United States Patent Office 3,113,861 Patented Dec. 10, 1963

3,113,861

AUSTENITIC STEEL ALLOY

Telfer E. Norman, Denver, Colo., assignor to American Metal Climax, Inc., New York, N.Y., a corporation of New York

No Drawing. Filed May 16, 1961, Ser. No. 110,337
7 Claims. (Cl. 75—123)

The present invention resides in novel alloy steels and in particular to high carbon austenitic steels characterized by high abrasion resistance, combined with good ductility, good impact resistance and a rapid rate of work-hardening when plastically deformed in service.

Cast or wrought steels for applications requiring a high degree of abrasion resistance are commonly made from compositions containing about 0.50 to 1.50% carbon, together with suitable alloy additions and heat treatments to produce certain desired combinations of hardness, strength, ductility and wear resistance. The microstructures existing in these steels may generally be classed as pearlitic, martensitic or austenitic or in some cases combinations of these microstructures may exist in certain abrasion resistant parts.

For a high carbon steel of a specific composition, greatest resistance to abrasion is normally obtained when its structure is made martensitic, which produces the maximum hardness obtainable from the composition. However, I have found that high carbon austenitic steels will have abrasion resistance which approaches that of martensitic steels of equivalent carbon content, provided the austenitic structure is sufficiently unstable so that it work hardens rapidly on its wearing surface when plastically deformed. Substantial amounts of suitable alloying elements are necessary in any high carbon steel in order for it to retain a fully austenitic structure at normal atmospheric temperatures. For example, in a steel containing 1.20% carbon, it requires a minimum of about 4.0% manganese, or about 5% chromium, or about 8% nickel or various combinations of these alloying elements in order to retain a fully austenitic structure at normal atmospheric temperatures. While each of these three alloying elements are capable of retaining an austenitic structure in a high carbon steel, they produce different effects on the relative toughness, work hardening characteristics and abrasion resistance of the austenitic structure. Molybdenum additions in amounts up to about 3.0% may also be used in combinations with other alloying elements to assist in retaining austenite in high carbon steels. The effect of molybdenum in these amounts is principally to assist in retaining the carbon in the austenite in solution, and this carbon in solution in turn has a potent effect in retaining an austenitic structure in a suitably heat treated steel.

In my present invention I have taken advantage of the various effects of austenite-retaining elements to produce a high carbon austenitic steel whose abrasion resistance approaches that of high carbon martensitic steels.

The austenitic steel of my invention has much greater ductility and impact resistance and is much easier to heat treat free from quench cracks or high residual stresses than high carbon martensitic steels. A further advantage of the alloy of my invention is that its structure and properties are obtainable by the use of relatively moderate amounts of alloying elements, so that it can be produced for an economical and competitive cost.

The chemical composition range of the alloy of my invention, in percent by weight, is as follows:

Carbon	1.00–1.50
Manganese	4.50–9.00
Silicon	0.20–0.90
Molybdenum	0.25–3.00

The balance is essentially iron. Elements which have been found to be harmful to the impact resistance and ductility of the alloy of my invention are phosphorus and chromium. To avoid excessive embrittlement, especially in heavy section castings, it is desirable to keep the phosphorus content under 0.08% and preferably under 0.05% while the chromium content should be less than 1.0% and preferably under 0.50%.

A preferred composition range suitable for most abrasion resistant parts is as follows:

Carbon	1.20–1.40
Manganese	5.00–7.00
Silicon	0.30–0.70
Molybdenum	0.50–1.50
Phosphorus	0.05% max.
Chromium	0.50% max.

In the foregoing preferred composition, the manganese may be held near the low side of the range when maximum abrasion resistance is desired, or the manganese may be held near the high side of the range when best impact resistance and improvement in other mechanical properties is desired.

The molybdenum content in the foregoing preferred composition may be held near the low side of the range in light-section, rapidly quenched parts and should be near the high side of the range in parts having cross section thickness greater than about 4 inches. When the alloy is used in a foundry to produce castings in a variety of sizes and thicknesses, a molybdenum content of about 0.8 to 1.20% represents a desirable and practical range.

The alloy of my invention is made fully austenitic by heating it to a temperature of 1900° F. to 2000° F. for a sufficient length of time to dissolve all or most of the carbon into solid solution in the austenitic matrix, after which it is quenched rapidly in water or other suitable liquid, or in the case of light section parts which can be air-cooled rapidly, it may be air quenched. An alternative treatment for certain castings is to remove the castings from their molds after they have solidified, but are still above about 1800° F., then quench them directly into water or other suitable quenching media. This direct quench procedure is particularly adaptable to castings which have been made in permanent metal or graphite molds or which have been cast as bars or rods in a continuous casting process. A modification and improvement of the direct quench procedure is to remove the castings from their molds soon after casting and solidfication, then place them in a furnace held at 1900° F., hold them in this furnace until the castings are uniformly at this temperature throughout their cross section, after which they are removed and quenched in the usual manner.

In order to study and evaluate various types and compositions of steel for abrasion resistant applications, I have developed a practical test which has been used in the ore grinding operations of Climax Molybdenum Company at Climax, Colorado, to evaluate and compare the relative abrasion resistance and impact resistance of various types of steel. For this test the steels to be studied are cast or forged into large grinding balls 4 to 5 inches in diameter. After being given the desired heat treatment, they are marked with suitable identification marks and are then charged simultaneously into a large commercially operating ball mill where the test balls are exposed to the normal abrasive and tumbling action in this mill for periods ranging from one to two weeks duration. The test balls are recovered from the mill after each test period and their weight losses and relative wear rates are determined. Also their susceptibility to breakage or spalling in service during the test is observed. To provide a standard of comparison, a group of high carbon martensitic steel balls having a specific composition and treatment is always included with the groups of test balls. Two

or more balls having the same composition and treatment are used for each group. This test was developed principally to evaluate materials for possible subsequent use in grinding mill liners but it also serves as a guide or indicator of abrasion resistance and toughness for other applications. The test is described in greater detail in my technical paper entitled "Factors Influencing the Resistance of Steel Castings to High Stress Abrasion," which was published in "Modern Castings" for May 1958, pages 89 to 98, and in the Transactions of the American Foundrymen's Society, volume 66 (1958), pages 187 to 196.

In the above mentioned AFS paper I also pointed out that my wear tests indicated the lean alloy types of austenite had much better abrasion resistance than the conventional Hadfield type 12% manganese austenitic steels. However, it was also pointed out that many of the lean alloy types of austenite had insufficient impact resistance or toughness for commercial use. The alloy of the present invention provides the desired combination of toughness and abrasion resistance.

The following table lists the observations and results of wear-impact tests and mechanical property tests on a series of 24 austenitic steel compositions. In this table the abrasion factors represent rates of wear relative to a rate of 100 for a martensitic steel containing 1.0% carbon, 0.8% manganese, 6.1% chromium, and 1.0% molybdenum. Low factors indicate good wear resistance and high factors indicate inferior wear resistance.

The alloy of my invention is exemplified by the first three examples. While it does not normally have as good ductility or impact resistance as the widely used Hadfield type 12% manganese steel (item 11 in table), there are many applications where the full ductility and impact resistance of the Hadfield type steel is unnecessary. It is in such applications that the alloy of my invention, with its substantially superior abrasion resistance, is commercially attractive.

improvement in wear resistance in these austenitic manganese steels. However, the principal function of molybdenum in the alloy of my invention is to suppress or prevent precipitation of embrittling types of carbides around grain boundaries or along crystallographic planes. When molybdenum is not present in the composition, these embrittling types of carbides tend to occur, especially in the heavier sections of high carbon, lean alloy austenitic manganese steels. A major virtue of the alloy is that it is ductile and work hardens to an important degree under impact.

Some of the advantages of the alloy of my invention may be summarized as follows:

(1) It has substantially better wear resistance than the Hadfield type 12% manganese austenitic steels.

(2) It has a more rapid rate of work hardening and greater resistance to flow, when exposed to repeated impact, than the Hadfield type 12% manganese austenitic steels.

(3) Its abrasion resistance approaches and in some cases equals the abrasion resistance of high carbon martensitic steels, while at the same time it has substantially greater ductility and impact resistance than the high carbon martensitic steels.

(4) Cost of alloying elements in the steel is moderate, its heat treatment is relatively simple and no special or unusual types of equipment are required for its production and heat treatment.

(5) It has a combination of tensile strength, impact strength, ductility and abrasion resistance which make it permissible and attractive for use in a wide variety of applications involving abrasive service.

What is claimed is:

1. An alloy steel consisting of 1.0 to 1.5% carbon, 4.5 to 9.0% manganese, 0.2 to 0.9% silicon, 0.25 to 3.0% molybdenum, the remainder essentially iron.

Item No.	Composition, Percent							0.2% Yield Str., p.s.i.	Tensile Str., p.s.i.	Elongation, Percent	Abrasion Factor [1]
	C	Mn	Si	Cr	Mo	Ni	Cu				
1	1.37	6.0	0.5		0.5			56,800	83,700	15.0	114
2	1.19	5.6	0.5		1.0			54,650	72,850	9.5	115
3	1.19	5.5	0.5		0.5			52,150	71,750	10.5	116
4	1.19	5.6	0.5					50,550	73,300	7.8	117
5	1.20	5.6	1.1					54,350	76,400	8.8	119
6	1.22	5.6	1.5					56,700	79,250	8.8	121
7	1.21	5.5	0.5				1.6	51,500	76,500	9.8	122
8	1.34	1.5	0.5	3.1	0.5	10.0		58,700	84,000	9.5	127
9	1.34	12.0	0.5	3.0	0.5			68,400	106,900	18.0	128
10	1.22	5.7	0.5				3.1	53,500	80,750	12.8	129
11	1.34	12.0	0.5		0.5			59,900	105,400	26.0	136
12	1.22	5.7	2.1					60,950	83,000	8.2	broke
13	1.34	3.0	0.5		0.5			cracked on quenching			broke
14	1.35	5.9	0.5	3.0	0.5			66,100	87,500	10.0	broke
15	1.33	3.0	0.5	3.1	0.5			67,100	82,600	4.5	broke
16	1.36	1.5		3.0	0.5			cracked on quenching			broke
17	1.34	1.5	0.5	3.0	0.5	5.1		59,900	67,800	4.0	broke
18	1.34	1.5	0.5	3.0	0.5	2.6		59,900	72,300	3.0	broke
19	1.33	1.5	0.5	3.0	0.5		3.0	63,000	72,700	2.5	broke
20	1.35	2.4	0.5	3.0	0.5		3.0	58,300	72,700	5.0	broke
21	1.35	2.4	0.5		0.5		6.3	56,800	70,400	5.0	broke
22	1.36	1.5	0.5	3.0	0.5		6.2	62,000	75,800	3.5	broke
23	1.35	1.5	0.5	3.0	1.0			cracked on quenching			broke
24	1.33	1.5	0.5	3.0	2.0			cracked on quenching			broke

[1] The term "broke" refers to breakage during the abrasion tests from which the abrasion factors were calculated.

The results presented in the table indicate that many austenitic steel compositions may not have sufficient toughness for use in commercially produced steel castings. In particular the addition of 3% chromium to many of the compositions in the table produced harmful effects. This chromium addition to the various steels produced carbide precipitates along crystallographic planes and around grain boundaries, which in turn were responsible for the embrittlement of these compositions. A high silicon content acts similarly and was responsible for the breakage of item 12. Furthermore it is known from other investigations that phosphorus contents in excess of about 0.06% tend to produce serious loss of ductility and impacts resistance in all types of high carbon austenitic steels.

Molybdenum additions of 0.5 to 1.0% provide a small

2. An alloy steel consisting of 1.0 to 1.5% carbon, 4.5 to 9.0% manganese, 0.2 to 0.9% silicon, 0.25 to 3.0% molybdenum, not over 0.08% phosphorus and not over 1.0% chromium and the remainder iron.

3. An alloy steel consisting of 1.2 to 1.4% carbon, 5.0 to 7.0% manganese, 0.3 to 0.7% silicon, 0.5 to 1.5% molybdenum, not over 0.05% phosphorus, not over 0.5% chromium and the remainder essentially iron.

4. An austenitic alloy steel consisting of 1.0 to 1.5% carbon, 4.5 to 9.0% manganese, 0.2 to 0.9% silicon, 0.25 to 3.0% molybdenum, the remainder essentially iron.

5. An alloy steel consisting of 1.0 to 1.5% carbon, 4.5 to 9.0% manganese a minimum of 0.2% and a maximum of 0.9% silicon, 0.25 to 3.0% molybdenum, a maximum

of 0.08% phosphorus, a maximum of 1.0% chromium, and the remainder essentially iron.

6. A cast alloy consisting of 1.2% to 1.4% carbon, 5.0 to 7.0% manganese, 0.3 to 0.7% silicon, 0.8 to 1.20% molybdenum, and the remainder iron.

7. A cast alloy consisting of 1.2 to 1.4% carbon, 5.00 to 7.00% manganese with the manganese content near the low end of the range when maximum abrasion resistance is desired and near the high end of the range when maximum impact resistance is desired, 0.3 to 0.7% silicon, 0.5 to 1.50% molybdenum with the molylbdenum content near the low end of the range in relatively thin section parts having a cross-sectional thickness lower than approximately four inches and near the high end of the range in relatively heavy section parts having a cross-sectional thickness higher than approximately four inches, and the remainder iron.

References Cited in the file of this patent

UNITED STATES PATENTS

1,601,787	Weitzenkorn	Oct. 5, 1926
2,206,846	Lorig	July 2, 1940

FOREIGN PATENTS

276,048	Great Britain	Aug. 11, 1927