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LOW-ALLOY, HIGH-HARDENABILITY STEEL
WITH HIGH TOUGHNESS AT HIGH HARD-
NESS LEVELS

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This invention relates to an improved low-alloy, high-strength steel characterized by high hardenability and by high impact strength after heat treatment to develop high strength or hardness.

Tough, high-strength, i. e., over 220,000 p. s. i. tensile strength, steels find many applications in aircraft, railroad, and automotive equipment where high-tensile strength combined with high impact strength often allows, through the use of somewhat lighter sections, a weight reduction with no sacrifice in safety. Some typical examples in which high toughness at high strength is required include landing-gear struts for large aircraft, rock-drill bits for pneumatic tools, and perforating guns for oil-well equipment. It has been the practice in the past to use steels of rather high-alloy contents, particularly high-nickel contents, for such applications. Steels for these applications must have sufficient hardenability to harden relatively large sections throughout. Despite their high-alloy contents, many of these steels are quite brittle when heat-treated to high-strength levels. In fact, John M. Thompson, Jr., has shown, in an article appearing in The Iron Age for March 8, 1945, that the impact strengths of most of the alloy steels used in aircraft applications vary inversely with the hardness or tensile strength and that at hardnesses of 48 to 50 Rockwell C or tensile strengths of 240,000 to 260,000 p. s. i. these steels will have low, room-temperature impact strengths, that is, on the order of 5 to 10 ft.-lbs. Thompson further states that any low-alloy steel heat-treated to a specified hardness or tensile strength will have about the same impact strength as any other low-alloy steel heat-treated to that hardness.

In general, steels of sufficient hardenability to harden large sections throughout, contain relatively large amounts of alloying elements, particularly large amounts of nickel, one of the most expensive alloying elements. For example, a total alloy content of 6.35% is characteristic of the frequently used 4% nickel-1.25% chromium steel. Likewise, AISI type 4340 steel has also been widely used for the high-strength applications to which the present invention is directed, and, although the total alloy content of the mean composition of the AISI 4340 specification range is only 3.85%, the nickel content of this steel may vary from 1.65 to 2.00%.

We have discovered on the contrary that not only can the high hardenability desired be attained without the foregoing loss of impact strength but moreover it can be obtained with less than 4% total alloy content along with less

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than 1% of nickel. Our improved steel containing less than 1% nickel has impact strengths equal to or better than expensive 4% nickel steels not only at room temperature but at temperatures as low as -200° F.

The chemical compositions of two steels typical of the present invention are given in Table I and the deep-hardening characteristics of the two steels are indicated in Table II. For comparison, there is also included in Table II the lower limit of the hardenability band for AISI 4340 steel.

TABLE I

Chemical composition—percent

Steel	C	Mn	Si	Ni	Cr	Mo	B
A	0.25	0.83	0.65	0.87	0.73	0.53	0.0036
B	0.35	0.92	0.71	0.88	0.83	0.54	0.0039

TABLE II

End-quench hardenability test results

Distance from Quenched-End in Sixteenths of an Inch	Hardness—Rockwell "C" Scale		
	Steel A	Steel B	AISI 4340 Lower Limit of Hardenability Band
1	48.5	54.5	52.5
2	48	54	52.5
4	48	53	52.5
8	47.5	53	52
12	47	53	51
16	47	53	50
24	45	52.5	46

NOTE: The differences in the carbon contents of the steels account for the differences in hardness levels.

The heat treatment of the steel of this invention involves conventional practices. After being austenitized at a temperature high enough and for a time long enough to effect adequate carbide solution, the steel is cooled in oil or water at a rate sufficiently rapid to avoid transformation at high temperatures. In this way an almost wholly martensitic microstructure is obtained. This quenching treatment is followed by a tempering treatment preferably in the range 400 to 500° F., the exact temperature depending on the carbon content and on the desired strength level. Tensile-strength levels between about 220,000 and 270,000 p. s. i. may be obtained from this steel by judicious selection of carbon content and of tempering temperature. After heat treatment, V-notch Charpy bar impact strengths of about 25 to 28 ft.-lbs.

at room temperature are characteristic of this steel. In addition, impact strengths as high as about 20 to 24 ft.-lbs. at -100° F. and as high about 18 to 20 ft.-lbs. at -200° F. are also characteristic. The fatigue strength of the steel after heat treatment to a tensile strength of 226,000 p. s. i. is about 118,000 p. s. i.

Table III below gives the mechanical properties of the 0.25% carbon steel A.

TABLE III

Heat treatment

Oil-quenched from 1600 F. and tempered at 440° F.

Mechanical properties

Hardness, Rockwell "C"	46
Yield strength, p. s. i. (0.2% offset)	185,900
Tensile strength, p. s. i.	226,300
Elongation in 1 inch, percent	14.0
Reduction in area, percent	57.9
V-notch, Charpy-bar impact values, ft.-lbs.:	
Tested at room temperature	28
Tested at -100° F.	24
Tested at -200° F.	20
Fatigue strength, p. s. i.	118,000

Table IV shows the properties of the 0.35% carbon steel B, and also a direct comparison of its properties with the properties of a more expensive, high-nickel steel of the following composition.

	Per cent
Carbon	.34
Manganese	.46
Silicon	.24
Nickel	4.38
Chromium	1.27

It is readily apparent that this steel contains more than 4% total alloying elements and also more than 1% nickel.

TABLE IV

Heat treatment

Both steels were oil-quenched from 1600° F. and tempered at 400° F.

Mechanical properties

	Steel B	High-Nickel Steel
Hardness, Rockwell "C"	51	50.5
Yield Strength, p. s. i. (0.2% offset)	210,500	210,300
Tensile Strength, p. s. i.	267,600	261,700
Elongation in 2 inches, per cent	13.0	13.5
Reduction in Area, per cent	43.6	43.4
V-Notch, Charpy-bar impact values, ft.-lbs.:		
Tested at room temperature	26	24
Tested at -100° F.	21	20
Tested at -200° F.	19	19

The desirable combination of properties here-

inbefore described can be obtained within the following composition ranges:

	Per cent
Carbon	0.22 to 0.37
Manganese	0.65 to 0.95
Silicon	0.55 to 0.75
Nickel	0.70 to 0.95
Chromium	0.70 to 0.90
Molybdenum	0.40 to 0.60
Boron	0.003 to 0.006

The remainder of the steel is substantially all iron except for the normal amounts of residual impurities consistent with killed-steel practice.

While we have described two 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. A high-hardenability steel characterized by less than 4% total alloy content and less than 1% nickel and tensile strengths in excess of 220,000 p. s. i. and a V-Notch, Charpy-bar impact value in excess of 20 ft.-lbs. at -100° F. after heat treating by cooling sufficiently rapidly from an austenitizing temperature to obtain a martensitic structure and thereafter tempering within the range of 400 to 500° F., said steel comprising .22 to .37% carbon, .65 to .95% manganese, .55 to .75% silicon, .70 to .95% nickel, .70 to .90% chromium, .40 to .60% molybdenum, .002 to .006% boron, balance iron and residual amounts of other elements.

2. A high-hardenability steel having less than 4% total alloy content together with less than 1% nickel and having a tempered martensitic structure resulting from rapidly quenching it from an austenitizing temperature and thereafter tempering it in the range of 400 to 500° F. characterized by a tensile strength in excess of 220,000 p. s. i. and a V-Notch, Charpy-bar impact value in excess of 20 ft.-lbs. at -100° F., said steel comprising .22 to .37% carbon, .65 to .95% manganese, .55 to .75% silicon, .70 to .95% nickel, .70 to .90% chromium, .40 to .60% molybdenum, .002 to .006% boron, balance iron and residual amounts of other elements.

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