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LOW-CARBON, HIGH-STRENGHT STRUCTURAL STEEL
WITH GOOD WELDABILITY
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Figure 1. ×15.000

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LOW-CARBON, HIGH-STRENGTH STRUCTURAL STEEL WITH GOOD WELDABILITY

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ABSTRACT OF THE DISCLOSURE

High strength structural steels having good weldability contain 0.04% to 0.08% carbon, from 0.6% to 2.0% manganese, from 0.1% to 0.5% silicon, from 2% to 5% chromium, from 0.01% to 0.05% metallic aluminum, from 0.03% to 0.1% niobium, the balance, apart from incidental impurities, being iron.

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of applicant's prior copending U.S. application Ser. No. 129,572, filed Mar. 30, 1971.

BACKGROUND OF THE INVENTION

The present invention concerns a low-carbon structural steel possessing good weldability characteristics. It has been prior practice to improve the strength characteristics of steels of this type by reducing the grain size, increasing the pearlite quantity, reinforcing the ferrite by alloying constituents dissolved in it, and precipitation hardening. The latest step of development in this particular field is represented by the so-called microalloyed fine grain steels. In these steels the carbon content is as a rule in the range of 0.1%–0.2% and the Mn content about 1.5%. For the achievement of fine grain and precipitation hardening, alloying agents forming carbides and nitrides, such as Al, V, Ti, Nb, etc. are added in small amounts. With these steels, in normalized condition, a yield point of about 50 kp./mm.^{2} is achieved, while impact strength and weldability still remain satisfactory. Further increasing of strength impairs the weldability and impact strength and raises the yield stress ratio above 0.8, which is undesirable according to present understanding.

In the steels described in Swedish patent application No. 3,612, Nov. 16, 1968, an addition of up to 5% manganese has been proposed for achieving sufficient hardenability. Manganese is a powerful hardenability-increasing agent, but its use at relatively high contents is associated with numerous difficulties. High manganese content causes, for instance, more powerful corrosion of refractory materials in the ladle than normal, while the high segregation tendency of manganese causes an inhomogeneous microstructure in the steel, and owing to the high oxidation sensitivity of manganese the corrosion resistance of steel with a high manganese content is lowered in comparison with conventional weldable structural steels.

Endeavours have been made to find new solutions for achieving higher strength values. Recent advances in metals theory indicate that the mechanical properties of steels are decisively affected by the dislocation structure of the metal crystals, that is of the number and grouping of dislocations in the crystals. Dislocations are one-dimensional faults in the regular crystal structure, on the mobility of which the plastic deformation of metals is based. Correspondingly, new dislocations are produced in

the crystals in great number e.g., on cold working. Increasing number of dislocations impedes their movement, whereby the resistance to subsequent deformation increases. This is called work hardening. Work hardening is in fact one of the most widely used means for increasing the strength of steel.

In developing the steel of the present invention the fundamental idea was to achieve in the steel a similar microstructure with abundant dislocations by means of heat treatment, whereby the steel is endowed with good strength characteristics. The principle, previously known in itself, has been carried out in the hardening of steel. Hitherto, steels intended to be hardened contained as a rule not less than 0.2% carbon. However, the high-carbon martensite present in prior steels on appropriate heat treatment is exceedingly hard and brittle, which is due to the very high dislocation density of the martensite lenses and to precipitation hardening caused by finely divided carbide precipitation.

SUMMARY OF THE INVENTION

According to the present invention, the hardness of the martensite produced on hardening by heat treatment is lowered and at the same time the ductility is improved by lowering the carbon content to 0.08% or below and preferably below 0.05%. Thus the invention provides steels having high strength and weldability, which contain between 0.04% and 0.08% carbon, from 0.6% to 2.0% manganese, from 0.1% to 0.5% silicon, from 2% to 5% chromium, from 0.01% to 0.05% metallic aluminum, and from 0.03% to 1.0% niobium, the balance, apart from incidental impurities, being iron.

A preferred group of steels of the invention contain from 0.04% to 0.05% carbon, between 1.2% and 1.4% manganese, from 0.1% to 0.3% silicon, between 3.2% and 3.6% chromium, between 0.01% and 0.05% metallic aluminum, and between 0.05% and 0.08% niobium, the balance, apart from incidental impurities, being iron. The preferred group of steels of the invention is characterized by higher hardenability and better ductility and weldability, due to its higher alloy content and lower carbon content, than the steels of the broader group. Steels of the preferred group are thus suitable for thicker dimensions when good weldability has to be guaranteed.

The martensite produced in the steels of the invention contains dislocations in abundance, which may form a certain kind of three-dimensional network structure, a so-called cell structure, within the martensite laths. The thin foil electron micrograph in FIG. 1 illustrates this kind of microstructure.

In low-carbon martensite steels of the invention no precipitation hardening occurs, and the martensite then possesses ductility without tempering.

In the steel according to the present invention the aim has been to produce a microstructure comprising a low-carbon martensite by controlled alloying of the steel and by rapid cooling thereof from the austenite range by quenching in oil or preferably in water. This type of microstructure is characterized by high strength and excellent ductility in the hardened condition even without tempering. Thus, in the present steels, the particular alloying elements and their amounts have been chosen in order to render possible the hardening of the steel by rapid cooling.

In the steel according to the present invention an amount of from 2% to 5% chromium has been used as the principal alloying agent by means of which the following advantages are gained, compared to the above mentioned high-manganese steels:

(a) chromium alloying does not increase the corrosion of refractory materials;

(b) the steels possess a more homogeneous microstructure, because the segregation tendency of chromium at the solidification stage is low; and

(c) as a result of chromium alloying the corrosion resistance of the steel improves (cf. Miekk'oja: Metallioppi, p. 354 which discloses that a 3% addition of Cr increases the resistance against corrosion in air by about fivefold).

The contents of other alloying agents and of impurities are consistent with the requirements imposed on good quality, weldable structural steel.

EXAMPLES

To illustrate the improved properties of steels of the invention, results will now be presented which were obtained by testing seven experimental alloys A to G having the compositions, by weight, identified in Table 1.

TABLE 1.—CHEMICAL ANALYSES

Alloy	C	Si	Mn	Cr	Al_{met}	Nb
A	0.060	0.38	1.30	2.75	0.023	0.080
B	0.040	0.15	0.87	3.27	0.002	0.040
C	0.047	0.28	1.22	3.32	0.010	0.053
D	0.045	0.19	1.33	3.54	0.050	0.085
E	0.058	0.25	0.64	4.99	0.011	0.07
F	0.051	0.21	1.84	2.00	0.009	0.03
G	0.050	0.29	0.92	2.80	0.004	0.09

NOTE.—Balance incidental impurities and iron.

The test material was produced in a 20 ton electric-arc furnace, cast into 3.5 ton ingots and hot rolled to the rod dimensions indicated in the subsequent tables. These rods were heat treated at 960° C. for ½ hour and quenched in water. Tests were made in as quenched condition. Tensile and impact testpieces were centrifugally machined from quenched rods. The results obtained in tensile and impact tests are presented in the following table.

TABLE 2.—RESULTS OF TENSILE TESTS

Alloy	ϕ, mm.	$\sigma_{0,2}$	σ_B	Percent of— δ_5	Percent of— ψ	KCU +20° C. k.p.m.
A	16	92.0	119.0	14.0	58.0	9.0
	40	79.0	106.0	13.5	57.0	9.0
B	16	82.0	102.5	15.2	69.7	11.7
	40	68.0	88.0	18.4	73.0	12.1
	90	59.0	82.0	16.6	72.7	----------
C	16	84.5	108.5	13.4	68.7	9.3
	40	79.6	101.5	15.2	71.8	11.2
	90	72.0	93.3	17.2	70.6	5.4
D	16	88.0	110.9	14.4	68.8	11.4
	40	75.0	97.1	16.0	72.7	13.0
	90	72.3	93.9	16.4	68.5	5.9
E	16	89.5	114.0	14.4	65.3	9.5
	40	89.0	113.0	13.2	60.4	9.0
	90	80.0	110.0	12.0	49.4	9.0
F	16	83.0	105.0	15.3	67.8	9.5
	40	75.8	91.4	16.4	66.1	12.0
G	16	78.6	104.1	15.3	69.9	9.2
	40	68.7	82.8	15.4	68.5	11.7

The impact tests were carried out with a Charpy U test bar at +20° C., and the figures stated in the table refer to impact energy in k.p.m.

It is seen from the test results that steels according to the present invention possess a combination of characteristics which has previously been unattainable with weldable structural steels, as is evident from the following summary.

According to the test results, a steel according to the invention is characterized by:

(d) High yield point with quenching into water depending on dimensions 70–85 kp./mm.² (0.2 limit).

(e) Low yield limit ratio; the above-mentioned strengths are achievable without exceeding the critical value of 0.8.

(f) Static ductility characteristics, which are best illustrated by the contraction magnitude, are excellent also at high strengths.

(g) Impact toughness, which in quenched condition is equal to or better than that of normal heat treated steels of the same strength in tempered condition.

(h) On the strength of analysis and of welding trials performed, the steel is completely weldable under any conditions.

(i) With slow cooling in air, the steel according to the invention obtains a pearlite-ferritic microstructure, which is favorable from the point of view of cold working and machining and shaping operations, and low strength (yield point about 30 kp./mm.²).

All the favorable characteristics of steel according to the present invention, enumerated above, which in many respects surpass what one has been accustomed to in the case of conventional weldable structural steels, can be accounted for by the advantageous alloying that has been used. Particularly great significance attaches to the use of chromium to achieve hardenability. Chromium, which in many respects is opposite to manganese in regard of its alloying properties, has on the basis of the test results proved to be particularly suitable for steel of this kind.

The better resistance of chromium steel to corrosion, again, is explained by the well-known passivating effect of chromium. It is advantageous in view of good ductility characteristics if the amount of carbon dissolved in the austenite in connection with heat treatment is as small as possible. As an alloying agent increasing the activity of carbon in the lattice (as a carbide former), chromium is advantageous also in this respect.

In order to eliminate the work aging tendency caused by nitrogen, in the steel according to the present invention aluminum alloying has been employed. For adjustment of grain size by the aid of difficultly soluble carbonitrides, niobium alloying has been employed. Niobium, which is a particularly powerful carbide former, also removes part of the harmful dissolved carbon. The niobium carbides have a beneficial effect on the dislocation structure as a result of austenite decomposition, and increase the strength of the steel by precipitation hardening effect.

I claim:

1. A low-carbon martensite structural steel having high strength and good weldability which consists essentially of

(a) from 0.04 to 0.08% carbon,
(b) from 0.6% to 2.0% manganese,
(c) from 0.1% to 0.5% silicon,
(d) from 2% to 5% chromium,
(e) from 0.01% to 0.05% metallic aluminum,
(f) from 0.03% to 0.1% niobium,

and the balance iron.

2. A steel according to claim **1**, wherein the carbon content is not more than 0.05%.

3. A steel according to claim **1** wherein the manganese content is not more than 1.4%.

4. A steel according to claim **1** wherein the chromium content is not less than 3%.

5. A low-carbon martensite structural steel having high strength and good weldability, which consists essentially of

(a) from 0.04% to 0.05% carbon,
(b) between 1.2% and 1.4% manganese,
(c) from 0.1% to 0.3% silicon,
(d) between 3.2% and 3.6% chromium,

(e) between 0.01% and 0.05% metallic aluminum,
(f) between 0.05% and 0.08% niobium,
and the balance iron.

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