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AGE HARDENING ALLOY STEEL OF HIGH HARDENABILITY AND TOUGHNESS

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This invention pertains to age or precipitation hardening alloy steels and to articles thereof.

It is an object of this invention to provide a relatively low alloy, age hardening steel, that is hardenable to an appreciable degree, that is, to upward of Rockwell "C" 35, by a relatively low temperature precipitation hardening treatment that is, around 900° to 1000° F. It is further the object of this invention to provide such a steel which as so hardened, has a relatively good notch impact value, that is, over about 10 ft. lbs. as measured by the conventional V-notch Izod test piece. Another object of this invention is to provide articles of such steel as so heat treated for use as die-blocks for die-castings or forgings of zinc and aluminum alloys; and for structural parts, such as shafts, gears, connecting rods, and so on, which are required to have high strength and toughness in large sections.

In the production of large parts of high strength, that is, those having sections over about 2 inches thick, it is necessary to use steels of high hardenability. Heretofore steels employed for such purposes are those which are hardenable by a quench and temper treatment, and the practice has been to heat treat parts made thereof by a quench and temper treatment after they have been machined. Such heat treatment, no matter how carefully carried out, introduces some size change in the steel and parts made thereof. Size change is of course undesirable in closely fitting parts and when it occurs a considerable amount of labor has to be expended in grinding and polishing parts after they are heat treated to restore the desired precise dimensions to them. Furthermore, when parts are very large, say over 10 to 12 inches in section there are few if any steels available which will develop high strength with good toughness by means of the conventional quench and temper procedure.

The steel of our invention has the advantage over conventional steels in respect both to size-change in hardening and limitation of size for effective hardening, in that it does not depend for its development of hardness on the formation of austenite and the subsequent transformation of austenite to the hard transformation products, martensite and bainite, with the unavoidable accompanying increase in volume of the steel. The steel of our invention hardens while it is held at a temperature of about 900° to 1000° F. and undergoes practically no size change during such hardening. Furthermore, the steel of our invention hardens throughout uniformly regardless of section since the hardening takes place during the heating and is independent of cooling rates, in contrast to the hardening of conventional steels in which hardening takes place during cooling from an austenitizing temperature, and in which different cooling rates, which vary of necessity from the outside to the center of large sections, bring about different degrees of hardening.

The steel of our invention contains nickel in amounts between 2.5 and 6% and aluminum in amounts between 0.8 and 3%, and preferably also molybdenum from about 0.10% up to about 2.0%. As is well known, nickel and aluminum form a compound which is soluble in ferrite at about 1200° to 1300° F., and which can be made to precipitate subsequently by reheating the steel for fairly

long times at about 900° to 1000° F. Since the aging temperature coincides with the temperature which is known to develop undesirable "temper brittleness" in steels, and since molybdenum minimizes temper brittleness, it is desirable to have a minimum of about 0.10% molybdenum in the steel, and preferably larger amounts up to about 2%. Molybdenum is desirable also for improving hardenability of the steel for the treatment of large sections prior to aging as will be discussed later.

Since the hardening of the steel of this invention does not depend on martensite formation, it is not essential that the steel contain sizeable amounts of carbon to develop hardness over about Rockwell "C" 35 and as shown hereinafter, the carbon content should not exceed about 0.55% if the desired notch toughness in the hardened condition is to be obtained. However, it is desirable for carbon to be present in the steel of this invention in amounts from about 0.10 up to about 0.55% in order to make the manufacture of the steel easier in regard to selection of raw materials; to improve the soundness and cleanliness of the finished steel; and to improve the hardenability of the steel for the prior treatment as will be explained later.

Manganese and silicon are present in the steel for desulfurization and deoxidation purposes. Manganese is also effective for improving the hardenability of the steel for the prior treatment as will be explained later and the manganese content may be up to 2%. However, to avoid difficulty in fabricating the steel, the silicon content should not exceed about 1%. Chromium also may be present in the steel up to about 2% without detriment to the hardening and toughness characteristics of the steel. It is also desirable for improving the hardenability of the steel for the prior treatment, as will be explained later.

The steel as outlined above as ordinarily produced has a definite shortcoming, and that is, a lack of notch toughness in the hardened condition. Now we have discovered, and this is the crux of our invention, that by additions of at least one of the active carbide formers, vanadium or columbium (or tantalum), or titanium, we can improve the notch impact resistance of the hardened steel appreciably. Furthermore, the addition of the carbide forming element must be apportioned within critical limits to the carbon content of the steel. Thus a vanadium addition should be limited to from a percentage equal to three-tenths the carbon content to a percentage equal to four times the carbon content; a columbium addition should be limited to from a percentage equal to four-tenths the carbon content to a percentage equal to six times the carbon content; a tantalum addition should be limited to form a percentage equal to eight-tenths the carbon content to a percentage equal to eleven times the carbon content; and a titanium addition should be limited to from a percentage equal to two-tenths the carbon content to a percentage equal to three times the carbon content.

Where more than one of the aforesaid active carbide forming elements is incorporated in the steel of the invention, the minimum carbon content should be at least equal to one-fourth of the vanadium content plus one-sixth of the columbium content plus one-eleventh of the tantalum content plus one-third of the titanium content.

Aside from the elements above mentioned the steel of the invention may contain up to about 5 percent in aggregate of other elements which do not impair the hardening and toughness properties of the steel, such as, for example, additions of cobalt, copper, tungsten, etc., the balance of the steel being substantially all iron.

As has already been indicated, the hardening of the steel of this invention is carried out by an aging at 900° to 1000° F. for durations up to about 15 to 20 hours. Before the steel is hardened, however, it must be put into a condition suitable for machining. The treatment to make the steel machinable should also include a step which constitutes a solution treatment for the compound which precipitates during the aging treatment. This treatment prior to aging will hereinafter be referred to as the prior treatment.

The solution temperature for the age hardening compound is above about 1200° F. The prior treatment must therefore include a heating at a temperature of 1200° F. or higher followed by a relatively rapid cool such as an air cool or an oil quench. This prior treatment may comprise any one of three procedures as follows:

(I) The as cast, as rolled, or as forged, steel may be merely heated to a temperature of 1200° F., or higher, and air cooled or oil quenched. If the steel is to be oil quenched the heating temperature must be below about 1350° F., otherwise the steel will be hardened as quenched, since the A–1 temperature of the steel is about 1300° to 1350° F., depending on the composition. Such martensitic hardening is undesirable from the viewpoint of machinability of the steel.

(II) The as cast, as rolled, or as forged, steel may be heated to a temperature above the A–1 temperature of the steel, say between 1350° and 1700° F., and cooled slowly down to about 1200° F., and then cooled in air to room temperature. This constitutes an annealing treatment, but since the steel in this treatment has been held at temperatures over 1200° F. it also constitutes a solution treatment for the age hardening compound.

Of the three prior treatments outlined above, treatment (III), namely, the oil quench from above A–3 followed by the temper at 1200° to 1350° F. is preferred, because the structure produced by such treatment, namely, a tempered martensite or other low temperature transformation product, is much more conducive to good toughness in the hardened steel than one containing free ferrite. Prior treatments (I) and (II) are much more likely to result in structures containing free ferrite than is prior treatment (III).

That a tempered martensite structure is preferred to one containing free ferrite is established by the following:

Two samples of a bar which analysed percentagewise as follows,

C	Mn	Si	Ni	Cr	V	Mo	Al
.19	.84	.52	3.62	.06	.44	.68	1.25

were heated to 1650° F., and then one was oil quenched and the other was cooled in the furnace to 1300° F., and then at a rate of 25 degrees per hour to 1200° F. and finally air cooled. The oil quenched piece was tempered at 1300° F. for four hours. Both pieces were then aged at 900° F. for 16 hours. The age hardened pieces were machined to standard V-notch Izod pieces and broken at room temperature. The data obtained are as follows:

Treatment	Structure	Hardness Rockwell "C"		V-notch Izod, ft. lbs., After Aging
		Prior to Aging	After Aging 16 hrs. at 900° F.	
Quenched from 1,650° F and tempered 1,300° F. for 4 hrs.	Tempered Martensite	32.5	41	15–17
Annealed 1,650° F. and slow cooled to 1,200° F.	Primarily free ferrite with less than 25% intermediate product.	25	41	7–8

(III) The as cast, as rolled, or as forged, steel may be heated to a temperature over the A–3 temperature of the steel say 1500° to 1700° F. and quenched in oil, and then tempered at about 1200° to 1350° F., and air cooled. By such a treatment the steel simultaneously gets a grain refinement treatment, because it has been heated above the A–3 temperature, and also develops a structure relatively free from ferrite, since during the quench the austenite formed above A–3 transforms to martensite, or some other low temperature transformation product. In the heating to 1200° to 1350° F. subsequent to the quench, the martensite or other low temperature transformation product is tempered so that the steel is made satisfactorily machinable, and at the same time the age hardening compound is put into solution.

This shows clearly that for a given composition, the preferred prior treatment is one which results in a tempered martensite structure. It should also be clear now that the steel should have high hardenability so that large sections after the prior treatment should have structures consisting of tempered martensite with a minimum of free ferrite.

After it is hardened by aging as described above, the steel made without the proper addition of V, Cb, Ta, or Ti generally has a low notch-impact value, around 5 ft. lbs., as measured by the V-notch Izod test. However, when the steel is made with proper additions of the active carbide forming elements, the notch-impact is appreciably improved and is generally over 10 ft. lbs. V-notch Izod, as is shown in Table I.

Table I.—V-Notch Izod values of age hardening steels

[Treatment prior to aging consisted of an oil quench from 1,650° F. and a 4 hour temper at 1,300° F. Aged for 16 hours at 900° F.]

Bar	Analysis, Percent								Rockwell "C"	V-notch Izod, ft. lbs.
	C	Ni	Cr	Mo	Al	V	Cb	Ti		
5948	.22	3.6	1.1	.34	1.3				41	6
2610	.10	3.7		.67	1.2	.09			38	11
5944	.17	3.6		.27	1.3	.17			41	16
5945	.22	3.5		.77	1.2	.17			42	11
5949	.24	3.6	1.3	.25	1.3	.20			41	11
5951	.22	3.6	1.1	.77	1.3	.21			43	11
2611	.19	3.6	0.1	.68	1.3	.44			42	14
5946	.20	3.6		.30	1.3	.47			41	17
5947	.16	3.6		.77	1.2	.47			41	20
2612	.22	3.7		.67	1.3	.80			42	11
2773	.28	3.6	0.1	.68	1.0	1.07			41	15
2774	.27	3.6	0.1	.70	1.1		1.4		38	13
2766	.28	3.7	0.1	.69	1.0			.53	39	11

NOTE.—These steels also contain Mn from 0.5 to 1.4%; P from .007 to .035%; S from .010 to .040%; Si from 0.2 to 0.9%; balance substantially all iron.

The data in the above tabulation show that impact values over 10 ft. lbs. V-notch Izod can be obtained in this steel as age hardened to over Rockwell "C" 35. However, as has already been indicated, the desired notch-impact values are not dependent merely on the presence of the active carbide-forming elements in the steel, but on the balance between carbon and the carbide-forming element, as may be seen in the tabulations below.

Table II.—Effect of balance of carbon and vanadium on notch impact value of age hardened steel

[Treatment prior to aging consisted of an oil quench from 1,650° F. and a 4 hour temper at 1,300° F. Aged for 16 hours at 900° F.]

Bar	Analysis, Percent					Ratio V to C	Hardness Rockwell "C"	V-notch Izod, ft. lbs.
	C	Ni	Mo	Al	V			
2609	.14	3.7	.66	1.2	.74	5.3	40	3
2612	.22	3.7	.67	1.3	.80	3.6	42	11
2206	.21	3.6	.64	1.2	1.23	5.9	37	6
2773	.28	3.6	.68	1.0	1.07	3.8	41	15

Table III.—Effect of balance of carbon and columbium on notch impact value of age hardened steel

[Treatment prior to aging consisted of an oil quench from 1,650° F. and a 4 hour temper at 1,300° F. Aged for 16 hours at 900° F.]

Bar	Analysis, Percent				Cb	Ratio Cb to C	Hardness Rockwell "C"	V-notch Izod, ft. lbs.
	C	Ni	Mo	Al				
2775	.28	3.7	.68	1.1	2.99	10.7	38	3
2774	.27	3.6	.70	1.1	1.41	5.2	38	13

Table IV.—Effect of balance of carbon and titanium on notch impact value of age hardened steel

[Treatment prior to aging consisted of an oil quench from 1,650° F. and a 4 hour temper at 1,300° F. Aged for 16 hours at 900° F.]

Bar	Analysis, Percent					Ratio Ti to C	Hardness Rockwell "C"	V-notch Izod, ft. lbs.
	C	Ni	Mo	Al	Ti			
2777	.28	3.7	.70	1.3	1.54	5.5	38	1
2776	.28	3.7	.69	1.0	.53	1.9	39	11

NOTE.—The steels listed in Tables II, III, and IV also contain Mn from 0.5 to 1.4%; P from .007 to .035%; S from .010 to .040; and Si from 0.2 to 0.9%; balance substantially all iron.

It will also be seen from the data in the following table that although the hardness of the steel increases with an increase in carbon content, the notch-impact value of the steel falls below 10 ft. lbs. when the carbon content exceeds about 0.55% even though the ratio of the active carbide former (vanadium) is maintained within the range set forth above.

Table V.—Effect of carbon on notch-impact value of age hardened steel

[Treatment prior to aging consisted of an oil quench from 1,650° F. and a 4 hour temper at 1,300° F. Aged for 16 hours at 950° F.]

Bar	Analysis, Percent							Ratio V to C	Hardness Rockwell "C"	V-notch Izod, ft. lbs.
	C	Mn	Si	Ni	V	Mo	Al			
6191	.35	.73	.38	3.42	1.02	.65	1.36	2.9	42	12
6192	.52	.71	.14	3.47	1.00	.67	1.41	1.9	43	11
6193	.52	.68	.36	3.45	1.74	.67	1.23	3.3	43	10
6194	.68	.78	.44	3.45	1.80	.68	1.36	2.6	45	8
6195	.67	.70	.41	3.35	1.74	1.74	1.33	2.6	45	8
6196	.98	.77	.42	3.44	1.71	1.75	1.25	1.7	48	5

Thus it has been shown that when the carbon and carbide-forming elements are properly balanced, the notch-impact value of the steel is much higher than when an excess of the carbide forming element is present, even though the hardness of the steel may also be higher.

Without limiting ourselves to any particular explanation to account for the improvement in the notch-impact of the hardened steel brought about by the addition to the steel of the active carbide forming elements V, Cb (or Ta), or Ti, it is our opinion that the following is reasonable:

1. In the absence of the active carbide forming elements (other than molybdenum and its recognised equivalent, tungsten) all of the carbon dissolves in the austenite during the quench-temper prior treatment and the resultant tempered martensite is relatively high in carbon.

2. When the active carbide formers V, Cb (or Ta), or Ti are present in the steel in moderate amounts, some of the carbon in the steel is combined with them in the form of insoluble carbides. During the quench and temper prior treatment, only that portion of the carbon which has not combined with the active carbide formers dissolves in the austenite and the resultant tempered martensite is relatively low in carbon. The steel with the relatively low carbon tempered martensite has higher notch-impact after aging than the steel with relatively high carbon tempered martensite.

3. The introduction of an excessive amount of the active carbide formers causes all of the carbon in the steel to combine with them to form insoluble carbides. During the heating for the quench-temper prior treatment at conventional temperatures, or even at much higher temperatures up to say 1800° F., little if any austenite forms and the resultant quenched and tempered structure will contain large amounts of excess ferrite. Such a structure has a very low notch-impact value after aging.

It is sometimes advantageous to nitride the surfaces of articles made from the steel of the invention. In such cases the nitriding is carried out in conventional manner, and since the nitriding temperature and age hardening temperature are about the same for this steel, nitriding and age hardening may be effected concurrently. The core of the resulting nitrided and age hardened article will have the high toughness above mentioned, namely, a minimum notch impact value of 10 ft. lbs.

This application is a continuation-in-part of our joint parent application Serial No. 176,766, filed July 29, 1950, now abandoned.

We claim:

1. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; up to 2% each of molybdenum, manganese, and chromium; up to about 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum, and 0.1 to 2% titanium; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

2. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in

having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese, and chromium; up to about 1 silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum; and 0.1 to 2% titanium; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

3. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum, and 0.1 to 2% titanium, the carbon content being so balanced in relation to the elements of said group, that the minimum carbon content equals one-fourth the vanadium content plus one-sixth the columbium content plus one-eleventh of the tantalum content plus one-third of the titanium content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

4. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium but not to exceed from 0.3 to 4 times the carbon content, 0.2 to 3% columbium but not to exceed from 0.4 to 6 times the carbon content, 0.2 to 6% tantalum but not to exceed from 0.8 to 11 times the carbon content, and 0.1 to 2% titanium but not to exceed from 0.2 to 3 times the carbon content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

5. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; 0.1 to 2% vanadium but not to exceed from 0.3 to 4 times the carbon content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

6. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; 0.2 to 3% columbium, but not to exceed from 0.4 to 6 times the carbon content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

7. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; 0.2 to 6% tantalum but not to exceed from 0.8 to 11 times the carbon content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

8. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten foot pounds in the age hardened condition, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; 0.1 to 2% titanium but not to exceed from 0.2 to 3 times the carbon content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

9. An age hardened steel article having a hardness of at least Rockwell "C" 35 and a V-notch Izod impact value of at least ten foot pounds, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; up to 2% each of molybdenum, manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum, and 0.1 to 2% titanium; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

10. An age hardened steel article having a hardness of at least Rockwell "C" 35 and a V-notch Izod impact value of at least ten foot pounds, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; up to 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum, and 0.1 to 2% titanium; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

11. An age hardened steel article having a hardness of at least Rockwell "C" 35 and a V-notch Izod impact value of at least ten foot pounds, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum, and 0.1 to 2% titanium, the carbon content being so balanced in relation to the elements of said group, that the minimum carbon content equals one-fourth the vanadium content plus one-sixth the columbium content plus one-eleventh of the tantalum content plus one-third of the titanium content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

12. An age hardened steel article having a hardness of at least Rockwell "C" 35 and a V-notch Izod impact value of at least ten foot pounds, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium but not to exceed from 0.3 to 4 times the carbon content; 0.2 to 3% columbium but not to exceed from 0.4 to 6 times the carbon content, 0.2 to 6% tantalum but not to exceed from 0.8 to 11 times the carbon content, and 0.1 to 2% titanium but not to exceed from 0.2 to 3 times the carbon content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

13. A nitrided, age hardened steel article having a core with a hardness of at least Rockwell "C" 35 and a V-notch Izod impact value of at least ten foot pounds, said steel containing about: 2.5 to 6% nickel; 0.8 to 3%

aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum, and 0.1 to 2% titanium; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

14. An age hardened, steel die-block for die casting, said die block having a hardness of at least Rockwell "C" 35 and a V-notch Izod impact value of at least ten foot pounds, said steel containing about: 2.5 to 6% nickel; 0.8 to 3% aluminum; 0.1 to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1 to 0.55% carbon; at least one element selected from the group consisting of 0.1 to 2% vanadium, 0.2 to 3% columbium, 0.2 to 6% tantalum, and 0.1 to 2% titanium; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

15. An age hardenable alloy steel characterized in being hardenable to a minimum of Rockwell "C" 35 on aging for about 15 hours at 900° to 1000° F., and in having a V-notch Izod impact value of at least ten-foot

pounds in the age hardened condition, said steel containing about 2.5% to 6% nickel; 0.8% to 3% aluminum; 0.1% to 2% molybdenum; up to 2% each of manganese and chromium; up to 1% silicon; 0.1% to 0.55% carbon; at least one element selected from the group consisting of vanadium, columbium, tantalum, and titanium, the carbon content being so balanced in relation to the elements of said group that the vanadium content is from 0.3 to 4 times the carbon content, the columbium content is from 0.4 to 6 times the carbon content, the tantalum content is from 0.8 to 11 times the carbon content, and the titanium content is from 0.2 to 3 times the carbon content; up to 5% of other elements which do not impair the hardening and toughness properties of the steel; and the balance iron.

References Cited in the file of this patent

UNITED STATES PATENTS

1,943,595 Foley ---------------- Jan. 16, 1934

FOREIGN PATENTS

431,248 Great Britain ----------- July 3, 1935