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ALLOY STEELS

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ABSTRACT OF THE DISCLOSURE

This specification describes improved low carbon steels having a valuable combination of strength, toughness and weldability. The steels, which are characterised by a fine-grained ferritic microstructure, consist essentially of up to 0.1% carbon, 0.85 to 2.5% manganese, 0.001 to 0.03% nitrogen, up to 0.5% silicon and at least one of niobium (0.01 to 0.20%) and vanadium (0.01 to 0.30%).

This invention is concerned with improvements in or relating to alloy steels with ferritic microstructures.

This application is a continuation-in-part of my application Ser. No. 448,244 filed Apr. 15, 1965, now abandoned.

One of the greatest problems facing the steel industry since the introduction of mild steel as a commercial structural material in 1862 has been to discover how to increase the strength of this steel without at the same time incurring too great a loss of toughness and weldability. Relatively little progress has been made, as can be seen by the fact that the allowable working stress for the most common structural steel (i.e., that meeting British standard specification BS. 15, 1961, which calls for a maximum carbon content of 0.25% and a minimum yield stress and a minimum ultimate tensile strength of 16 and 28 tons per square inch respectively) has been raised from 4½ tons/sq.in. to only 9½ tons/sq.in. in 100 years. In a much shorter time, that is in the period since 1920, the allowable working stress of reinforced concrete, the principal competitor to structural steel, has increased by 500%.

Many attempts have been made to improve the competitive position of structural steel by increasing the yield strength. One technique has been to raise the carbon content and introduce alloying elements, such as manganese, to improve toughness and aid grain refinement. A typical example of such a practice is steel meeting British standard specification BS. 548, 1934 in which a yield stress and an ultimate tensile strength of 23 tons per square inch and 37 tons per square inch (as compared to the 16 tons per square inch and 28 tons per square inch of British standard specification BS. 15, 1961) is achieved by raising the maximum carbon content to 0.30% and the maximum manganese content to 1.5%.

Welding difficulties were experienced with this type of steel due to the high carbon content, and a lower carbon, higher manganese British standard specification BS. 968, 1941 was introduced. This specification calls for a maximum carbon content of 0.23%, a maximum manganese content of 1.8% and the same minimum yield stress and ultimate tensile strength as BS. 548, 1934. Difficulties with welding this steel and in controlling its toughness have also been experienced, the most notorious example being the failure of the King Street Bridge in Melbourne, Australia in 1962.

A revised BS. 968 specification (British standard specification BS. 968, 1962, which specifies a maximum carbon content of 0.20%, a maximum manganese content of 1.5%, a minimum yield stress of 23 tons per square inch, a minimum ultimate tensile strength of 32 tons per square inch, and a Charpy V notch impact energy of 20 foot-

pounds at −15° C.) was then introduced in which both the carbon and manganese were reduced but advantage was taken of the grain refining effect of the element niobium (see U.S. Patent 2,158,651) to retain the minimum yield strength of 22 tons/sq.in. Even this steel is, however, not free from welding and toughness problems.

All the above steels are of the type known as ferrite/pearlite steels in which there are two microstructural constituents, ferrite, which is almost pure iron, and pearlite, which is a lamellar mixture of ferrite and iron carbide. The presence of the pearlite has always been considered essential because of its strengthening effect and because its precipitation in the ferrite restrains ferrite grain growth and thus adds to yield strength and toughness.

I have now found that, because other strengthening methods are now available and because strong carbide formers, such as niobium, exert a strong grain refining effect, pearlite is no longer essential as a constituent of high strength structural steels. I have further found that if the carbon content and the other alloying constituents of the steel are so chosen that the amount of pearlite present in the structure is less than 2% by volume, the resulting steel is remarkably tough and is also readily weldable.

According to the present invention, I provide an alloy steel having a ferritic microstructure containing precipitated carbides or carbonitrides of at least one of the elements niobium and vanadium and not more than 2% by volume of pearlite, a yield strength minimum of 22 tons per square inch, a Charpy impact transition temperature at 40 ft. lbs. of less than 0° C. and a Charpy shelf impact absorbed energy value of more than 100 ft. lbs., said alloy steel consisting essentially of up to 0.08% carbon, from 0.85 to 2.5% manganese, from 0.001 to 0.03% nitrogen, up to 0.5% silicon, and at least one of the elements niobium and vanadium in the proportions 0.01 to 0.20% Nb and 0.01 to 0.30% V, the valance being iron and incidental impurities and quantities of such elements which may be required to facilitate the steelmaking practice.

The preferred manganese content is from 1.25 to 2.00%, but if extra high yield strength is required then up to 2.5% can be tolerated or if the best possible weldability is required, the manganese content can be reduced to 0.85%.

While 0.08% is the stated upper limit of carbon content, the steel may, according to a modification of the invention, contain up to 0.10% carbon. When a carbon content between 0.08 and 0.10% is used, the niobium and vanadium content should be at the upper ends of the ranges mentioned above, that is at least 0.06% in the case of each of these carbide-forming elements, in order that the steel should not contain more than 2% by volume of pearlite. The steel may also contain up to 1.2% silicon, but 0.5% or less silicon is preferred.

For steels containing 0.08% or less of carbon, the preferred content of each of the carbide-forming elements is from 0.03 to 0.06%.

The incidental constituents which may be present in the steels according to the invention are, firstly, the impurities which normally arise in steelmaking practice, such as sulphur (typically up to 0.025%) and phosphorus (typically up to 0.05%), and secondly, small quantities of additional alloying elements, such as nickel (suitably up to 0.5%) where additional toughness is required, and chromium (suitably up to 0.5%) or copper (suitably up to 0.5%) where additional corrosion resistance is required.

The alloy compositions according to the invention are suitable for production as rimming or semi-skilled steel.

The steels according to the invention can be normalised or rolled at low or high finishing temperatures ac-

cording to the properties required in the finished steel. Thus products with particularly good yield stress properties are obtained by using the steels in the rolled condition, the rolling schedule being arranged so that the final pass is made in the temperature range 650° C. to 950° C.

Toughness in steels is measured in several ways but the two clearest indications of the toughness of a structural steel are the Charpy impact transition temperature and the Charpy "shelf" impact absorbed energy. The lower the first and the higher the second, the tougher the steel. Reducing the pearlite content from its normal value of about 15% to 2% can reduce the transition temperature by 30° C. Reducing the pearlie content to 0% can reduce the transition temperature by a further 60° C. The Charpy "shelf" impact absorbed energy can be raised simultaneously from a normal value of 80 ft. lb. to one of more than 220 ft. lb.

Any loss in strength occasioned by the removal of the pearlite to these low limits is more than compensated for in the steels according to the invention by the presence of the niobium and vanadium which contribute strength by precipitation hardening and grain refinement, by using a manganese content at the upper end of the above-mentioned range, if necessary, and by finish rolling at low temperature to improve grain refinement.

The removal of pearlite so improves the toughness and weldability of these steels that quite wide variations in the incidental constituents and the processing conditions can be tolerated without materially impairing these properties and a very wide range of strength and toughness can be achieved in what is basically a single class of steel. For example by finish rolling a steel containing 0.05% C, 1.9% Mn, 0.06% Nb, 0.011% N at 700° C., a yield strength of 41 tons/sq. in. can be obtained, coupled with a transition temperature of −85° C. and a Charpy shelf value of more than 220 ft. lb. On the other hand by normalising at 900° C. and air cooling a steel containing 0.05% C, 1.56% Mn, 0.27% Si, 0.05% Nb, 0.06% V, 0.013% N, a yield strength of 24 tons/sq. in. can be obtained coupled with a transition temperature of −130° C. and a Charpy shelf value of more than 220 ft. lb.

The removal of pearlite also reduces the extent of segregation of the various constituents in the steel and in particular, reduces the incidence of laminations which in other steels are most often caused by the presence of pearlite.

Production and testing of many alloys within the scope of the present invention has enabled us to determine that the alloys according to the invention all have a yield strength of more than 22 tons/sq. in., a Charpy impact transition temperature at 40 ft. lbs. of less than 0° C., and a Charpy "shelf" impact absorbed energy value of more than 100 ft. lbs. This combination of properties is superior to that possessed by known structural steels which meet British standard specifications 548, 1934; 968, 1941; and 968, 1962.

The following examples are given by way of illustration only:

Example 1

A steel of the following composition, the balance being iron, was prepared:

0.06% C; 0.022% S; 0.04% P; 1.32% Mn; 0.034% Cr; 0.0272% Ni; 0.008% Sn; 0.0022% N; 0.032% Nb.

The yield strength of the steel was in the range 27–30 tons/sq. in., its Charpy transition temperature was less than −60° C. and its weldability was much superior to any other structural steel presently available.

Examples 2–19

Steels of the compositions indicated below were prepared and finish rolled at the temperatures indicated and the lower yield strength (in tons/sq. in.), Charpy impact transition temperature (in ° C. at 40 ft. lbs.) and Charpy impact shelf energy (in ft. lbs.) of the finished steels were determined. In each case, the balance of the alloy composition was iron and unavoidable impurities.

Ex.	Finish rolling temp., °C	C	Mn	Nb	N_2	V	Si	Yield strength, tons/sq. in.	Trans. temp., °C	Impact shelf energy, ft. lbs
2	940	.04	1.51		0.18	.054	.23	28.5	−38	214
	835							29.1	−70	>202
3	1,019	.041	1.25		.02	.049	.24	28.45	−27	>169
	935							28.95	−48	>209
	830							29.3	−72	212
4	1,020	.041	1.97	.125	.026	.115		*30.55	−2	>174
	965							31.0	−74	216
	855							32.1	−118	216
5	955	.035	1.55	.07	.023	.13		30.1	−58	216
	845							30.05	−90	216
6	950	.052	1.59		.022	.12	1.11	30.7	−55	>185
	855							34.85	−106	216
	735							40.3	−75	>197
7	1,020	.045	1.52		.025	.12	.26	33.75	−14	>105
	940							33.1	−65	>182
	835							33.5	−120	216
8	965	.04	1.7	.135	.017		.25	28.95	−74	>213
	850							30.35	−105	>213
	770							31.25	−108	116
9	1,010	.049	2.03	.135	.0145			28.55	−19	>138
	985							31.7	−73	>203
	857							31.65	−109	216
	765							31.0	−115	216
10	990	.044	2.03	.13	.024	.125	.26	31.2	−32	>201
	840							29.35	−103	>186
11	1,020	.085	1.41	0.75	.008			28.1	0	
	940							29.3	−62	>200
	830							29.4	−112	>205
12	1,040	.0305	1.49	.033	.007			22.65	−21	
	950							24.6	−55	>200
	835							26.4	−112	>215
13	935	.055	1.23	.054	.005			26.55	−51	214
	845							26.95	−92	215
14	950	.049	1.91	.061	.011			28.55	−21	216
	725							31.8	−64	215
	690							41.0	−85	211
15	915	.049	1.81	.06	.0145			29.95	−48	204
	845							30.7	−105	215
	780							30.75	−68	215
16	945	.018	.85	.058	.008			23.65	−8	216
	860							24.7	−91	216
17	950	.04	1.52	.052	.0055			26.1	−50	215
	860							28.3	−103	216
	700							36.25	−65	216
18	940	.039	2.13	.097	.013		.93	29.4	−74	>164
	840							30.0	−102	>204
	785							35.05	−103	>146
19	1,015	.03	1.55	.104	.016			31.45	−28	>205
	965							29.85	−77	216
	770							29.2	−87	216

In the case of the product of Example 4, finish rolled at 1020° C., the figure with asterisk in the "Yield Strength" column is the value of Proof Stress, in tons/sq. in., for an 0.2% permanent set.

The alloy compositions of Examples 2 to 19 all contained 2% by volume or less of pearlite.

I claim:

1. An alloy steel having a fine grained ferritic microstructure containing precipitated carbides or carbonitrides of at least one of the elements niobium and vanadium and not more than 2% by volume of pearlite, a yield strength minimum of 22 tons per square inch, a Charpy impact transition temperature at 40 ft. lbs. of less than 0° C., and a Charpy shelf impact absorbed energy value of more than 100 ft. lbs., said alloy steel consisting of up to 0.08% carbon, from 0.85 to 2.5% manganese, from 0.001 to 0.03% nitrogen, up to 0.5% silicon, and at least one of the elements niobium and vanadium in the proportions 0.01 to 0.20% Nb and 0.01 to 0.30% V, the balance being iron and incidental impurities and quantities of such elements which may be required to facilitate the steelmaking practice.

2. An alloy steel having a fine grained ferritic microstructure containing precipitated carbides or carbonitrides of at least one of the elements niobium and vanadium and not more than 2% by volume of pearlite, a yield strength minimum of 22 tons per square inch, a Charpy impact transition temperature at 40 ft. lbs. of less than 0° C., and a Charpy shelf impact absorbed energy value of more than 100 ft. lbs., said alloy steel consisting of from 0.01 to 0.04% carbon, from 1.4 to 2.4% manganese, from 0.001 to 0.03% nitrogen, up to 0.5% silicon, and at least one of the elements niobium and vanadium in the proportions 0.01 to 0.20% Nb and 0.01 to 0.3% V, the balance being iron and incidental impurities and quantities of such elements which may be required to facilitate the steelmaking practice.

3. An alloy steel according to claim 1 in which the contents of the at least one of niobium and vanadium is from 0.03 to 0.06%.

4. An alloy steel according to claim 1 in which the manganese content is from 1.25 to 2.00%.

5. An alloy steel having a fine grained ferritic microstructure containing precipitated carbides of carbonitrides of at least one of the elements niobium and vanadium and not more than 2% by volume of pearlite, a yield strength minimum of 22 tons per square inch, a Charpy impact transition temperature at 40 ft. lbs. of less than 0° C., and a Charpy shelf impact absorbed energy value of more than 100 ft. lbs., said alloy steel consisting of up to 0.60% carbon, from 0.85 to 2.5% manganese, from 0.001 to 0.03% nitrogen, up to 1.2% silicon, and at least one of the elements niobium and vanadium in the proportions 0.01 to 0.20% Nb and 0.01 to 0.30 V, the balance being iron and incidental impurities and quantities of such elements which may be required to facilitate the steelmaking practice.

6. An alloy steel according to claim 5 in which the content of the at least one of niobium and vanadium is from 0.03 to 0.06%.

7. An alloy steel according to claim 1 in which the manganese content is from 1.25 to 2.00%.

8. An alloy steel having a fine grained ferritic microstructure containing precipitated carbides or carbonitrides of at least one of the elements niobium and vanadium and not more than 2% by volume of pearlite, a yield strength minimum of 22 tons per square inch, a Charpy impact transition temperature at 40 ft. lbs. of less than 0° C., and a Charpy shelf impact absorbed energy value of more than 100 ft. lbs., said alloy steel consisting of up to 0.10% carbon, from 0.85 to 2.5% manganese, from 0.001 to 0.03% nitrogen, up to 0.5% silicon, and at least one of the elements niobium and vanadium in the proportions 0.01 to 0.20% Nb and 0.01 to 0.30 V, the balance being iron and incidental impurities and quantities of such elements which may be required to facilitate the steelmaking practice.

9. An alloy according to claim 3 wherein the manganese content is from 1.25 to 2.00%.

10. An alloy steel according to claim 5 wherein the manganese content is from 1.25 to 2.00%.

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