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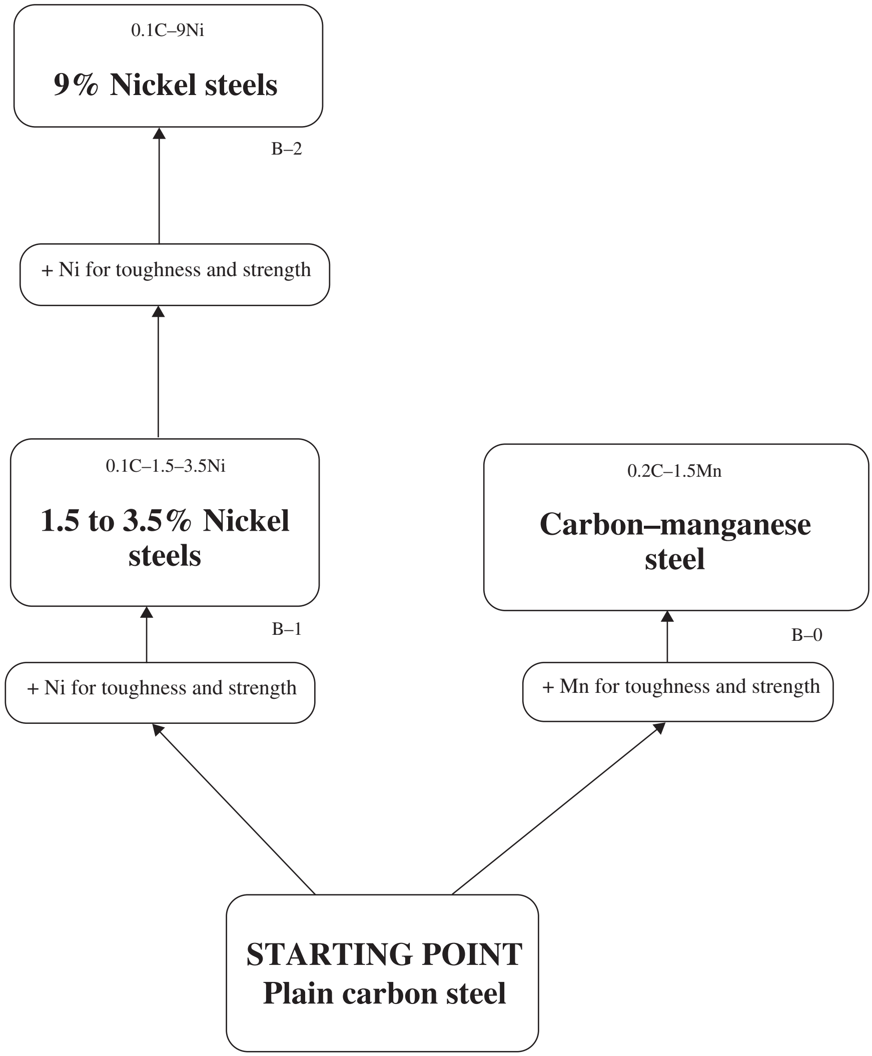
Group B

Cryogenic, nickel low-alloy steels



Group B: Cryogenic, nickel low-alloy steels.

Introduction

As for Group A, the starting point for Group B is plain carbon steel. There are two branches to this simple group. The first of these illustrates the effect of modest increases in manganese, which improves both strength and toughness and enables service down to –50 °C. The alternative branch shows how nickel can increase both strength and toughness. At 2–3% nickel level, steels are produced that are suitable for service down to –100 °C. Increasing the nickel to 9% leads to a low-alloy steel that has high strength and toughness at temperatures as low as –196 °C.

B–0

0.2% carbon, 1.5% manganese fine-grained structural steel

Also known generically as CMn steels

Description

This is a general-purpose steel with a moderate carbon content of 0.2% and about 1.5% manganese to ensure reasonable strength and good weldability. The steel is usually fully deoxidised with silicon and aluminium, and sometimes niobium, and is fine grained for optimum toughness. Its typical composition is:

	C	Mn	Si	S	P	Al
Weight %	0.2	~1.5	0.3	<0.02	<0.02	0.05

The steel is normally supplied in accordance within one of many national and international standards, a small selection of which is given below:

UNS	ASTM	EN
K03008 (wrought)	A333 Gr 1	10025 Gr. S235
K03006	Gr 6	Gr. S275
J03003 (cast)	A352 Gr LCB	Gr. S335
J02505	Gr LCC	

Carbon–manganese steels are usually supplied in the normalised condition to ensure a fine-grained pearlitic microstructure.

Background

Carbon–manganese steels represent the most cost-effective method of alloying to achieve reasonable strength and toughness combined with good weldability. Modern steels are bulk produced in very large oxygen converters and can be refined to give very low levels of sulphur. However, other residuals and tramp elements depend very much on the quantity and quality of scrap being incorporated into the melt. The quality of the final product from different producers can vary somewhat.

Most bulk steels of this type are produced using continuous casting and are therefore fully killed using manganese, silicon and aluminium as deoxidants.

Performance

The properties of these steels depend upon the exact carbon and manganese contents and on the heat treatment and the plate thickness. However, proof strengths up to about 500 MPa can readily be achieved. Provided a correct normalising treatment is carried out, toughness is very good, with excellent properties at sub-zero temperatures and useful properties down to about –50 °C.

Clearly, with no significant alloying content, these steels will corrode rapidly in the open air and more so in marine and industrial environments. They are usually protected by painting, coating or zinc galvanising, depending upon the particular application.

Applications

These are the workhorse grades for the general construction and engineering industries. They are suitable for a wide range of operating conditions where extremes of temperature and corrosive conditions will not be encountered.

They are very widely used in ships, pipelines, bridges, building frames and offshore structures, both fixed and mobile, where good toughness down to well below zero is often an essential design consideration. In addition, they are used in the construction of tanks and pressure vessels for the chemical and petrochemical industries where the temperature range is between about –50 °C and about +250 °C and corrosion conditions are relatively benign.

B–1

1.5%–3.5% nickel cryogenic steels

Also known generically as A333 Gr 9 and Gr 3

Description

These steels are similar to plain carbon–manganese steels but have an addition of 1.5–3.5% nickel to increase strength and, in particular, low-temperature fracture toughness. Grade 9 also contains about 1% copper. In both cases the typical carbon content is reduced to 0.1% since it is not required for alloy strengthening and has a detrimental effect on toughness. These steels are grain refined with aluminium to further improve toughness. Typical compositions are:

		C	Mn	Si	S	P	Ni	Cu	Al
Weight %	**Grade 9**	0.1	0.5	0.3	<0.02	<0.02	2	1	0.05
	Grade 3	0.1	0.5	0.3	<0.02	<0.02	3.5	-	0.05

The steels are normally supplied in accordance within one of the following specifications:

	UNS	ASTM	EN
Grade 9	K31050	A350 Gr. LF5, A352 Gr. LC2	10028
	J22500	A333 Gr. 9	Gr. 1.6228
Grade 3	K13050	A350 Gr. LF3, A352 Gr. LC3	
	K31918	A333 Gr. 3	Gr. 1.5367
	J31550		

These steels are usually supplied in the normalised, normalised and tempered, or quench and tempered (Q + T) condition, to ensure a fine-grained, strong, tough microstructure.

Background

Relatively small amounts of nickel, in the range 2–3%, can result in a significant improvement in fracture toughness, in particular bringing about a reduction in the ductile–brittle transition temperature. In addition, the carbon content can be reduced without seriously compromising tensile strength.

Performance

The properties of these steels depend upon the exact alloying content and on the heat treatment and the plate thickness. However, proof strengths up to about 500 MPa can readily be achieved. Provided a correct normalising treatment is carried out, toughness is very good with excellent properties down to –60 °C for the 2% nickel grades, and –100 °C for the 3.5% nickel grades. It should be noted that it is sometimes difficult to achieve similar properties with matching composition weld metals. For this reason, the 3.5% nickel steels are often welded with nickel-based welding consumables, if good toughness is specified at –100 °C. For lower temperatures, down to –196 °C, 9% nickel steels are used (B–2).

The combination of nickel and copper in Grade 9 also improves corrosion performance and provides some 'weathering' resistance to atmospheric corrosion.

Applications

These alloys are used where operating temperatures below those safe for carbon–manganese steels are likely to be encountered. The main applications are in the oil and gas and petrochemical industries, where they are used for valves, pumps, piping and vessels processing and handling liquefied petroleum gases (LPG), such as propane and butane at temperatures above about –100 °C. They are also exploited in general pressure equipment which may experience a rapid depressurisation and corresponding cooling resulting from adiabatic expansion of the vessel contents.

The enhanced fatigue performance combined with good strength and toughness can be used to advantage in the manufacture of fatigue loaded and rotating engineering components such as shafts and rotors.

B–2

9% nickel cryogenic steels

Also known generically as '9% nickel'

Description

These steels are a metallurgical evolution of the lower nickel steels, with the nickel being increased to about 9% to improve fracture toughness and further reduce the safe operating temperature at reasonably modest alloying cost. A typical composition is:

	C	Mn	Si	S	P	Ni
Weight %	0.06	0.6	0.25	<0.01	<0.02	9.5

The steels are normally supplied in accordance within one of the following specifications

UNS	ASTM	EN
K81340	A333 Gr. 8	1.5662
K71340	A352 Gr. LC9	1.5663
	A553 type I	

They are usually supplied in the quenched and tempered condition to ensure a lath-like martensitic microstructure. Careful temperature control during heat treatment is essential if the optimum microstructure and properties are to be achieved.

Background

Inco (International Nickel Company, now Special Metals) developed 9% nickel steel in 1944 for use at service temperatures down to –196 °C (liquid nitrogen). The alloy was adopted by the ASME code in 1956, but a PWHT was required, which essentially restricted its use to relatively smaller, shop-built fabrications. Following work by U.S. Steel, Inco, and the Chicago Bridge & Iron Company, it was established that the use of PWHT actually had an adverse effect and was not necessary for serviceability and safety. The ASME code was subsequently amended to allow the use of plates up to 50 mm in thickness without PWHT, which opened the way for the steel's use in the manufacture of very large liquefied natural gas (LNG) storage tanks.

Performance

The 9% nickel steels combine high strength and fracture toughness at temperatures down to at least –196 °C. Typical tensile strengths are greater than 650 Mpa and impact values in excess of 100 J would normally be expected. Fracture mechanics tests such as crack tip opening displacement (CTOD) are usually carried out to validate materials, and values well in excess of 1 mm are achieved.

It is almost impossible to obtain the necessary weld metal properties using matching composition 9% nickel welding consumables. For this reason, special high-strength, high-toughness nickel-base welding consumables have been developed that meet the specified requirements and are metallurgically compatible with the base steel.

Applications

The steels are used for handling, transportation and storage of liquefied gases at very low temperatures. By far the most important application is the manufacture of very large, land-based LNG storage tanks and tanks on board LNG carrier ships. These are an essential part of the worldwide storage and distribution of LNG and therefore key to the sustained economic development of many countries that do not have sufficient indigenous energy resources. Needless to say, the bulk storage of highly inflammable liquid gas is safety-critical and every effort is made to ensure the safe construction and operation of these tanks by using only steels from reliable producers, which are subject to extensive testing and validation.