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ALLOY STEELS

Harry L. Anthony III and Gopal K. Bhat, Pittsburgh, Pa., assignors, by mesne assignments, to Wilson Brothers, New York, N.Y., a corporation of Illinois
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This invention relates to alloy steels and particularly to an alloy steel having a relatively low level of alloying elements.

Modern developments in missiles, aircraft, high strength pressure vessels and the like require alloy steels having high yield strength levels. These high yield strength levels have in the past been deemed obtainable only by the use of special steels having relatively high concentrations of alloying elements such as the H-11 (nominal composition carbon 0.40%, manganese 0.30%, silicon 0.90%, chromium 5.00%, molybdenum 1.30%, vanadium 0.45%, sulfur and phosphorus below 0.020% and balance iron) hot work tool and die steels and the like. These tool and die steels, however, have many drawbacks. They require special care in their manufacture and in their heat treatment. The segregation of complex alloy carbides and particularly the control of their size and distribution during heat treatment is difficult. Welding of such steels poses difficult problems to fabricators, and uniform hardness is difficult to attain.

We have discovered an alloy steel composition which reduces these problems and attains the high yield strength levels desired without the need for relatively large quantities of alloying elements.

We provide an alloy having a composition within the following limits:

Carbon	About 0.35% to about 0.45%.
Manganese	About 0.60% to about 1.10%.
Phosphorus	0.025% maximum.
Sulfur	0.025% maximum.
Silicon	About 0.60% to about 1.50%.
Chromium	About 0.80% to about 1.50%.
Molybdenum	About 0.15% to about 0.40%.
Tungsten	May be substituted for molybdenum in ratio of 2:1.
Vanadium	About 0.10% to about 0.25%.
Cobalt	About 0.85% to about 1.34% but may be absent when vanadium is above 0.15%.

Balance iron with usual impurities in ordinary amounts.

In a preferred composition of our alloy we provide:

Carbon	About 0.40%.
Manganese	About 0.70%.
Phosphorus	About 0.010%.
Sulfur	About 0.010%.
Silicon	About 0.80%.
Chromium	About 1.00%.
Molybdenum	About 0.20%.
Vanadium	About 0.10%.
Cobalt	About 1.00%.

Balance iron with usual impurities in ordinary amounts.

We have melted and tested several heats of steel made according to our invention and have found that in every case they had the high yield strength level desired as well as a large differential between offset yield strength and ultimate tensile strength.

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Example I

A 4,000 pound heat of steel was made of the following composition:

	Percent
5 Carbon	0.38
Manganese	0.70
Sulfur	0.020
Phosphorus	0.020
Silicon	1.00
10 Chromium	0.90
Molybdenum	0.25
Vanadium	0.10
Cobalt	1.00
15 Balance iron with usual impurities in ordinary amounts.	

This material was formed into bars and sheets and tested. The material, after being austenitized at 1700° F., quenched in oil and tempered at 600° F., gave the following physical values:

20 0.2% offset yield strength	About 232,000 p.s.i.
Ultimate tensile strength	About 272,000 p.s.i.
Elongation, in two inches	About 5.5% to about 6.5%.

The same results were obtained when the quenching was done in molten salt at 400° F. and tempered as above.

Example II

30 A 4,000 pound heat of steel was melted in an electric furnace to the following composition:

	Percent
Carbon	0.39
Manganese	0.89
35 Sulfur	0.013
Phosphorus	0.013
Silicon	0.85
Chromium	1.15
Molybdenum	0.23
40 Vanadium	0.10
Cobalt	0.99
Balance iron with usual impurities in ordinary amounts.	

45 This material was heat treated as in Example I and gave the following physical values:

0.2% offset yield strength	About 227,000 p.s.i.
Ultimate tensile strength	About 279,000 p.s.i.
50 Elongation, in two inches	About 6.0%.

Example III

A 1,000 pound heat of steel was melted to a composition of:

	Percent
55 Carbon	0.41
Manganese	0.72
Sulfur	0.012
Phosphorus	0.014
Silicon	0.88
60 Chromium	1.31
Molybdenum	0.27
Vanadium	0.10
Cobalt	0.92
65 Balance iron with usual impurities in ordinary amounts.	

Bars and sheets were formed, heat treated and tested as in Example I and gave the following physical values:

70 0.2% offset yield strength	About 226,000 p.s.i.
Ultimate tensile strength	About 267,000 p.s.i.
Elongation, in two inches	About 6.5%.

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Example IV

A heat was made according to the following analysis:

	Percent
Carbon -----	0.44
Manganese -----	0.54
Sulfur -----	0.006
Phosphorus -----	0.017
Silicon -----	1.51
Chromium -----	1.20
Molybdenum -----	0.30
Vanadium -----	0.14
Cobalt -----	1.34
Balance iron with usual impurities in ordinary amounts.	

Physical values of bars and sheets tested as in Example I were:

0.2% offset yield strength -----	About 265,000 p.s.i.
Ultimate tensile strength -----	About 300,000 p.s.i.

A comparison of the 0.2% offset yield strength with the ultimate strength shows the broad range between the two.

Similar but not as good results can be obtained by increasing the vanadium content above about 0.15% to about 0.25% and reducing or entirely eliminating the cobalt content. For example, a heat of steel was made to the composition:

Example V

	Percent
Carbon -----	0.35
Manganese -----	0.84
Sulfur -----	0.007
Phosphorus -----	0.019
Silicon -----	1.09
Chromium -----	1.36
Molybdenum -----	0.25
Vanadium -----	0.21
Cobalt -----	None
Balance iron with usual impurities in ordinary amounts.	

The above alloy was formed, treated and tested as in Example I and gave the following physical values:

0.2% offset yield strength -----	About 213,000 p.s.i.
Ultimate tensile strength -----	About 267,000 p.s.i.
Elongation, in two inches -----	About 4.0% to about 5.5%.

We have found that tungsten can be substituted for part or all of the molybdenum in the ratio of two parts of tungsten to one part of molybdenum.

The following heat of steel was made:

Example VI

	Percent
Carbon -----	0.47
Manganese -----	1.20
Sulfur -----	0.007
Phosphorus -----	0.006
Silicon -----	1.23
Chromium -----	1.46
Vanadium -----	0.19
Cobalt -----	1.02
Tungsten -----	0.62
Balance iron with usual impurities in ordinary amounts.	

Physical values of bars and sheets tested as in Example I were:

0.2% offset yield strength -----	About 249,000 p.s.i.
Ultimate tensile strength -----	About 297,000 p.s.i.
Elongation, in two inches -----	About 7.5%.

Material from the foregoing examples was reverse drawn into thin walled missile cases with satisfactory results. Except for the steel in which tungsten was sub-

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stituted for molybdenum (Example VI above), which was not fabricated, the material was welded without any of the difficulties which had characterized the cases made of H-11 hot work tool steels.

While we have illustrated and described certain preferred compositions and practices of our invention, it will be understood that this invention may be otherwise embodied within the scope of the following claims.

We claim:

1. A high strength article made from a worked alloy steel consisting essentially of carbon about 0.35% to about 0.43%, manganese about 0.60% to about 1.10%, phosphorus about 0.025% maximum, sulfur about 0.025% maximum, silicon about 0.60% to about 1.09%, chromium about 0.80% to about 1.36%, molybdenum about 0.15% to about 0.27%, vanadium about 0.10% to about 0.25%, cobalt about 0.85% to about 1.30%, and the balance iron with usual impurities in ordinary amounts, said article being characterized by a 0.2% offset yield strength in excess of about 225,000 p.s.i. and an ultimate tensile strength about 40,000 p.s.i. greater than the yield strength.

2. A high strength article made from a worked alloy steel consisting essentially of carbon about 0.40%, manganese about 0.70%, phosphorus about 0.010%, sulfur about 0.010%, silicon about 0.80%, chromium about 1.00%, molybdenum about 0.20%, vanadium about 0.10%, cobalt about 1.00%, and the balance iron with usual impurities in ordinary amounts, said article being characterized by a 0.2% offset yield strength in excess of about 225,000 p.s.i. and an ultimate tensile strength about 40,000 p.s.i. greater than the yield strength.

3. A high strength article made from a worked alloy steel consisting essentially of carbon about 0.35% to about 0.45%, manganese about 0.60% to about 1.10%, phosphorus 0.025% maximum, sulfur 0.025% maximum, silicon about 0.60% to about 1.50%, chromium about 0.80% to about 1.50%, molybdenum about 0.15% to about 0.40%, vanadium about 0.10% to about 0.25%, cobalt about 0.85% to about 1.34%, and the balance iron with usual impurities in ordinary amounts, said article being characterized by a 0.2% offset yield strength in excess of 225,000 p.s.i. and an ultimate tensile strength about 35,000 p.s.i. greater than the yield strength.

4. A high strength worked alloy steel consisting essentially of carbon about 0.35% to about 0.45%, manganese about 0.60% to about 1.10%, phosphorus 0.025% maximum, sulfur 0.025% maximum, silicon about 0.60% to about 1.50%, chromium about 0.80% to about 1.50%, molybdenum about 0.15% to about 0.40%, vanadium about 0.10% to about 0.25%, cobalt about 0.85% to about 1.34%, and the balance iron with usual impurities in ordinary amounts.

5. A high strength worked alloy steel consisting essentially of carbon about 0.35% to about 0.45%, manganese about 0.60% to about 1.10%, phosphorus 0.025% maximum, sulfur 0.025% maximum, silicon about 0.60% to about 1.50%, chromium about 0.80% to about 1.50%, molybdenum about 0.15% to about 0.40%, tungsten substituted for said molybdenum in a ratio of two parts tungsten by weight for each part of molybdenum by weight, vanadium 0.10% to about 0.25%, cobalt about 0.85% to about 1.34%, and the balance iron with usual impurities in ordinary amounts.

6. A high strength alloy steel consisting essentially of carbon about 0.35% to about 0.43%, manganese about 0.60% to about 1.10%, phosphorus about 0.025% maximum, sulfur about 0.025% maximum, silicon about 0.60% to about 1.09%, chromium about 0.60% to about 1.36%, molybdenum about 0.15% to about 0.27%, vanadium about 0.10% to about 0.25%, cobalt in an effective amount not less than 0.85% to produce an alloy steel being characterized by a 0.2% offset yield strength in excess of about 225,000 p.s.i., good weldability, freedom from car-

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bide segregation, when heated to about 1700° F., quenched and tempered at about 600° F. and the balance iron with usual impurities in ordinary amounts.

7. A high strength alloy steel consisting essentially of carbon about 0.35% to about 0.45%, manganese about 0.60% to about 1.10%, phosphorus 0.025% maximum, sulfur 0.025% maximum, silicon about 0.60% to about 1.50%, chromium about 0.80% to about 1.50%, molybdenum about 0.15% to about 0.40%, tungsten substituted for said molybdenum in a ratio of two parts tungsten by weight for each part of molybdenum by weight, vanadium 0.10% to about 0.25%, cobalt about 0.85% to about

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1.34%, and the balance iron with usual impurities in ordinary amounts.

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