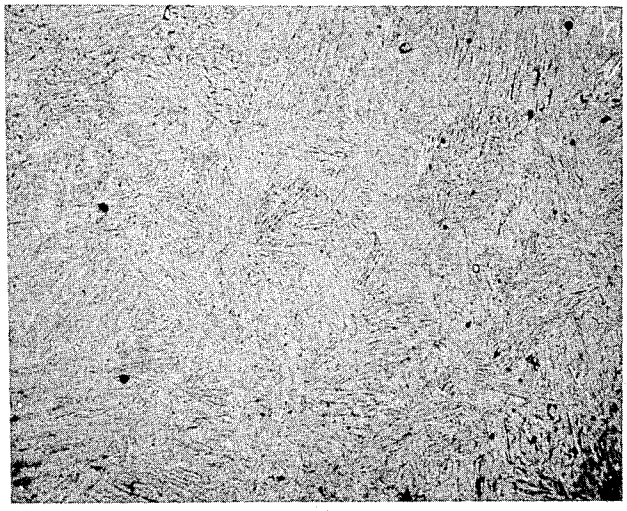
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STEEL ALLOY

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STEEL ALLOY

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The present invention relates generally to ferrous alloys and more particularly to an improved steel alloy characterized by ultrahigh strength, simplicity of formation and which is especially adapted for casting into parts for constructional and abrasive applications.

In the past, failures of certain cast steel structures have occurred under normal service or operating conditions because of a characteristic brittle condition that developed.

Extensive investigation revealed that brittle fractures of this type were caused by an adverse combination of two factors, to wit: (1) a notched condition in the steel structure resulting from either design or workmanship; and (2) an inherent notch sensitivity of the steel itself under operating conditions.

Although by careful design notching may be minimized, it is virtually impossible to avoid sharp corners in all instances, and even when the best has been done from a design point of view, notches may occur from inadvertent or careless workmanship. It thus becomes important to control the second factor, viz., the inherent notch sensitivity of the steel itself.

Although the desirability of developing cast steel alloys which have a high resistance to brittle fracture has become apparent, no satisfactory method of consistently and economically making a cast steel alloy to meet such requirements at high hardness levels, i.e., above 440 BHN, has heretofore been available to the steel industry. Indeed, in the past the only techniques known have required extensive foundry controls and the addition and control of auxiliary reagents such as the nickel addition taught in Payson, U.S. 2,447,084.

Still another prior approach, when tensile or impact loading has been demanded heretofore, has been to greatly overdesign the part and resign oneself to operation at a relatively low hardness level. The waste and expense of such an approach is obvious.

Where either overdesigning or the addition of auxiliary reagents has not been practiced, the prior materials possessed a general lack of toughness, particularly in the presence of notches or other cracklike defects.

An important feature of the present invention is the discovery that in the strategic composition range hereinafter described, a vastly improved cast steel alloy is provided which is exceedingly tough and has high impact resistance even at hardness levels in excess of 440 BHN.

Still other important features of the present invention lie in the provision of a cast steel alloy which readily obtains tensile strengths on the order of 250,000 p.s.i. T.S. at a hardness of 500 Brinell while having an elongation (in a 2 inch gage length) of 7 to 12 percent; Charpy V-notch impact values of 15 to 30 foot pounds at 80° F. and 10 to 20 foot pounds at —40° F., which contains no strategic or critical alloying elements, and which is easy to formulate and to handle.

Accordingly, a prime object of the present invention is to provide an improved cast steel alloy which is exceedingly tough, has superior resistance to brittle fracture and abrasion, and is suitable for use in large structures and for other structural purposes where castings are employed.

Another object of the present invention is to provide an improved cast steel alloy which possesses ultrahigh strength and toughness at high hardness levels without

containing any weakly functioning or critical alloying elements.

Another important object of the present invention is to provide an improved cast steel alloy characterized by a fully martensitic matrix, a tensile strength of 230,000 to 265,000 p.s.i., a yield strength of about 180,000 to 220,000 p.s.i., an elongation (2 inch gage length) of 7.0 to 12.0 percent; a reduction of area of 15 to 40 percent; a Charpy impact of 15 to 30 foot pounds at 80° F. and 10 to 20 foot pounds at —40 F.; and a hardness of from 440 to 560 BHN.

Still another important object of the present invention is to provide an improved ultrahigh strength cast steel alloy which obtains its desired properties through a strategic and synergistic combination of carbon, silicon and molybdenum with iron and eliminates the need for the addition of other alloying agents, such as nickel and aluminum, heretofore deemed necessary for producing tough alloy steels of this type.

Still another object of the present invention is to provide an improved ultrahigh strength cast steel alloy which is easy to prepare and simple to formulate and which eliminates complex foundry controls for its production.

These and still further objects are fulfilled by the present invention in a remarkably unexpected fashion as can be readily discerned from a perusal of the following detailed description of certain exemplary embodiments thereof, especially when considered in conjunction with the attached drawing showing the microstructure of an alloy embodying the present invention etched with picral and magnified to 500 times.

One process for preparing the unique alloy of the present invention will be described, it being understood that such variations and modifications of the process as may occur within the realm of conventional steel making practices will not be a departure therefrom.

Thus, while the alloy of the present invention may be formed in both basic and acid lined open hearths, both basic and acid lined electric furnaces, or in an induction furnace, its production will be described for a basic electric furnace to exemplify the techniques involved. It should be remembered, however, that while basic lined furnaces readily permit the addition of lime or like scavengers to reduce the sulfur and phosphorous content of the initial charge to the desired range, the addition of lime to acid lined furnaces is to be discouraged because of its adverse effect on the acid linings of these furnaces. Instead, preliminary care must be exercised when acid equipment is used to assure that sulfur and phosphorus levels are minimal before the initial charge is placed in the furnace.

In a basic electric furnace, a charge of relatively pure iron or steel scrap (no cast iron) is melted at a temperature of about 3000° F. If the carbon content of the charge is too high, that is, falls in excess of about 0.40 percent by weight of the charge, the excess carbon is burned out by an addition of lime to the melt. If desired, iron ore may be added to the melt to effect a carbon boil whereupon the carbon will be oxidized to carbon monoxide and become evanescent. The carbon is thus reduced most probably to levels considerably less than that which will be ultimately desired.

Next about one-third of the total silicon desired in the final analysis is added to the melt as ferro silicon to control the gas activity of the heat and calm the bath.

Next sufficient manganese is thrown into the bath, either as ferro manganese or as electrolytic manganese, to provide the final analysis with at least 0.1% manganese (to prevent hot shortness) but not more than 2.25%.

Next, molybdenum is added as ferro molybdenum in sufficient quantity to provide the final analysis with from

about 0.80 to 1.10 percent (by weight) of molybdenum.

Thereafter, another one-third of the silicon is added to the melt to redeoxidize the melt and prepare it for carbon additions to come. Because silicon functions as a fairly active deoxidizer, it is preferred that it be added in increments although exact adherence to the proportions described is not necessary.

Next, the carbon content is adjusted to provide a carbon content in the final analysis of about 0.25 to 0.35 percent (by weight). The carbon adjustment may be effected in any suitable manner such, for example, as by the addition of an appropriate number of graphite sticks or by the addition of a suitable quantity of cast iron.

The melt is then tapped into a ladle. In the usual practice, where castings weighing less than one ton are being produced, the ladle will have a capacity equal to that of the furnace. In this instance, the remaining increment of silicon, i.e., sufficient to provide from 1.40 to 2.25 percent (by weight) of silicon in the final analysis, will be placed in the ladle either before or while the melt is contained thereby. When a plurality of ladles are required to contain the contents of the furnace, this final silicon increment will, of course, be prorated among the several ladles.

The ladles are next poured into sand molds which, when later machineability is desired, will be permitted to sit while the castings slowly cool. When later machining is not required, the molds may be shaken out as soon as possible and the casting air cooled. When the castings have cooled to or slightly below red heat, they are placed in a furnace heated to about 1750° F. ±50° for a period of from about 1 to about 4 hours, depending upon the size of the casting. A good rule of thumb for determining the duration of the heat treatment at the prescribed heat is to continue heating one hour for each inch of casting thickness up to four inches, i.e., not over about four hours.

After heating, the casting is quenched, in either oil or water, to a temperature below 400° F. whereupon a matrix of untempered martensite is produced.

The untempered martensitic casting is then tempered for a period of from about 2 to about 4 hours (depending again on section size) at a temperature of 500° F. ±50°. The tempered casting is then cooled and is ready for using in structural applications or for machine components such for example, as roller track bushings and the like; or in abrasion applications, such as ball mill screen plates and the like.

The alloy thus formed has the following general composition by weight percent:

Carbon	0.25–0.35
Silicon	1.40–2.25
Molybdenum	0.80–1.10
Manganese	0.1–2.25
Phosphorus	0.03 max.
Sulfur	0.03 max.
Iron	Remainder

and possesses the following physical properties:

Tensile strength—p.s.i.	230,000–265,000
Yield strength—p.s.i.	180,000–220,000
Elongation (in 2 inches)—percent	7.0–12.0
Reduction of area—do	15–40
Hardness—BHN	440–560
Charpy impact—	
@ 80° F—ft.-lbs.	15–30
@ −40° F—ft.-lbs.	10–20

Thus, a unique cast steel alloy, especially designed for toughness at high hardness levels is provided which contains no weakly functioning or critical alloying elements. Rather the composition presents a cast steel alloy having an optimum molybdenum concentration synergistically coacting with the gross silicon additions to provide remarkably unexpected though admittedly superior physical properties.

The compositions of several heats performed within the scope of the present invention are recorded below in Table I. The physical properties developed by these heats are recorded in Table II.

Table I

Heat No.	Composition (Wt. Percent)			
	Carbon	Silicon	Molybdenum	Manganese
1	0.26	1.66	1.02	1.27
2	0.33	1.62	0.99	1.26
3	0.27	1.82	1.03	1.90
4	0.26	1.63	1.00	2.17
5	0.25	1.41	1.07	2.07
6	0.33	1.51	0.84	1.55
7	0.26	2.22	1.22	1.07
8	0.26	2.23	0.84	1.08
9	0.26	1.75	0.83	1.28
10	0.30	1.70	1.03	1.30
11	0.28	1.61	1.01	1.32
12	0.27	1.87	1.03	1.78
13	0.32	1.76	1.63	1.88
14	0.30	1.79	1.02	1.78
15	0.31	1.68	1.01	1.74
16	0.28	1.65	1.00	1.06
17	0.27	1.85	0.99	0.18
18	0.25	1.81	0.98	0.63
19	0.32	1.80	0.62	1.28
20	0.29	1.58	1.01	0.80
21	0.29	1.60	1.03	1.61
22	0.29	1.57	1.03	2.02

Table II

Heat No.	Physical Properties			Charpy-V @ 80° F. (ft.-lbs.)	Charpy-V @ −40° F.
	Tensile Strength (p.s.i.)	Elongation (percent)	Reduction in Area (percent)		
1	234,500	11.0	36.0	30, 31	16, 16
2	276,000	7.0	15.0	15, 16	11½, 10
3	[1] 240,800	9.0	26.6	27, 25	15, 16
4	242,000	10.0	26.6	23, 22	16, 16
5	225,750	10.0	28.0	28, 27	19, 19
6	268,500	7.0	15.0	17½, 16	11, 10
7	239,500	9.0	26.0	18, 20	10, 10
8	238,000	11.0	31.0	28, 25	14, 12
9	225,000	10.0	28.0	30, 31	12, 13½
10	235,000	9.0	18.0	26, 24	12, 10
11	250,800	8.0	22.0	17, 18	12, 12
12	[1] 252,000	8.5	27.0	21, 20	12, 11
13	[1] 258,000	7.5	15.2	15, 15	10, 13
14	[1] 245,000	10.5	31.0	30, 28	18, 20
15	[1] 241,250	9.0	22.0	27, 23	16, 14
16	[1] 244,000	8.5	22.0	----------	----------
17	[1] 239,500	9.0	28.0	----------	----------
18	230,000	12.0	39.5	31, 30	20, 18
19	259,500	8.5	26.0	17, 16	10, 9
20	236,500	8.0	26.0	18, 14	10, 12
21	245,000	8.0	22.0	15, ---	----------
22	243,250	10.0	28.0	20½, 18	----------

[1] 150 pound melts; all others 20 pound melts.

From the foregoing it becomes apparent that an ultra-high strength cast steel has been developed which is suitable for structural and abrasion applications. Apart from its excellent mechanical properties at high hardness levels, all of the reported heats had hardnesses in excess of 440 BHN, a major advantage of the alloy is its simplicity. Thus, the few elements essential to its analysis minimize foundry control problems and, in particular, the gross deoxidation by silicon is in sharp contrast to the normally critical deoxidation operations involved in the addition of small amounts of more active agents as heretofore was deemed essential for such alloys. Furthermore, the heat treatment of the alloy involves only simple quench and temper operations to develop maximum properties. Complex prenormalizing, homogenization or double tempering are not required. Still further, this alloy is nonstrategic and contains no nickel, heretofore deemed essential for toughness. Similarly the critical control of aluminum heretofore taught for procuring improved physical properties is completely obviated.

Indeed, additions of or scrap materials containing aluminum should be conscientiously avoided since the addition of even very small amounts of aluminum drastically reduces the ductility of steel due to the formation of a sec-

ond micro-structural phase. This relatively weak phase, called "ferrite" does not respond to heat treatment and hence remains in the finished part.

It is further apparent that a new cast steel alloy has been herein described which fulfills all of the aforestated objects to a remarkable extent and in a totally unobvious fashion. It is, of course, understood that such alterations, modifications and applications as will readily occur to the artisan when confronted by this disclosure are intended within the spirit of this invention, especially as it is defined by the scope of the claim appended hereto.

Having now particularly described and ascertained the nature of my said invention and the manner in which it is to be performed, I declare that what I claim is:

A cast ball mill screen plate, of a martensitic alloy steel consisting (by weight) of from about 0.25 to not more than 0.35 percent carbon, from about 1.40 to about 2.25 percent silicon, from about 0.80 to about 1.10 percent molybdenum, from about 0.1 to not more than 2.25 percent manganese; nil to not more than 0.03 percent sulfur; nil to not more than 0.03 percent phosphorus; and a remainder essentially of iron.

References Cited in the file of this patent

FOREIGN PATENTS

352,548 Great Britain ---------- July 13, 1931

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,126,303 March 24, 1964

Charles H. Armitage

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 38, for "Payson, U. S. 2,447,084" read -- Payson, U. S. 2,447,089 --.

Signed and sealed this 29th day of September 1964.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents