~720	17			34		d=2 a	d=3 a
	E	460	440	420	360	550~720	17				27	d=2 a	d=3 a

(3) Application

The addition of alloy elements into the steel can modify the organization and properties of steel. If 18Nb or 16Mn (the yield point is 345MPa) with the similar carbon content (0.14%~0.22%) is compared with Q235 (the yield point is 235MPa), the yield point is improved by 32%, and it has good plasticity, impact toughness and weldability and can resist low temperature and corrosion; and under the same conditions, it can make the carbon structural steel save steel consumption by 20%~30%.

The ore or the original alloy elements in steel waste, such as niobium and chromium, are often used for the alloying of steel; or some cheap alloy elements, such as silicon and manganese, are added; if there is special requirement, a little amount of alloy elements, such as titanium and vanadium, can be used. The smelting equipment is basically the same with the equipment to produce carbon steel, so the cost increases a little.

The adoption of low-alloy structural steel will reduce the weight of structures and extend the useful time, and the high-strength low-alloy structural steel is especially used in the large-span or large column-grid structures for better technical and economical effects.

8.4.2 Steel for Concrete Structures

Recently, the steel used for concrete structures mainly includes: hot-rolled reinforced bar, cold-drawn hot-rolled reinforced bar, cold-drawn low-carbon steel wire, cold-rolled ribbed bar, heat-tempering bar, steel wire and strand for pre-stressed concrete, and cold-rolled-twisted bar.

1. Hot-rolled Reinforced Bar

The hot-rolled reinforced bars used for concrete structures should have high strength, a certain plasticity, toughness, cold bending and weldability.

The hot-rolled reinforced bars mainly are the plain round bar rolled by Q235 and the ribbed steel made of alloy steel.

(1) Standard and Property of Hot-rolled Reinforced Bar

Based on *Hot-rolled Plain Round Steel Bars for the Reinforcement of Concrete* (GB13013), the national standard, the hot-rolled vertical round bars are level I, and the strength grade is HPB 235(see Table 8.8); the grades of the plain steel bars are represented by HRB and the minimum value of the yield point of the grade, and grades include HRB335, HRB400, and HRB500. H represents "hot-rolled", R represents "ribbed", and B represents "bar", the numbers afterwards represents the minimum value of the yield point (see Table 8.9).

Table 8.8 Technical Requirements for Hot-rolled Plain Round Bars

Surface Shape	Bar Level	Strength Grade	Nominal Diameter (mm)	Yield Point σ_s (MPa)	Tensile Strength σ_b (MPa)	Elongation δ (%)	Cold Bending d—diameter of bending heart a— nominal diameter of bar
				≥			
Plain Round	I	HPB235	8~20	235	370	25	180° d=a

Table 8.9 Grades and Technical Requirements for Hot-rolled Bars

Grade	Nominal Diameter (mm)	σ_s (或 $\sigma_{p0.2}$) (MPa)	σ_b (MPa)	δ_5 (%)
		≥		
HRB335	6~25 28~50	335	490	16
HRB400	6~25 28~50	400	570	14
HRB500	6~25 28~50	500	630	12

(2) Application

Steel bar grade Ⅰ or HRB 335 and HRB 400 can be used as the non-prestressed bars in ordinary concrete based on the using conditions; the pre-stressed bars should be HRB400 or HRB 335. The hot-rolled bars grade Ⅰ is the plain round bars, and others are the crescent ribbed bars whose coarse surface can improve the gripping power between concrete and steel bars.

2. Cold-drawn Hot-rolled Bar

Cold-drawn hot-rolled bar is made at the room temperature by drawing the hot-rolled steel bar with a kind of stress up to or beyond the yield point but less than the tensile strength and then unloading. The cold drawing can improve the yield point by 17%~27%, the material will become brittle, the yield stage becomes short, the elongation decreases, but the strength after cold-drawn ageing will increase a little. In practice, all the cold drawing, derusting, straightening, and cutting can be combined into one process, which simplifies the procedure and improves the efficiency; cold drawing can save steel and make pre-stressed bars, which increases the varieties of steel, and the equipment is simple and easy to operate, so it is one of the most common method for the cold working of steel. According to *Construction and Acceptance Codes for Concrete Structures* (GB50204-2002), the national standard, the technical requirements should be in line with Table 8.10.

Table 8.10 Properties of Cold-drawn Hot-rolled Bars (GB50204-2002)

Grade	Diameter (mm)	Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Elongation δ_{10} (%)	Cold Bending	
		≥			Bending Angle (°)	Bending Diameter (mm)
HPB235	≤12	280	370	11	180°	3d
HRB335	≤25	450	510	10	90°	3d
	28~40	430	490	10	90°	4d
HRB400	8~40	500	570	8	90°	5d
HRB500	10~28	700	835	6	90°	5d

Note: 1) d is the diameter of steel bar (mm);

2) The value of the yield strength of cold-drawn bars in the table is the standard strength value of cold-drawn bars regulated in *Design Specifications for Concrete Structure*, the existing national standard.

3) The cold bending diameter of the cold-drawn steel bars HRB400 and HRB500 with the diameter more than 25mm should increase 1d.

3. Cold-rolled Ribbed Bar

The cold-rolled ribbed bar is the bar made by cold drawing or cold rolling the ordinary low-carbon steel, the quality carbon steel or the low-alloy hot-rolled coiled bar to reduce the diameter and form crescent cross ribs on three faces or two faces of the bar. The base metal of the cold-rolled ribbed bar should be in line with the existing national standard *Cold-rolled Ribbed Bar* (GB13788). At present, most of the cold-rolled ribbed bars produced at home adopt passive cold rolling machine to reduce diameter and form crescent cross ribs on three faces of bars. The other one is the active rolling machine which can reduce diameter and form crescent cross ribs on two faces of bars.

Cold-rolled ribbed bar uses CRB as the grade code. According to JGJ95-2003 and J254-2003, the cold-rolled ribbed bar has five grades divided by tensile strength: CRB550, CRB650, CRB800, CRB970, and CRB1170. C represents "cold-rolled", R represents "ribbed", and B represents "bar". The value is the minimum value of tensile strength. The mechanical and technological properties of the cold-rolled ribbed bars should be in line with Table 8.11.

Table 8.11 Mechanical and Technological Properties of Cold-rolled Ribbed Bars (JGJ95-2003)

Grade	Tensile Strength σ_b (MPa) (≥)	Elongation (%)		Cold Bending180° Diameter of Bending Heart —d Nominal Diameter of Bar—a	Alternating bending frequency	Relaxation ratio (initial stress σ_{con} =0.7 σ_b)	
		δ_{10}	δ_{100}			1000h (≤) (%)	10h(≤) (%)
CRB550	550	8	—	d=3a	—	—	—
CRB650	650	—	4.0	—	3	8	5
CRB800	800	—	4.0	—	3	8	5
CRB970	970		4.0	—	3	8	5
CRB1170	1170	—	4.0	—	3	8	5

Note: 1) There should be no crack on the surface of the bending parts.

2) If the nominal diameters of the bars are 4mm, 5mm and 6mm, the bending diameter of the alternating bending should be 10mm, 15mm, and 15mm respectively.

3) For various bars supplied in coils, their tensile strength after straightening should be still in line with the table.

4) δ_{10} is the elongation of the bar whose standard measured distance is 10 times of its diameter; δ_{100} is the elongation of the bar whose standard measured distance is 100mm.

The cold-rolled ribbed steel bars have high strength, good plasticity, high cohesion force with concrete, and stable quality. Grade 550 steel bars are mainly used for reinforced concrete structures, especially the main load-bearing bars of slab members and the non-prestressed steel bars in pre-stressed concrete structures. Based on the need of projects and the actual conditions of materials, the cold-rolled ribbed steel bars with diameter of

4~12mm can be upgraded by 0.5mm. When grade 550 steel bars are used as the main load-bearing bars, their diameters should be 5~12mm. At present, the diameter of the steel bars used greatly in cast-in reinforced concrete slabs is 6mm above. Grade 650 bars are mainly used in the pre-stressed hollow slabs, with the diameter of 5mm or 6mm in several places. Grade 800 bars are the low-alloy coiled bars with diameter of 6.5mm and strength of 550MPa.

4. Heat-tempering Bar

Heat tempering is a technological process that the steel is heated, insulated, and cooled based on some rules to make its organization change and gain a required property. Heat-tempering bar is the bar made by quenching and high tempering the hot-rolled ribbed bar (middle-carbon low-alloy steel). Its plasticity decreases little, but its strength increases a lot, and the comprehensive property is ideal. Table 8.12 shows the mechanical indexes of the national standard GB4463-84.

Table 8.12 Mechanical Properties of Heat-tempering Bars (GB4463-84)

Nominal Diameter (mm)	Grade	Yield Point (MPa) (kgf/mm^2)	Tensile Strength (MPa) (kgf/mm^2)	Elongation δ_{10} (%)
		no less than		
6 8.2 10	$40Si_2Mn$ $48Si_2Mn$ $45Si_2Cr$	1325(135)	1470(150)	6

Heat-tempering bars are mainly used for the pre-stressed concrete sleepers in stead of carbon steel wires. Because they are easy to be made, have stable quality and good anchoring ability, and can save steel, they starts to be used in pre-stressed concrete projects.

5. Cold-drawn Low-carbon Steel Wire

The cold-drawn low-carbon steel wire is made by tungsten alloy wire-drawing model whose cross-section is less than Q235 (or Q215) coiled bars with diameter of 6.5~8mm. The cold-drawn steel wire undertakes not only tension but also extrusion, shown in Figure 8.9. The yield strength of the steel wire undertaking drawing once or more is improved by 40%~60%, and it has already lost the property of low-carbon steel and become hard and brittle, belonging to hard steel wire. The national standard (GB50204-92) regulates that the cold-drawn low-carbon steel wire has two grades of strength: the first grade is pre-stressed wire, and the second grade is non-prestressed wire. When a concrete plant conducts cold-drawing by itself, it should strictly control the quality of steel wires and check their appearances in batches randomly. There should be no rust, oil pollution, scratching, soap spot, and crack. The plant should check the coiled bars one by one to find whether their mechanical and technical properties are in line with Table 8.13. All the bars whose elongation is unqualified should not be used in the pre-stressed concrete members.

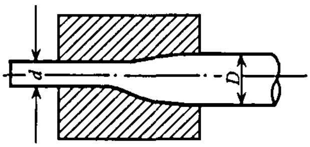


Figure 8.9 Cold Drawing

Table 8.13 Mechanical Properties of Cold-drawn Low-carbon Steel Wires (GB50204-92)

Grade	Diameter (mm)	Tensile Strength (MPa) Group 1 ≥	Tensile Strength (MPa) Group 2 ≥	Elongation δ_{10} (%)	180° Repeated Bending (number)
First Grade	5	650	600	3.0	4
	4	700	650	2.5	4
Second Grade	3~5	550		2.0	4

Note: After the pre-stressed cold-drawn low-carbon steel wire is adjusted by machine, the standard tensile strength should be decreased by 50MPa.

6. Pre-stressed Steel Wire for Concrete or Steel Strain

They are the special products made by cold working, re-backfiring, cold rolling or crossing the high-quality carbon structural steel, also called high-quality carbon steel wire or steel strain.

The national standard (GB5223-2002) regulates that the pre-stressed steel wire for concrete can be divided by processing way: cold-drawn steel wire (code of WCD) and stress-relieved wire, the two types. The stress-relieved wire can be divided into low loose plain round wire (code of P), spiral rib steel wire (code of H), and deformed steel wire (code of I), the three types. The mechanical properties of cold-drawn wire, stress-relieved wire, spiral rib steel wire, and stress-relieved deformed wire are shown in Table 8.14, Table 8.15, and Table 8.16.

Table 8.14 Mechanical Properties of Cold-drawn Steel Wires

Nominal Diameter d_n (mm)	Tensile Strength σ_b (MPa) (≥)	Specified Non-proportional Elongation Stress $\sigma_{p0.2}$ (MPa) (≥)	Total Elongation under the Maximum Stress (L_0=200mm) δ_{gt} (%) (≥)	Bending Number (number/ 180°) (≥)	Bending Diameter R (mm)	Shrinkage Ratio of Section ϕ (%) (≥)	Twisting Number of Every 210mm Torque	Relaxation Ratio after 1000h, when the initial stress equals to 70% of nominal tensile strength r (%) (≤)
3.00	1470	1100	1.5	4	7.5	—	—	8
4.00	1570	1180		4	10	35	8	
• 5.00	1670	1250		4	15		8	
	1770	1330						
6.00	1470	1100		5	15	30	7	
7.00	1570	1180		5	20		6	
8.00	1670	1250		5	20		5	
	1770	1330						

Table 8.15 Mechanical Properties of Stress-relieved Plain Round and Spiral Rib Steel Wires

Nominal Diameter d_n (mm)	Tensile Strength σ_b (MPa) (≥)	Specified Non-proportional Elongation Stress $\sigma_{p0.2}$ (MPa) (≥)		Total Elongation under the Maximum Stress (L_0=200mm) δ_{gt} (%) (≥)	Bending Number (number/ 180°) (≥)	Bending Diameter R (mm)	Stress Relaxation Property		
							Percentage of Initial Stress to Nominal Tensile Strength (%)	Relaxation Ratio after 1000h r (%) (≤)	
		WLR	WNR					WLR	WNR
							For All Specifications		
4.00	1470	1290	1250	3.5	3	10	60	1.0	4.5
4.80	1570	1380	1330		4	15	70	2.0	8
5.00	1670	1470	1410				80	4.5	12
	1770	1560	1500						
	1860	1640	1580						
6.00	1470	1290	1250		4	15			
6.25	1570	1380	1330		4	20			
7.00	1670	1470	1410		4	20			
	1770	1560	1500						
8.00	1470	1290	1250		4	20			
9.00	1570	1380	1330		4	25			
10.00	1470	1290	1250		4	25			
12.00					4	30			

Table 8.16 Mechanical Properties of Stress-relieved Deformed Wires

Nominal Diameter d_n (mm)	Tensile Strength σ_b (MPa) (≥)	Specified Non-proportional Elongation Stress $\sigma_{p0.2}$ (MPa) (≥)		Total Elongation under the Maximum Stress (L_0=200mm) δ_{gt} (%) (≥)	Bending Number (number/ 180°) (≥)	Bending Diameter R (mm)	Stress Relaxation Property		
							Percentage of Initial Stress to Nominal Tensile Strength (%)	Relaxation Ratio after 1000h r (%) (≤)	
								WLR	WNR
		WLR	WNR				For All Specifications		
≤5.0	1470	1290	1250	3.5	3	15	60	1.5	4.5
	1570	1380	1330						
	1670	1470	1410						
	1770	1560	1500				70	2.5	8
	1860	1640	1580						
>5.0	1470	1290	1250			20	80	4.5	12
	1570	1380	1330						
	1670	1470	1410						
	1770	1560	1500						

For the pre-stressed steel wires for concrete, the national standard GB5223-2002 regulates that the mark of the products should contain the following content: pre-stressed steel wire, nominal diameter, tensile strength grade; code of processing state, code of appearance, and standard code.

Example 1: The mark of the cold-drawn plain and round wire with diameter of 4.00mm and tensile strength of 1670MPa should be: pre-stressed steel wire 4.00-1670-WCD-P-GB/T5223-2002.

Example 2: The mark of the low loose spiral rib steel wire with diameter of 7.00mm and tensile strength of 1570MPa should be: pre-stressed steel wire 7.00-1570-WLD-H-GB/T5223-2002.

Steel strand is made by 7 steel wires undertaking crossing hot treatment. The national standard GB5224-85 regulates that the diameter of steel strand should be 9~15mm, failure load should be 220kN, and its yield strength should be 185kN.

7. Cold-rolled-twisted Bar

After the low-carbon hot-rolled coiled bar is formed once by getting straightened by specific cold-rolled-twisted machine, cold rolling and cold twisting, the continuous spiral bars with regulated shape of cross-section and pitch is the cold-rolled-twisted bar (shown in Figure 8.10). Pitch is the advancing distance that the cross-section of cold-rolled-twisted bar turns 1/2 circle (180°) along the axis of bar; the rolled thickness is the size of the smaller side of the rectangle cross-section or the shorter diagonal size of the diamond cross-section after the cold-rolled-twisted bar is formed; and the mark diameter is the nominal diameter (*d*) of the raw material (base metal) before getting rolled, with the mark of "ϕ'".

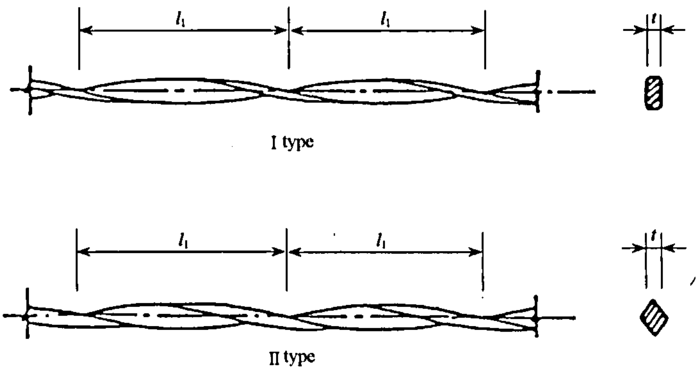
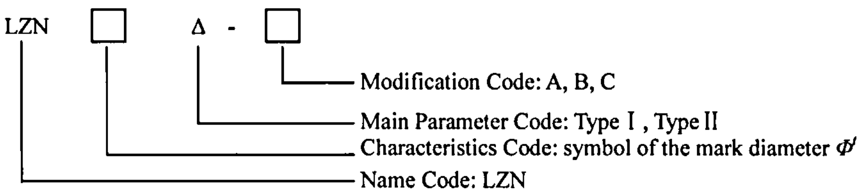


Figure 8.10 Shape and Cross-section of Cold-rolled-twisted Bar

t. rolled thickness; l_1. pitch

Cold-rolled-twisted bar has rectangle section I and diamond section II, based on the cross-section shapes. The mark of the product contains name code, characteristics code, main parameter code, and modification code, the four parts.



Example: the cold-rolled-twisted bar with the mark diameter of 10mm and rectangle section should be marked as: LZN ϕ' 10(I).

The low-carbon non-torsion-control cold hot-rolled wire rod (high speed wire rod) regulated in YB4027 is the best raw material for cold-rolled-twisted bar. The low-carbon hot-rolled wire rod in line with GB701 can also be used. The grade of raw material is Q235 and Q215. When Q215 is adopted, the carbon content should not be less than 0.12%.

The rolled thickness and pitch of cold-rolled-twisted bar should accord with Table 8.17. Its nominal cross-section area and nominal weight should accord with Table 8.18. Its mechanical properties should be in line with Table 8.19.

There should be no cracks, fold, scar, indentation, mechanical damage or other defects that affecting the normal use.

Table 8.17 The Rolled Thickness and Pitch (mm)

Type	Symbolic Diameter d	Rolled Thickness t (≥)	Pitch l_1 (≤)
I	6.5	3.7	75
	8	4.2	95
	10	5.3	110
	12	6.2	150
	14	8.0	170
II	12	8.0	145

Table 8.18 Nominal Section Area and Nominal Weight

Type	Mark Diameter d (mm)	Nominal Section Area A(mm^2)	Nominal Weight G (kg/m)
I	6.5	29.5	0.232
	8	45.3	0.356
	10	68.3	0.536
	12	93.3	0.733
	14	132.7	1.042
II	12	97.8	0.768

Table 8.19 Mechanical Properties

Tensile Strength σ_b (N/mm^2)	Elongation δ_{10} (%)	Cold Bending 180° (Bending Diameter = 3d)
≥ 580	≥ 4.5	No Cracks on the Surface of Bending Part

Note: 1) d is the mark diameter or cold-rolled-twisted bar.

2) δ_{10} is the elongation at break of the sample whose standard distance is 10 times of mark diameter.

8.5 Fire Protection of Steel

8.5.1 Fire Protection of Steel Structures

Though steel does not burn with fire and does not supply fuels to fire, it will quickly become soft with fire. And when a steel structure stay in fire for about 15~20min, the roof truss and other member bars will collapse. With the damage of members, the whole structure will lose balance and be destroyed. Moreover, the steel structure cannot be repaired after damage. In order to conquer the poor fire-resistance of steel structures, the following protection methods can be adopted to guarantee the security of steel structures after encountering fire.

1) Protection methods should be chosen according to different requirements for fire-resistant limit. Fire-resistant limit refers to the period from the time that the building member starts to encounter fire to the time that it loses supporting ability, or the whole member is destroyed or lose the fire-insulated ability, when it is conducted fire-resistant test based on the standard curve of time and temperature, expressed by hour. If the fire-resistant limit is high, the thickness of the heat-insulating board should be increased accordingly.

2) Add box coat to the steel columns, and inject water into the box. In fire, the temperature of the steel columns rises slowly due to the protection of water.

3) Paint fire retardant coatings on the steel structures to improve their fire-resistant limit.

Recently, the last method is used commonly. The fire retardant coatings painted on the steel structures include LG fireproof and heat-insulating coatings (thick layer type), LB thin-layer fire retardant coating, JC-276 fire retardant coating and ST1-A fire retardant coating. The last two coatings can be used not only to prevent fire for steel structures but also for the fireproof treatment of the pre-stressed concrete structures.

8.5.2 Fire Protection of Steel Bars

The reinforced concrete structure refers to the members, such as beams, boards, columns, roof trusses, consisting of concrete and steel bars. In these structures, the steel bars are enwrapped by concrete, but their mechanical properties will still lose due to the fire to destroy the whole structure.

Because the thermal conductivity of concrete is big and the thermal expansion rate of steel bars is 1.5 times of that of concrete after being heated, their elongation strain is bigger than that of concrete. Thus, the thickness of protecting layer should be added accordingly within the allowable range of structure design, which will reduce or delay the elongation strain of steel bars and the losing of pre-stressed value. If the structure design does not allow the adding of thickness, fire retardant coatings can be painted on the surface of the tensile area of the concrete to protect the structure.

8.6 Corrosion and Prevention of Steel

When the surface of steel contacts with the surrounding environment under a certain condition, it will be corroded. The corrosion will reduce the load-bearing cross-section of steel, the uneven surface will lead to the convergence of stress, which will lower the load-bearing ability of steel; also, the corrosion will lower the fatigue strength greatly, especially the impact toughness of steel, which will result in the brittle fracture of steel. If the steel bars in concrete are corroded, there will be expansion of volume, which makes the concrete crack along bars. Thus, the measures to resist corrosion should be adopted in order to prevent the corrosion of steel in working.

8.6.1 Reasons for Corrosion of Steel

There are two kinds of corrosion based on different functions of the surface of steel and its surrounding media.

1. Chemical Corrosion

It is a pure chemical corrosion caused by the electrolyte solution or various dry gases (such as O_2, CO_2 and SO_2. etc.), without any electric current. Usually, this kind of corrosion will generate loose oxide on the surface of steel by oxidation, and it is very slow under the dry condition, but it will be very fast under high temperature and humidity.

2. Electrochemical Corrosion

When steel contacts with electrolyte solution and generates electric current, there will be the electrochemical corrosion caused by the role of primary battery. The steel contains ferrite, cementite, and non-metal impurities, and all of these components have different electrodes and potentials, which means their activity are diversified; if there is electrolyte, it will be easy to form two poles of primary battery. When the steel contacts with humid media, like air, water, and earth, a layer of water film will cover its surface and various ions coming from the air dissolves in water, which forms electrolyte. At first, the ferrite in steel lose its electron, that is, $Fe \rightarrow Fe^{2+} + 2e$, to become anode, and cementite becomes cathode. In acidic electrolyte, H^+ obtains electron to become H_2 and runs away; in neutral media, water gets OH^- due to the deoxidation of oxygen and generates insoluble $Fe(OH)_2$; it can be oxidized into $Fe(OH)_3$ and its dehydration product $Fe_2(OH)_3$ which is the major component for bronze rust.

8.6.2 Corrosion Prevention of Steel

There are three methods to prevent the corrosion of steel.

1. Protective Film

This method is to isolate the steel from the surrounding media with the protective film to prevent or delay the damage caused by the corrosion of external corrosive media. For example, paint coatings, enamel or plastic on the surface of steel; or use the metal coating as the protective film, such as zinc, tin, and chrome.

2. Electrochemical Protection

Current-free protection is to connect a piece of metal, such as zinc and magnesium, more active than steel to the steel structure, and because zinc and magnesium have lower potentials than steel, the anodes of the corrosion cells coming from zinc and magnesium have be destroyed, but the steel structure will be protected. This method can be used for the places which are difficult or impossible to be covered with protective layer, such as steam boiler, shell of steamboat, underground pipe, maritime structure, and bridge.

Impressed current protection is to emplace some waste steel or other refractory metals around the steel structure, such as high silicon iron and silver-lead alloy, and to connect the cathode of the impressed direct current to the protected steel structure and the anode to the refractory metals, and the refractory metals become the anode to be corroded and the structure becomes the cathode to be protected.

3. Alloying

The addition of alloy elements into carbon steel to produce various alloy steel will improve its anti-corrosion, such as nickel, chrome, titanium, and copper.

The above method can be adopted to prevent the corrosion of the steel bars in concrete, but the most economic and effective way is to improve the density and the alkalinity of concrete and make sure that the steel bars are thick enough.

In the hydration products of the cement, there is about 1/5 $Ca(OH)_2$, and when the pH value of the media reaches to about 13, there is passive film on the surface of steel bars, so the bars in concrete are difficult to generate rust.

But when CO_2 in the air diffuses into the concrete and reacts with $Ca(OH)_2$ to neutralize the concrete. When pH value falls to 11.5 or below, the passive film will be destroyed and the steel surface reveals active state; and if there is humid and oxygen condition, the electrochemical corrosion will start on the surface of steel bars; because the volume of rust is 2~4 times than steel, it will lead to the cracking of concrete along bars. CO_2 diffuses into the concrete and carries the carbonization, so the improvement of the density of concrete will effectively delay the carbonization process.

Because CL^- will destroy the passive film, the consumption of chloride should be controlled in the preparation of reinforced concrete.

Questions

8.1 What is steel? What is construction steel? What are the properties of steel?

8.2 From what aspects is steel divided? How many subdivisions of each aspect? How is the construction steel divided?

8.3 How is steel produced? What kind of influence does each production modes have on the properties of steel?

8.4 What are the technical properties of construction steel? How to express each property? What is the actual significance? How to determine?

8.5 In the figure of stress-strain curve of low-carbon steel, how many stages are there? What are the characteristics and indexes of each stage?

8.6 What is yield ratio? What is the actual significance in projects?

8.7 What is the basic organization of steel? What are the characteristics? What kinds of impact do the chemical components of steel have on the properties?

8.8 What is cold working and aging? How does the property of steel change after cold working and aging?

8.9 What is the major element affecting the weldability of steel?

8.10 How to express the grade of carbon structural steel and low alloy structural steel?

8.11 In steel structures, why can Q235 and low alloy structural steel be commonly used?

8.12 How to divide the grades of hot-rolled steel? What is the application range of each level?

8.13 What are the common steel bars, steel wires, and steel strands used in concrete projects? How to select them?

8.14 What kinds of corrosions do construction steel have? How to resist corrosion?

8.15 What are the fire protection measures of steel bars?

References

Cao Wenda, Cao Dong. 2000. Building Project Materials, Beijing: Golden Shield Press.

Chen Yafu. 1998. Building Materials. Guangzhou: South China University of Technology Press.

Chen Zhiyuan, Li Qiling. 2000. Civil Engineering Materials. Wuhan: Wuhan University of Technology Press.

Gao Qiongying. 1997. Building Materials: Wuhan: Wuhan Univeristy of Technology.

State Bureau of Quality and Technical Supervision. 2000, 2001, 2002, 2003. National Standards of P.R.C.

Hunan University, et al. 1989. Building Materials (Third Edition), Beijing: China Architecture & Building Press.

Liu Xiangshun. 1989. Building Materials, Beijing: China Architecture & Building Press.

Sun Dagen. 1997. Building Materials and Project Quality, Guangzhou: South China University of Technology Press.

Xi'an University of Architecture & Technology, et al. 1997. Building Materials, Beijing: China Architecture & Building Press.

China Architecture & Building Press. 2000. Comprehensive Criteria of Existing Building Materials (Supplement), Beijing: China Architecture & Building Press.

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Wood

This chapter mainly states the structure and the physics characteristics of wood. Furthermore it also introduces the corruption and the insect pest caused and the preventive measures to them. This chapter also tells something about artificial plate and its usage.

In the ancient history of Chinese architectural history, the wood used to be combined with materials of construction and those of decoration. The architectures built of them amazes the whole world for the outstandingly perfect usage of wood. Take the world famous Beijing Qi'nian Palace for example, which was made up of completely wood. Nowadays wood is mainly used for interior decoration and ornament.

Wood is used as architectural and decoration material for its several advantages as follows: its specific strength is intense, and it is light-weight and high-strength; it has great elasticity and tenacity that it can bear certain grade of bow and shock wave; its thermal conductivity is low but thermal isolation is good; Being conserved properly, it can be very durable; it is also easy to process, and it can be made into products in various shapes; the wood is beautiful-grained, mild-toned, elegant-styled and well-effected in decoration; the combination of its elasticity, heat isolation and warm tone makes us comfortable; moreover it has high insulating ability without poison.

And for sure the wood also has following disadvantages: it is not even in structure, and it is of anisotropy; its quality and usage are affected by the numerous natural disadvantages; it expands with wetness and shrinks with dryness, so it is liable to crack or warp when being used incorrectly; if not properly conserved, it may be corrupted or mildew and rot or even eaten by worms; in addition its fireproof is poor and is liable to burn.