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STRONG FRACTURE-TOUGH STEEL

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U.S. Cl. 75—123 3 Claims

ABSTRACT OF THE DISCLOSURE

A maraging steel containing, in addition to iron, nickel, cobalt and vanadium as essential constituents, the steels being characterized by a good combination of strength and toughness.

This application is a continuation-in-part of application Ser. No. 574,948, filed Aug. 25, 1966, now abandoned.

The present invention relates to ferrous-base alloys, and more particularly to special and novel maraging steels manifesting a combination of high strength and fracture toughness of such magnitude that the steels can be used for structural purposes.

As is now generally recognized by those skilled in the art of ferrous metallurgy, the introduction of the maraging steels but a few years ago sparked a new area of research and development in the search for stronger and tougher steels. As a general proposition, until that time the quenched and tempered low alloy steels found a most substantial, if not exclusive, use in applications where high strength (above 200,000 pounds per square inch) was required. While such steels are still in great use, nonetheless, they remain afflicted with the same serious drawbacks which have always been their lot. These drawbacks have been well documented, notably the distortion and undesirable dimensional changes flowing from the quenching operation, a notoriously severe operation at best. Also, a further serious and inherent shortcoming is found in their lack of toughness, a property virtually nonexistent at strengths of 250,000 to 300,000 p.s.i.

There is little doubt that the unique metallurgical characteristics of the maraging steels generally described in the U.S. patents to Bieber, No. 3,093,518 and to Decker, Goldman and Eash, No. 3,093,519, were responsible for their rather spontaneous commercial acceptance. For example, the now well established nickel-cobalt-molybdenum maraging steels can be readily both hot and cold worked, require but a simple aging treatment (without recourse to any quenching operation whatever) and yet afford an excellent combination of strength and toughness. Now, the steels of the subject invention, while of the maraging type, do not require molybdenum as an esential constituent, the element perhaps most responsible for strength and toughness in the alloys of U.S. Patent No. 3,093,519. Yet, a high combination of strength and toughness is obtained; for example, yield strengths well above 200,000 p.s.i. (0.2% offset), tensile elongations of 10% and more, reductions in area of above 50% are readily attainable together with a ratio of notch tensile strength to ultimate tensile strength well above unity.

It is an object of the present invention to provide new and useful maraging steels notable for the degree of strength and toughness which they afford.

Other objects and advantages will become apparent from the following description.

Generally speaking, the present invention contemplates maraging steels containing (in percent by weight) from

about 15% to 20%, e.g., 16% to 19%, nickel; at least 1% and up to 8%, e.g., 2.5% to 6%, vanadium; about 5% to about 20%, e.g., 6% to 10%, cobalt; carbon in an amount up to 0.05% and advantageously not more than 0.03%; up to 0.5% of each of manganese and silicon, the respective amounts of manganese and silicon preferably not exceeding 0.25% to thereby obtain maximum toughness; and the balance essentially iron. In referring to the iron content as constituting the balance or essentially the balance of the steels, it is to be understood, as will be readily appreciated by those skilled in the art, that the presence of other elements is not excluded, such as those commonly present as incidental elements, e.g., deoxidizing and cleansing elements, and impurities ordinarily associated therewith, in small amounts which do not adversely affect the basic characteristics of the steels. In this connection, elements such as lead, tin, arsenic, antimony, sulfur, phosphorus, bismuth, hydrogen, oxygen, nitrogen and the like should be kept as low as is consistent with good commercial steelmaking practice. However, the following supplemental elements within their given ranges can be present: up to 1.5%, e.g., up to 1%, titanium; up to 1.5%, e.g., up to 1%, aluminum; up to 2%, e.g., up to 1% tungsten; up to 1%, e.g., up to 0.5%, tantalum; up to 1%, e.g., up to 0.5%, columbium; up to 0.5% e.g., up to 0.3%, beryllium; up to 0.1%, e.g., up to 0.01%, boron; and up to 0.25%, e.g., up to 0.1%, zirconium. The total amount of the supplemental elements should not exceed about 7%. In addition, up to 5% chromium can be employed provided the total sum of nickel plus chromium does not exceed about 22%. Calcium and/or magnesium can be used in accordance with good deoxidation practice.

It is perhaps worthy of note to mention that the element vanadium was considered an auxiliary hardener in the aforementioned U.S. Patent No. 3,093,519, it being deemed that such steels had to contain molybdenum before a substantial hardening was effected as a matter of first course. Actually, it is described therein that cobalt per se in a low carbon, 18% to 20% nickel steel conferred no hardening effect. And, small amounts of vanadium per se in such steels have not been known to impart appreciable hardening. In any case, it has now been found that cobalt and vanadium exert, when copresent, a most pronounced influence in potently contributing to hardness and strength in otherwise controlled alloy compositions.

The nickel content of the subject steels should not be below 15%; otherwise, toughness is adversely affected. On the other hand, nickel contents much above 20% can lead to undesired retained austenite; that is to say, excessively high amounts of nickel, e.g., 22% or 23%, apart from being unnecessary, depress the M_S transformation temperature whereby austenite stability is promoted which, in turn, greatly detracts from strength. While such an effect might be obviated by the use of cold treatment, e.g., refrigeration or cold working or both, little is to be gained by resort to such extraneous treatments when they are unnecessary. Accordingly, it is advantageous to employ a nickel range of about 17% to 19%.

Low cobalt contents, i.e., below about 5%, can markedly contribute to inadequate strength. While cobalt contents above 20% will result in higher strength, it is considered that lower toughness is the consequence. This same effect is attributable to vanadium. Thus, for an optimum combination of properties, it is advantageous to employ a cobalt range of about 6% to 10%, advantageously from about 6.5% to 9%, and a vanadium range of about 3.5% to 4.5%.

In carrying the invention into practice, the steels should be prepared using materials of relatively high purity and or selected scrap as the basic melting charge. The usual malleabilizing and/or deoxidizing constituents, e.g., boron,

zirconium, calcium, lithium, magnesium and the like, can be employed. The cast ingots obtained upon solidification should be rather thoroughly homogenized by soaking at temperatures of about 2200° F. to 2400° F. followed by hot working and, if desired, cold worked to desired size. Prior to aging, the steels should be solution annealed at temperatures of from about 1400° F. to about 1600° F., although temperatures up to 2000° F. can be employed to some advantage in achieving optimum toughness. While the annealing treatment is not mandatory, it provides greater assurance of obtaining reproducible properties. The steels are then cooled to achieve a martensitic condition, i.e., a transformation from austenite to martensite. It is important that a martensitic structure be obtained prior to aging in order to achieve the high strength levels characteristic of the steels. Thus, as used herein, the term martensite (or martensitic) refers to steels having a structure of martensite (or which is substantially martensitic) in both the solution annealed condition and in the aged condition. The transformation from austenite to martensite is normally accomplished by cooling through the M_s–M_f transformation range to room temperature (from the annealing temperature). If it is desired to be assured of attaining as complete a transformation as possible, it may be desirable to cool the steels below room temperature, e.g., down to minus 100° F., as by, for example, refrigeration. Cold working prior to aging can also be used to effect the completion of transformation to martensite.

The aging treatment should be conducted over the temperature range of about 700° F. to about 1000° F. and preferably 750° F. to 950° F. for about one hour to 50 hours, e.g., three hours at 900° F. or 24 hours at 800° F. Aging temperatures appreciably above 1000° F. should be avoided; otherwise retention of undesirable austenite can result. In addition, overaging of the precipitate can occur and thus cause or induce an undesired age hardening effect. Since aging temperatures of 700° F. require undesirably long aging times, it is preferable to use an aging temperature range of about 800° F. to about 925° F. Generally, shorter periods should be used at the higher aging temperature.

For the purpose of giving those skilled in the art a better understanding of the invention, the following illustrative data are given:

Alloys A and B, alloys within the invention and having compositions as set forth in Table I, were melted in an air induction furnace, cast into billets, homogenized, hot forged and then hot rolled to bar. Specimens were annealed at about 1500° F. for about one hour, air cooled and then aged, Alloy A being aged for three hours at 900° F. and Alloy B for 24 hours at 800° F. Included in Table I is a cobalt-containing but vanadium-free steel (Steel 1) described at lines 37 to 50, column 9 of the aforementioned U.S. Patent No. 3,093,519, the steel having been aged at 900° F. for three hours.

TABLE I

Steel	Percent								
	C	Ni	Co	V	Ti	Al	Si	Mn	Fe
A	0.03	16.4	6.9	4.0	0.14	0.10	0.17	<0.05	Bal.
B	0.18	17.8	8.06	4.32	0.08	0.11	0.09	0.11	Bal.
1	0.02	18–20	7		0.4				Bal.

Bal.=Iron plus impurity levels of any one or more of molybdenum, chromium, boron, zirconium, calcium, sulfur and phosphorus.

The various mechanical properties for the steels of Table I are given in Table II below:

TABLE II

Steel	Y.S. (0.2% Offset), K s.i.	U.T.S., K s.i.	El., Percent	R.A., Percent	N.T.S., K s.i.	N.T.S., U.T.S
A	223	223	11	52	324	1.45
B	233	238	13	56	324	1.31
1		130–149*				

Y.S.=Yield strength.
U.T.S.=Ultimate tensile strength.
K s.i.=1,000 pounds per square inch.
El., percent=Percent elongation.
R.A., percent=Percent reduction in area.
N.T.S.=Notch tensile strength.
*Approximate.

The data in Table II reflect the quite satisfactory combination of strength and toughness characteristic of the steels within the invention. In comparison with the vanadium-free Steel 1, Steels A and B manifested an increase in strength on the order of 100,000 p.s.i., a considerable boost by any standard.

The present invention is particularly applicable to the production of high strength structural elements, assemblies and the like. The aged steels of the invention can be used in the form of sheet, plate, rods, bars, extrusions, etc. Further, the steels can be machined and/or otherwise shaped or formed while in the annealed condition and can be thereatfer age hardened without occurrence of detrimental distortion or dimensional change.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand.

We claim:

1. A novel maraging steel characterized by a good combination of strength and toughness, said steel consisting of about 15% to about 20% nickel, at least 1% and up to 8% vanadium, about 6% to 10% cobalt, carbon in an amount up to 0.5%, up to 0.5% manganese, up to 0.5% silicon, up to 1.5% titanium, up to 1.5% aluminum, up to 2% tungsten, up to 1% tantalum, up to 1% columbium, up to 0.5% beryllium, up to 0.1% boron, up to 0.25% zirconium, the sum of the titanium, aluminum, tungsten, tantalum, columbium, beryllium, boron and zirconium not exceeding 7%, up to 5% chromium, the sum of the nickel plus chromium not exceeding about 22%, and the balance iron.

2. The steel set forth in claim 1 in which the vanadium content is about 2.5% to 6%.

3. The steel set forth in claim 1 consisting of about 17% to 19% nickel, about 3.5% to 4.5% vanadium, about 6.5% to 9% cobalt, up to 0.03% carbon, up to 0.25% manganese, up to 0.25% silicon, up to 1% titanium, up to 1% aluminum, and the balance iron.

References Cited

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3,093,518 6/1963 Bieber ..... 75—123 X
3,093,519 6/1963 Decker et al. ..... 75—123 X

CHARLES N. LOVELL, Primary Examiner

U.S. Cl. X.R.

75—124, 128; 148—31

D-1050
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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

atent No. 3,488,186 Dated January 6, 1970

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It is certified that error appears in the above-identified patent
nd that said Letters Patent are hereby corrected as shown below:

Column 1, line 56, for "esential" read --essential--.
Column 4, line 7 Table II, Steel 1, "130-149*" read --130-140*--.

SIGNED AND
SEALED
NOV 17 1970

(SEAL)
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