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LOW ALLOY HIGH TENSILE STRENGTH, HIGH IMPACT STRENGTH STEEL

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This invention pertains to a relatively low alloy steel characterized by extremely high impact strength when heat treated to high tensile strength and hardness.

In the past, low alloy steels have not been used at their maximum efficiency because of the brittleness which accompanies the highest strengths. While many of the well known low alloy steels can be heat treated in relatively small sections to tensile strengths over 200,000 pounds per square inch (P. S. I.), their toughness, as measured by the Izod or notched bar impact test, has been too low for adequate safety against fracture when shock loads are applied. For this reason, low alloy steels have been used at lower strengths than the maximum that can be obtained. In industries such as railroad, automotive and aircraft where the strength weight ratio is of major importance, this lack of toughness at high strengths has been a serious disadvantage, as it has meant that larger and consequently heavier sections had to be used to compensate for the lower strengths necessary for good impact strength. It has been considered that the impact strength at a given hardness was relatively independent of the composition of the steel provided it had been properly heat treated. For example, a recent article entitled "Impact resistance vs. Hardness of aircraft low alloy steels" by John M. Thompson, Jr., appearing in the March 8, 1945 issue of Iron Age dealt with the impact strength vs. hardness relationship of three widely used low alloy aircraft steels, viz., S. A. E. X4130, S. A. E. 4140 and S. A. E. X4340. Thompson found that the impact strength varied inversely with the hardness, and was substantially the same at any given hardness for all of the above steels. He accordingly concluded that "This straight line graph also shows that any low alloy steel that will heat treat to a certain tensile strength or Rockwell hardness will have nearly the same Izod impact resistance value as any other low alloy steel heat treated to the same hardness and strength. It is possible to predict on the basis of this graph the approximate Izod impact resistance of any low alloy steel from its Rockwell hardness reading." According to the information set forth in the Thompson article, any low alloy steel when heat treated to a Rockwell "C" hardness of about 43 to 50, will have an Izod notched impact resistance of only about 10 to 5 foot-lbs., the lower value applying to the higher hardness.

I have discovered to the contrary, that a low alloy, manganese - silicon - nickel - molybdenum

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steel within certain narrow limits of composition as specified below, is characterized by unusually high toughness at high tensile strengths and hardnesses. The toughness at about Rockwell "C" 50 is generally four to five times as high as would be expected from the usual low alloy steels. On the basis of the aforementioned article, an Izod impact strength of only about 5 ft. lb. would be expected at a Rockwell "C" hardness of 50, but with my steel an Izod impact strength of at least 25 to 30 ft. lbs. can be obtained at the same hardness. Furthermore, the impact strength of my steel is substantially unchanged even at temperatures as low as —100° F. This low temperature toughness is highly advantageous in airplanes, for instance, where the temperature of exposed portions may reach this low level.

The broad analysis limits of my steel are:

Over about 0.15 to under 0.40% carbon
Over about 1.00 to 2.50% manganese
Over about 0.80 to 3.00% silicon
About 1.00 to 5.00% nickel
About 0.25 to 1.00% molybdenum

This steel is capable of attaining about 200,000 P. S. I. tensile strength or the equivalent Rockwell "C" 44 in sections up to at least 1 inch round with an accompanying Izod impact strength of about 38 ft.-lbs. at both room temperatures and —100° F.

The carbon range of my steel is set by limitations in attainable hardness and weldability. Unless the carbon content is about 0.15% or more, the steel will not be capable of hardening to the required tensile strength. Table I below gives the results for a steel according to my invention containing about the minimum permissible carbon.

Table I

Analysis.—0.17% C, 1.27% Mn, 1.58% Si, 1.79% Ni, 0.41% Mo.

Heat treatment.—Oil quenched from 1550° F. and tempered at 450° F.

Mechanical properties:	
0.2% offset yield strength, P. S. I.	165,000
Tensile strength, P. S. I.	206,000
Elongation per cent in 2 in.	10.0
Reduction of area, per cent	38.2
Izod impact strength, ft.-lbs.—	
At room temperature	37
At —100° F.	38
Hardness—Rockwell "C"	44

With a slightly lower carbon content, this steel would have been incapable of attaining the de-

sired minimum tensile strength of approximately 200,000 P. S. I. On the other hand, 0.40% carbon or higher will give difficulties in welding as steel with this higher carbon requires careful preheating and postheating to prevent cracking. Likewise, steels with 0.40% carbon are more likely to crack in processing and heat treatment.

Manganese contents under 1% cause lower impact strengths as is shown by the following table:

Table II

Heat treatment.—Samples oil quenched from 1550° F., and tempered at 450° F.

Analysis					Rockwell "C" Hardness	Izod Impact Strength, ft.-lbs., at—	
%C	%Mn	% Si	% Ni	%Mo		70° F.	−100° F.
0.26	0.4	1.5	1.8	0.4	49	21	14
0.26	0.8	1.4	1.8	0.4	50	23	23
0.24	1.3	1.5	1.8	0.4	49	31	29
0.25	1.6	1.5	1.8	0.4	49	33	33

Therefore, the manganese should be over 1% to assure the desired impact strength of at least 25 ft.-lbs. The upper limit of 2.50% manganese is necessitated by considerations of annealing. If the manganese exceeds 2.50%, the steel is very sluggish and cannot be annealed soft enough for machining by a commercially practicable annealing treatment.

Low silicon contents of 0.80% and under have a deleterious effect both on the hardenability (that is, on the maximum size that can be hardened throughout) and on the impact strength. Silicon contents of over 0.80% have been found essential to give superior impact strength and to assure proper hardening in sizes of at least one inch in section. On the other hand, too high a silicon content is undesirable as it induces a susceptibility to decarburization which makes the steel impractical to heat treat commercially. If the silicon is over 3.0%, the decarburization during the usual annealing and heat treatment is so great that a hardness of Rockwell "C" 50 cannot be obtained on the outer portions of the part where the loads are usually highest. Naturally this weakness resulting from decarburization makes it impossible to utilize the very high silicon compositions in applications demanding the maximum strength and maximum impact properties.

A minimum nickel content of about 1% is required for adequate hardenability. Steels with lower nickel contents will harden through only in very small sections which would not be adequate for parts such as gears, shafts and springs. The attempted use of such low nickel steels in larger sections is completely unsatisfactory as they have low hardness and low impact strength. High nickel contents over 5.00% are troublesome in annealing and hardening as they decelerate the reaction rate of the steel. Therefore, excessively long annealing cycles are necessary for softening. Likewise, austenite is likely to be retained on oil quenching as the austenite-martensite reaction is not completed at room temperature. The presence of soft austenite decreases the hardness and has a somewhat undesirable influence on the impact strength.

Under 0.25% molybdenum results in inadequate hardenablity when the other elements are kept within the specified limits. Large additions, i. e., over 1.00%, not only increase the cost but also necessitate longer austenitizing during heat treatment for proper solution of the carbides. Within my broad range, I have found the following narrow range to have outstanding properties in the respects above noted:

	Per cent
Carbon	0.20 to 0.30
Manganese	0.10 to 2.10
Silicon	1.00 to 2.00
Nickel	1.50 to 2.50
Molybdenum	0.30 to 0.50

A typical heat within this preferred range gave the following results:

Table III

Analysis.—0.26% C, 1.3% Mn, 1.4% Si, 1.8% Ni, 0.4% Mo.

Heat treatment.—Oil quenched from 1550° F., tempered at 450° F.

Mechanical Properties:

0.2% offset yield strength, p. s. i	198,000
Tensile strength, p. s. i	242,000
Elongation per cent in 2 in	12.2
Reduction of area, per cent	47.0
Izod impact strength ft.-lb.—	
At room temperature	32
At −100° F	26
Hardness: Rockwell "C"	48.5

Jominy hardenability: (as quenched from 1550° F.)

Rockwell "C" Hardness	Distance from Quenched End in 1/16th's of an inch
50	1
50	3
50	5
49.5	8
49.5	11

The tensile strength found for this material corresponds to about Rockwell "C" 50 at which previous experience would indicate an Izod of about 5 ft.-lbs. Yet this steel shows an impact strength of 32 ft.-lbs. at room temperature. In other words, despite the accepted belief that impact strength at a given hardness is independent of composition, I have discovered a steel capable of attaining high hardnesses with an impact strength over six times that expected from former steels.

In the appended claims, by the expression "balance substantially all iron" is meant iron except for impurities, within commercial tolerances, and other elements, not exceeding about 1% in aggregate, which do not substantially affect the defined characteristics of the steel.

What I claim is:

1. A low alloy steel characterized in having an Izod notched impact resistance of at least 25 foot pounds and a tensile strength of at least 200,000 pounds per square inch, when heat treated by cooling sufficiently rapidly from an austenitizing temperature to avoid high temperature transformations, and thereafter tempering at temperatures on the order of 450° F., said steel containing: about 0.15 to 0.4% carbon; about 1 to 2.5% manganese; about 0.8 to 3% silicon; about 1 to 5% nickel; about 0.25 to 1% molybdenum; and the balance substantially all iron.

2. A low alloy steel characterized in having an Izod notched impact resistance of at least 25 foot pounds and a tensile strength of at least 200,000 pounds per square inch, when heat treated by cooling sufficiently rapidly from an austenitizing

temperature to avoid high temperature transformations, and thereafter tempering at temperatures on the order of 450° F., said steel containing: about 0.2 to 0.3% carbon; about 1.1 to 2.1% manganese; about 1 to 2% silicon; about 1.5 to 2.5% nickel; about 0.3 to 0.5% molybdenum; and the balance substantially all iron.

3. A low alloy steel, heat treated by cooling sufficiently rapidly from an austenitizing temperature to avoid high temperature transformations, and thereafter tempering at temperatures on the order of 450° F., said steel having an Izod notched impact resistance of at least 25 foot pounds and a tensile strength of at least 200,000 pounds per square inch, said steel containing: about 0.15 to 0.4% carbon; about 1 to 2.5% manganese; about 0.8 to 3% silicon; about 1 to 5% nickel; about 0.25 to 1% molybdenum; and the balance substantially all iron.

4. A low alloy steel, heat treated by cooling

sufficiently rapidly from an austenitizing temperature to avoid high temperature transformations, and thereafter tempering at temperatures on the order of 450° F., said steel having an Izod notched impact resistance of at least 25 foot pounds and a tensile strength of at least 200,000 pounds per square inch, said steel containing: about 0.2 to 0.3% carbon; about 1.1 to 2.1% manganese; about 1 to 2% silicon; about 1.5 to 2.5% nickel; about 0.3 to 0.5% molybdenum; and the balance substantially all iron.

PETER PAYSON.

REFERENCES CITED

The following references are of record in the file of this patent:

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