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AGE HARDENABLE LOW ALLOY STEELS

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6 Claims. (Cl. 75—123)

The present invention relates to age hardenable, low carbon steels and more particularly to age hardenable, low carbon steels having a bainitic or martensitic microstructure characterized by high yield strength combined with good toughness.

This application is a continuation-in-part of our copending application Ser. No. 349,463, filed Mar. 4, 1964, now abandoned.

Heretofore attempts to produce steels having high yield strengths in the range of 150,000 to 200,000 p.s.i. have resulted in steels having poor toughness and ductile qualities. We have discovered that within certain compositional limits, low carbon steels having a microstructure of bainite or martensite or mixtures thereof will have high strength combined with good toughness in the age hardened condition. The desired properties are obtained within the following compositional limits in percent by weight:

Carbon	.05 to .2
Nickel	8 to 10
Molybdenum	.5 to 2.5
Cobalt	3 to 5
Manganese, max.	.25
Phosphorus, max.	.10
Sulphur, max.	.10
Silicon, max.	.2
Aluminum, max.	.1

Balance iron and residual impurities.

Other elements may be present in amounts which do not adversely affect the properties.

Steel within such range will have a yield strength within the range of 150,000 to 200,000 p.s.i. and Charpy V-notch values in excess of 60 foot-pounds at +80° F. and 50 foot-pounds at —80 to —100° F., if quenched from an austenitizing temperature in the range of 1500 to 1700° F. sufficiently rapidly to produce a structure of martensite or bainite or mixtures thereof and thereafter aged within the range of 800 to 1000° F. for 2 to 5 hours.

The examples of the following Table I will serve to illustrate the invention.

These steels were oil quenched from 1700° F. to develop a microstructure of martensite and had the properties set forth in the following Table II after aging as therein indicated:

TABLE I

Steel No.	C	Mn	P	S	Si	Ni	Mo	Co	Al
1	0.11	0.22	0.003	0.006	0.057	8.89	2.91	------	0.089
2	0.003	0.13	0.003	0.006	0.001	8.90	2.87	3.83	0.003
3	0.12	0.16	0.003	0.006	0.019	8.79	2.82	3.90	0.051
4	0.088	0.12	0.003	0.005	0.041	8.81	1.02	3.95	0.002

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TABLE II

Heat No.	Aging Treatment	0.2% Offset Yield Strength, p.s.i.	Tensile Strength, p.s.i.	CVN, foot-pounds	
				+80	—100° F.
1	5 hr. at 900 F	165,000	190,000	27.5	20.5
2	2 hr. at 800 F	115,000	137,000	26	9
3	5 hr. at 900 F	171,000	201,000	19	14.5
4	5 hr. at 1,000 F	166,000	174,000	76	60

A review of the data of Table II indicates that Steel No. 4, which is within the compositional range of this invention, has an excellent combination of properties with a yield strength in excess of 150,000 p.s.i. and Charpy V-notch values in excess of 60 foot-pounds at +80° F. and 50 foot-pounds at —100° F. However the other three steels which are not within the range of the steel of this invention are deficient either in strength or ductility.

The following Table III comparing Steel No. 4 in the air cooled, and air cooled and aged condition, thus having a bainitic structure shows the steel to have somewhat better impact values at lower strength than with a martensitic microstructure.

TABLE III

Aging Treatment	0.2% Offset Yields Strength, p.s.i.	Tensile Strength, p.s.i.	CVN, foot-pounds	
			+80	—80° F.
Air-cooled	108,000	148,000	108	112
Air-cooled plus 5 hr. at 1,000 F	138,000	156,000	110	104

Another heat, identified as Steel 5 of the following composition further illustrates the invention:

	Percent
Carbon	0.10
Manganese	0.002
Silicon	0.004
Nickel	8.96
Molybdenum	.95
Cobalt	3.99
Aluminum	0.002

Balance iron and residual impurities.

This steel was vacuum melted and vacuum carbon deoxidized and had the properties given in the following Table IV after treating as therein indicated:

TABLE IV

	Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Charpy V-Notch	
			+80 ft.-lb.	−80 ft.-lb
Air-cooled	105,000	147,000	136	131
Air-cooled and Aged	132,000	156,000	135	130
Oil-quenched and Aged (5 hrs. at 1,000 F.)	160,000	165,000	119	114

As above indicated, the steel in the air cooled condition had a bainitic microstructure and in the oil quenched condition had a martensitic microstructure.

Steel 6 of the following composition also was vacuum melted, and vacuum carbon deoxidized.

	Percent
Carbon	0.19
Manganese	0.21
Silicon	0.005
Nickel	8.94
Molybdenum	0.95
Cobalt	4.08
Aluminum	0.002

Balance iron and residual impurities.

After treating as indicated in the following Table V, Steel 6 exhibited the properties therein set forth:

TABLE V

	Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Charpy V-Notch	
			+80 ft.-lb.	−80 ft.-lb.
Air-cooled	135,000	197,000	68	59
Air-cooled and Aged	174,000	183,000	89	78
Oil-quenched and Aged (5 hrs. at 1,000 F.)	176,000	185,000	75	65

The air cooled specimens had a predominantly bainitic microstructure and the oil quenched specimens a predominantly martensitic microstructure.

It is thus apparent that the steel of this invention has high yield strength combined with good ductility as indicated by a Charpy V-notch value in excess of 60 foot-pounds at room temperature and 50 foot-pounds at −80 to −100° F. when quenched to a martensitic microstructure. In the air cooled condition having a bainitic microstructure, the steel has somewhat less yield strength but better impact values. Thus for certain uses where optimum impact values are desired, a bainitic microstructure resulting from slower air cooling may be desirable. However when the combination of optimum tensile strength and good ductility is required, the steel should be liquid quenched to a martensitic microstructure after austenitizing in the range of 1500 to 1700° F. and aged within the range of 800 to 1000° F. for 2 to 5 hours. Depending on thickness, air cooling or liquid, quenching may develop a microstructure consisting of a mixture of bainite and martensite. In such condition, the strength and toughness will be intermediate those noted hereinabove.

With the composition of this invention, the combination of high strength along with good toughness results from the quenching to a martensitic or bainitic microstructure or mixture thereof, together with a subsequent heat treatment to improve toughness while retaining strength. The retention of strength, after the toughening heat treatment, results from an age hardening reaction brought about by the precipitation of intermetallic compounds.

While we have shown and described several specific embodiments of our invention, it will be understood that these embodiments are merely for the purpose of illustration and description and that various other forms may be devised within the scope of our invention, as defined in the appended claims.

We claim:

1. Low carbon, age hardenable steel containing in percent by weight

Carbon	.05 to .2
Nickel	8 to 10
Molybdenum	.5 to 2.5
Cobalt	3 to 5
Manganese, max.	.25
Phosphorus, max.	.10
Sulphur, max.	.10
Silicon, max.	.2
Aluminum, max.	.1

with the balance iron and other elements in amounts which do not adversely affect the properties.

2. Low carbon steel having a microstructure of the class consisting of martensite, bainite or mixtures thereof characterized in the age hardened condition by a yield strength in excess of 150,000 p.s.i. combined with a Charpy V-notch value in excess of 60 foot-pounds at room temperature and 50 foot-pounds at −80° F., said steel containing in percent by weight

Carbon	.05 to .2
Nickel	8 to 10
Molybdenum	.5 to 2.5
Cobalt	3 to 5
Manganese, max.	.25
Phosphorus, max.	.10
Sulphur, max.	.10
Silicon, max.	.2
Aluminum, max.	.1

with the balance iron and other elements in amounts which do not adversely affect the properties.

3. Age hardened, low carbon steel having a microstructure of the class consisting of bainite, martensite or mixtures thereof, a high yield point and a Charpy V-notch value in excess of 50 foot-pounds at −80° F., said steel consisting essentially of, in percent by weight

Carbon	.05 to .2
Nickel	8 to 10
Molybdenum	.5 to 2.5
Cobalt	3 to 5
Manganese, max.	.25
Phosphorus, max.	.10
Sulphur, max.	.10
Silicon, max.	.2
Aluminum, max.	.1

with the balance iron and other elements in amounts which do not adversely affect the properties.

4. Age hardened, low carbon steel quenched to a microstructure of the class consisting of bainite, martensite or mixtures thereof and aged at a temperature between 800 and 1000° F., said steel containing in percent by weight

Carbon	.05 to .2
Nickel	8 to 10
Molybdenum	.5 to 2.5
Cobalt	3 to 5
Manganese, max.	.25
Phosphorus, max.	.10
Sulphur, max.	.10
Silicon, max.	.2
Aluminum, max.	.1

with the balance iron and other elements in amounts which do not adversely affect the properties, said steel being characterized by a high yield strength and a Charpy V-notch value in excess of 50 foot-pounds at −50° F.

5. Low carbon steel having a microstructure of the class consisting of martensite, bainite or mixtures thereof characterized in the age hardened condition by a yield strength in excess of 150,000 p.s.i. combined with a Charpy V-notch value in excess of 60 foot-pounds at room temperature and 50 foot-pounds at −80° F., said steel consisting essentially of, in percent by weight

Carbon	.05 to .2
Nickel	8 to 10
Molybdenum	.5 to 2.5
Cobalt	3 to 5
Manganese, max.	.25
Phosphorus, max.	.10
Sulphur, max.	.10
Silicon, max.	.2
Aluminum, max.	.1

with the balance essentially iron.

6. Age hardened, low carbon steel having a microstructure of the class consisting of bainite, martensite or mixtures thereof, a high yield point and a Charpy V-notch value in excess of 50 foot-pounds at −80° F., said steel consisting essentially of, in percent by weight

Carbon	.05 to .2
Nickel	8 to 10
Molybdenum	.5 to 2.5
Cobalt	3 to 5
Manganese, max.	.25
Phosphorus, max.	.10
Sulphur, max.	.10
Silicon, max.	.2
Aluminum, max.	.1

with the balance essentially iron.

No references cited.

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Notice of Adverse Decision in Interference

In Interference No. 96,840 involving Patent No. 3,338,709, A. J. Baker and F. J. Lauta, AGE HARDENABLE LOW ALLOY STEELS, final judgment adverse to the patentees was rendered June 1, 1972, as to claim 1.

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