June 20, 1967 A. S. KENNEFORD 3,326,675

ALLOY STEELS

Filed May 18, 1964 6 Sheets-Sheet 1

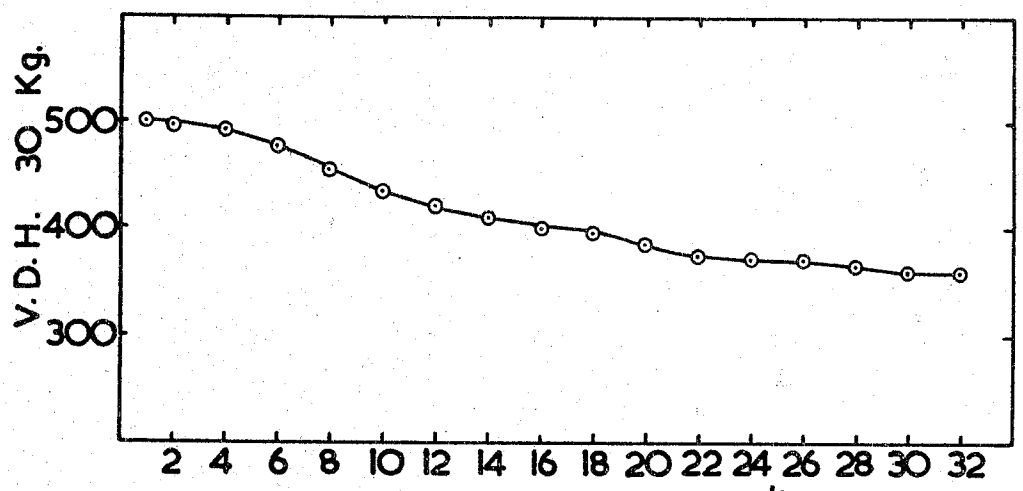


FIG. 1.

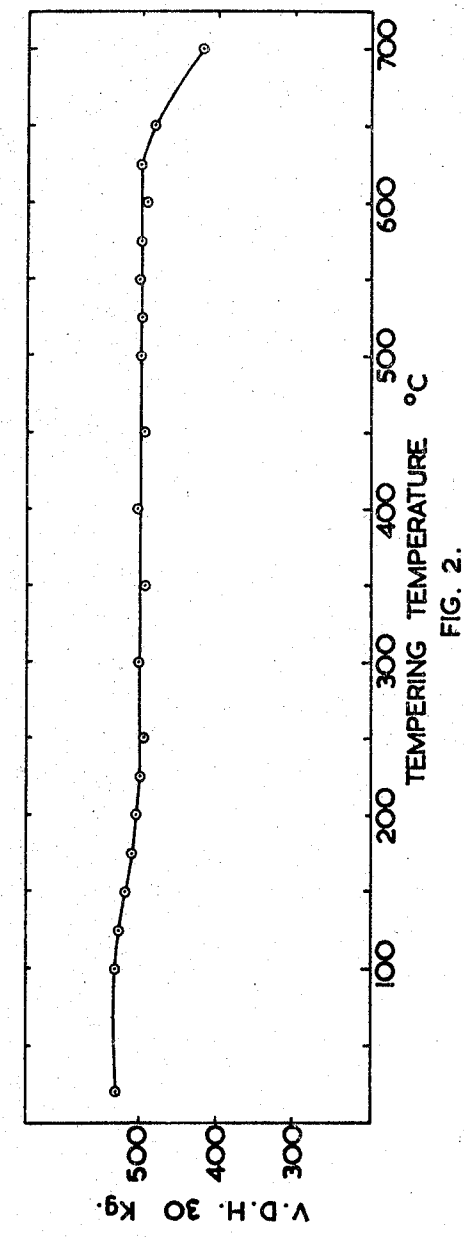

V.D.H. 30 Kg.
500
400
300
100
200
300
400
500
600
700
TEMPERING TEMPERATURE °C

FIG. 2.

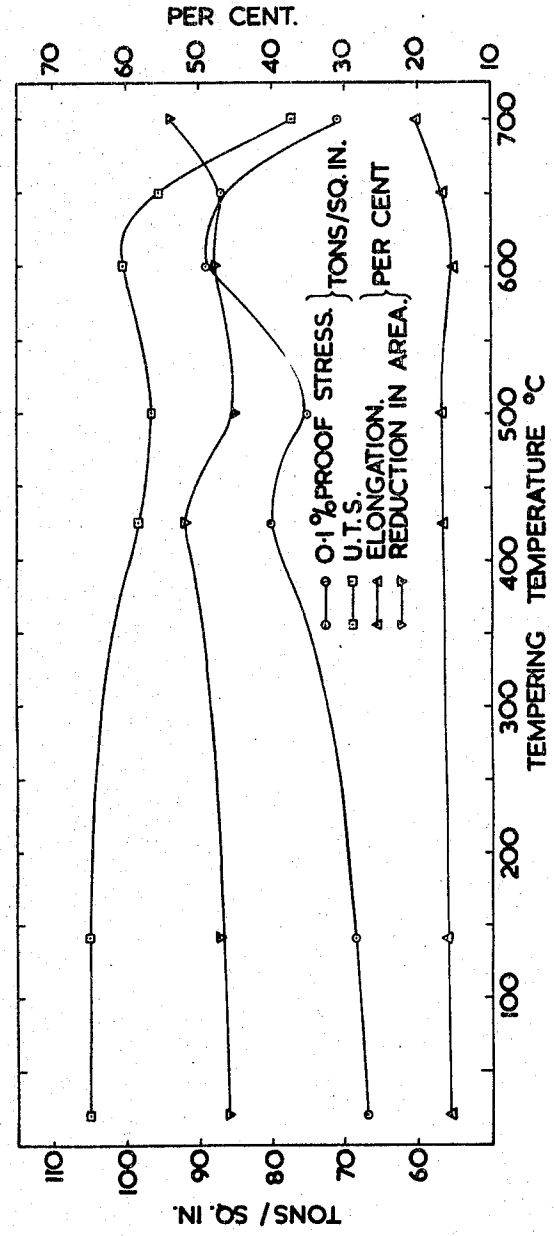

PER CENT.
70
60
50
40
30
20
10
0·1% PROOF STRESS. } TONS/SQ. IN.
U.T.S.
ELONGATION. } PER CENT
REDUCTION IN AREA.
700
600
500
400
300
200
100
TEMPERING TEMPERATURE °C
110
100
90
80
70
60
TONS / SQ. IN.

FIG. 3.

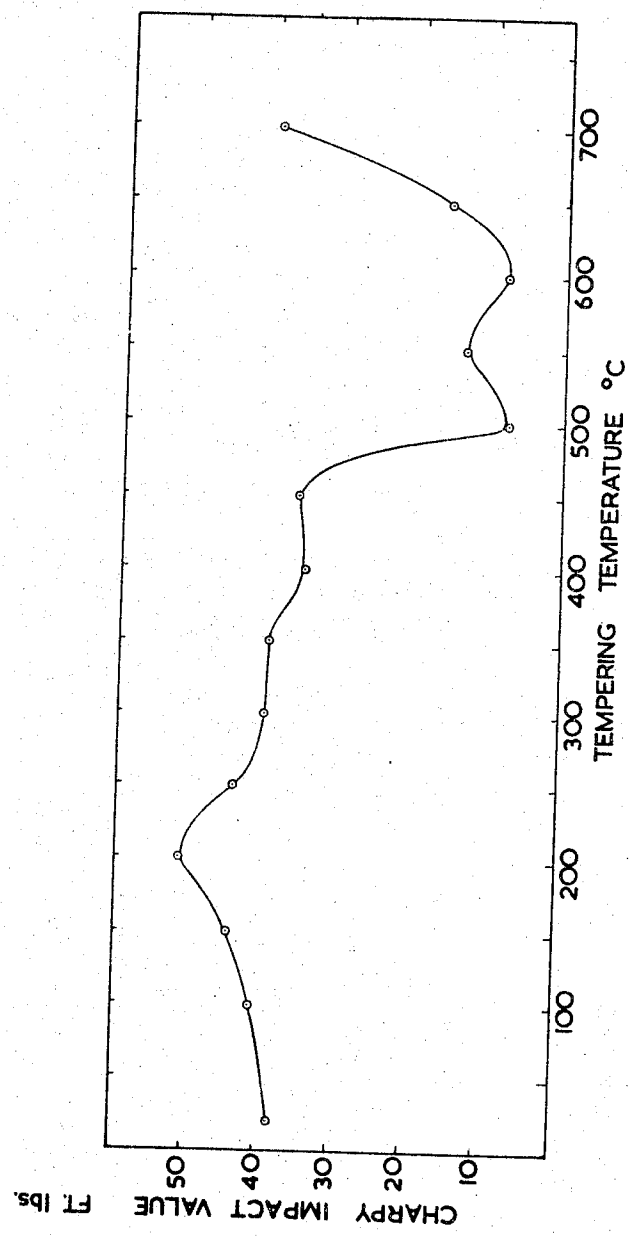

CHARPY IMPACT VALUE FT. lbs.
10
20
30
40
50
100
200
300
400
500
600
700
TEMPERING TEMPERATURE °C

FIG. 4.

FIG. 5

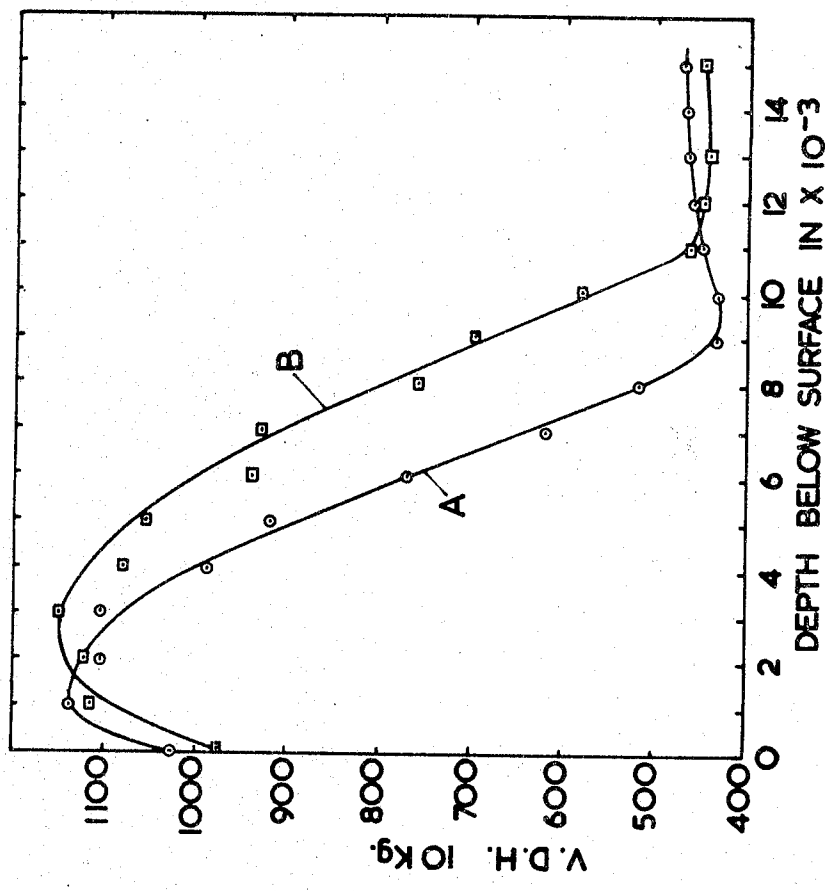
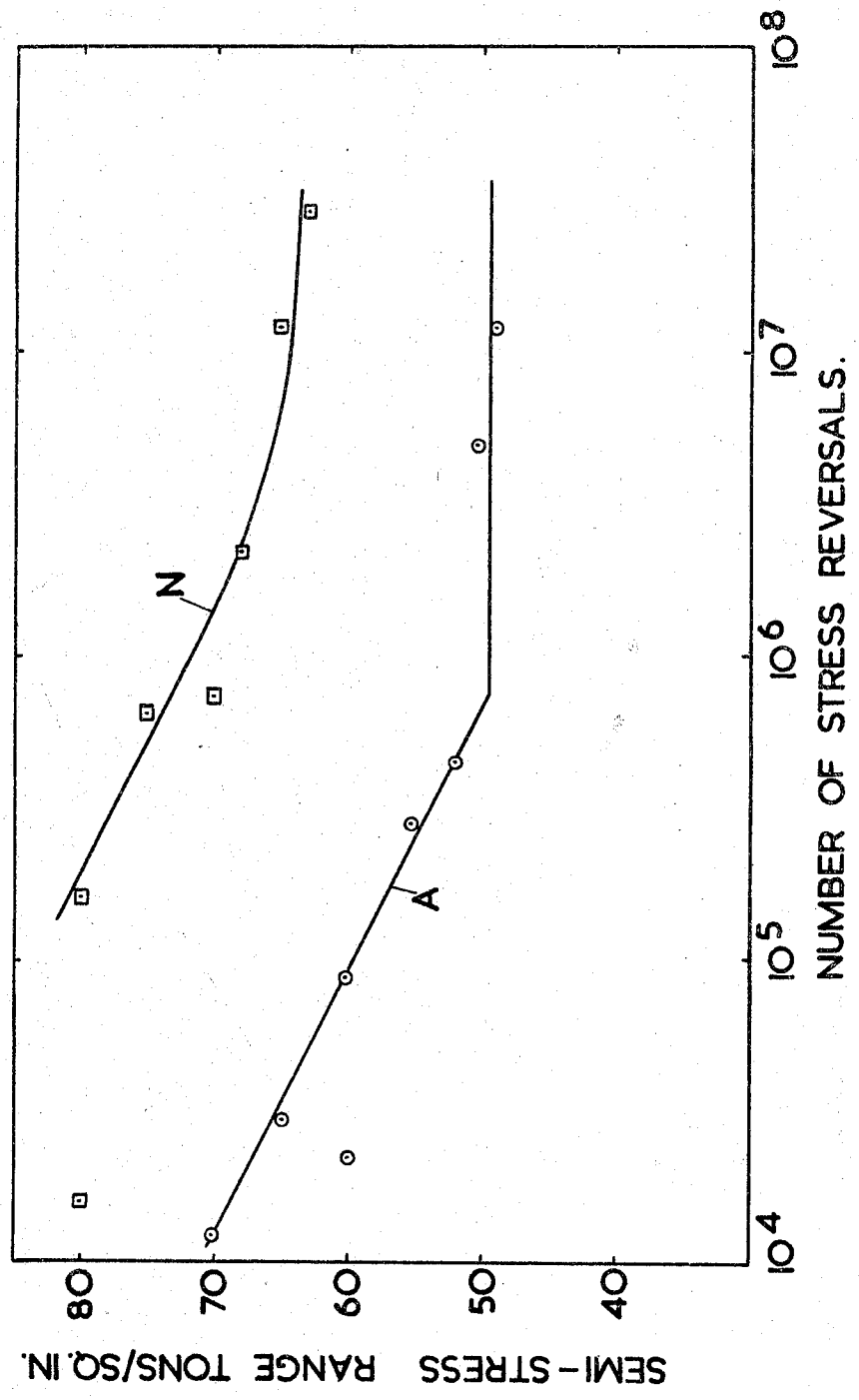

V. D.H. 10 Kg.
1100
1000
900
800
700
600
500
400
0
2
4
6
8
10
12
14
DEPTH BELOW SURFACE IN X 10⁻³
A
B

FIG. 6.


SEMI-STRESS RANGE TONS/SQ. IN.
80
70
60
50
40
NUMBER OF STRESS REVERSALS.
10^4
10^5
10^6
10^7
10^8
N
A

United States Patent Office

3,326,675

Patented June 20, 1967

3,326,675

ALLOY STEELS

Arthur Spencer Kenneford, Ruddington, England, assignor to National Research Development Corporation, London, England

Filed May 18, 1964, Ser. No. 368,238
Claims priority, application Great Britain, May 24, 1963, 20,791/63
9 Claims. (Cl. 75—124)

The present invention relates to high-tensile alloy steels which are heat-treated by heat soaking above the AC_3 transition temperature, and then quenching (in oil or water, for example) following by tempering.

Although alloy steels are known which have high-strength for structural purposes at ambient temperatures these properties are not retained at the high operating temperatures which are required in various modern service conditions.

The invention provides a high-tensile alloy steel which has very valuable properties, including great strength, hardness and adequate ductility, which properties are retained to a remarkable degree when the alloy steel is tempered at temperatures up to at least 600° C. Heat-treatment of these steels results in a more complete relief of thermal and transformation stresses with a higher endurance ratio for a given tensile strength. The high permissible tempering temperatures not only permits the steel to be used at high temperatures in service but also to be treated at higher temperatures for such purposes as hydrogen removal, welding and for surface treatment as hereinafter described.

In accordance with the invention, a high-tensile alloy steel which can be tempered at temperatures of at least 600° C. without appreciable softening is a medium-carbon alloy steel which comprises 0.15–0.5% (preferably 0.2–0.5%) carbon, 0.25–3% manganese, 1–2½% silicon, ½–2% aluminium, ½–3% molybdenum, 1–3% copper and 0.2–1% vanadium, the balance being essentially iron with any of its common impurities, e.g. nickel and chromium and the non-metallic impurities sulphur and phosphorus in small amounts usual in commercial steels. The copper content is preferably not more than 2 or 2½% and the silicon content preferably not more than 2%.

This alloy steel has properties in many respects equivalent or superior to more expensive steels and other expensive alloys, e.g. titanium alloys. The properties of the alloy steel when the heat treatment has involved tempering at a temperature of at least about 500° C. and even up to about 650° C. are particularly good. For example, alloy steels in accordance with the invention, even having a carbon content less than 0.3%, when heat-treated with tempering at 650° C. can have an ultimate tensile strength and 0.1% proof stress of 90–100 and 80–90 tons/sq. in. respectively with adequate hardness (Vickers diamond hardness V.D.H. value nearly 500). Alloy steels in accordance with the invention have good fatigue properties and workability, e.g. hotworking such as forging or rolling.

Very high values of surface hardness, i.e. around a V.H.D. value of 1,000, can be produced in alloy steels by nitriding. However the nitriding alloy steels in common use (i.e. chromium-molybdenum-vanadium steels and aluminium-chromium-molybdenum steels) suffer from the fact that they do not retain good mechanical properties at temperatures around 500° C. at which the nitriding process must take place, so that high surface hardness is gained at a cost of reduced core strength and their use in highly stressed components therefore tends to be limited as much as possible.

An outstanding property of the alloy steels in accordance with the invention is that they can be nitrided to

produce very high surface hardness without impairing the high strength and other advantageous properties of the core as above described. On the contrary, notwithstanding the retention of high strength at high temperatures, the fatigue strength of the alloy steels is still considerably increased by nitriding; (the fatigue limit can be increased from a stress of about ±50 tons/sq. in. to about 65 tons/sq. in.) so that alloy steels in accordance with the invention can have, when nitrided, most exceptional properties, combining high tensile strength with high fatigue strength, very high surface hardness and good workability, which properties are highly desirable for highly stressed components such as gears, subject to wear and sliding contact in service. Furthermore, these exceptionally good properties are possessed by an alloy steel which is not so inherently expensive as special purpose steels and other alloys and so can find wide application in the field of more common commercial steels particularly, for example, where a higher strength-weight ratio is desirable.

In accordance with an important feature of the invention therefore, an alloy steel as above defined is, after a heat-treatment which involves tempering at a temperature of more than 500° C., nitrided at a temperature less than the previous tempering temperature. The nitriding is advantageously carried out at the normal temperature of about 500° C. and the tempering temperature is then selected to give the alloy steel properties as appropriate as possible for the designed use. In any case, as the nitriding temperature is less than the preceding tempering temperature, nitriding will not cause deterioration of the mechanical properties of the alloy steel.

In accordance with a further feature of the invention, an alloy steel as above defined is heat-treated which involves tempering at about 550° C. followed by nitriding at about 500° C.

The depth of the surface region having an increased hardness increases with the duration of the nitriding treatment. An increased hardness can be produced in the surface layer to a depth of about 0.01 in. by nitriding for about 48 hours and this depth can be increased by increasing the treatment time.

The outstanding properties of this alloy steel are illustrated by the results of tests carried out on a typical alloy steel in accordance with the invention. The percentage content of the alloying elements in the steel is as follows:

0.24 carbon, 0.5 manganese, 1.77 silicon, 1.02 aluminium, 0.81 molybdenum, 1.79 copper, and 0.35 vanadium; the residual nickel and chromium being each 0.05 and residual sulphur and phosphorus being each 0.01.

Tests carried out in a standard manner showed that the critical range for this steel is 800–1025° C. while Stage I of martensite breakdown is at 140° C. and Stage III at 450°–500° C. The high AC_3 temperature of 1025° C. is accounted for by the presence of both silicon and aluminium.

The results of further tests on this typical alloy steel, are shown graphically in FIGURES 1 to 6 of the accompanying drawings.

FIGURE 1 shows the hardenability of a specimen under standard end quench conditions (S.A.E. handbook 1947), at various depths from an end which has been water quenched after heat soaking at 1075° C. for one hour.

FIGURE 2 shows the effect on the hardness of the quenched alloy steel of a standard heat-treatment, i.e. heat soaking for one hour at 1075° C., water quenching and tempering for one hour, when the tempering is carried out at various temperatures. The values of Vickers diamond hardness V.D.H. at a 30 kg. load given on the

graph clearly shows the remarkable consistency of hardness value and resistance to softening of the 0.24% carbon steel on tempering up to temperatures of 600° C. possessed by this new alloy steel.

FIGURE 3 shows the effect of the standard heat-treatment involving tempering for one hour at various temperatures on the tensile properties of the quenched steel. Again the good tensile properties of the new alloy steel are maintained up to temperatures of about 650° C.

FIGURE 4 shows the Charpy impact values obtained from tests on standard specimens (10 x 10 x 56 mm. with a 45° notch 2 mm. deep) subjected to the standard heat-treatment involving tempering for one hour at various temperatures. The graph shows that high values are obtained for tempering temperatures up to 450° C., while a satisfactory value of 14 ft. lbs. is obtained at 550° C. and an even higher value at 650° C.

FIGURE 5 shows the hardness of the surface layer obtained by nitriding specimens of the alloy steel after the standard heat-treatment with tempering at 550° C. Curve A shows the result of nitriding at about 500° C. in an atmosphere of dried ammonia for 48 hours and curve B for 72 hours. The increased depth of surface hardness and increase over the core hardness achieved by the longer process is clearly shown.

FIGURE 6 shows a fatigue curve A for a set of specimens given the standard heat-treatment involving tempering at 550° C. only and a fatigue curve N for another set similarly treated and then nitrided as above described for 72 hours. The graph clearly shows the considerable improvement in fatigue strength produced by nitriding, i.e. an increase in stress from about ±50 tons/sq. in. to ±65 tons/sq. in.

By tempering at 550° C., the steel is assured of good tensile properties as shown in FIGURE 3 and a satisfactory Charpy impact value as shown in FIGURE 4. Nitriding can be carried out at a conventional temperature, i.e. about 500° C., and a good surface hardness as shown in FIGURE 5 and fatigue strength as shown in FIGURE 6 are obtained.

By increasing the carbon content above 0.25% a considerably harder and stronger steel can be obtained, for example, after tempering at 550° C. the corresponding 0.35% carbon steel has a V.D.H. 30 value of 530 (instead of 470) and can be readily forged machined, heat-treated and nitrided if required.

I claim:

1. A medium carbon steel consisting essentially of about 0.15 to 0.5% carbon, about 0.25 to 3% manganese, about 1 to 2.5% silicon, about 0.5 to 2% aluminium, about 0.5 to 3% molybdenum, about 1–3% copper and about 0.2 to 1% vanadium, the remainder being essentially iron.

2. A steel according to claim 1 which contains 1 to 2% silicon.

3. A steel according to claim 1 which contains 1 to 2.5% copper.

4. A steel according to claim 1 which contains 0.2 to 0.5% carbon.

5. A method of making a high strength heat treated alloy steel comprising the steps of soaking a steel alloy consisting essentially of about 0.15 to 0.5% carbon, about 0.25 to 3% manganese, about 1 to 2.5% silicon, about 0.5 to 2% aluminium, about 0.5 to 3% molybdenum, about 1–3% copper and about 0.2 to 1% vanadium, the remainder being essentially iron, at a soaking temperature higher than the AC_3 transition temperature of said alloy, quenching the alloy, and tempering the quenched alloy at a temperature of up to about 650° C.

6. A method of making a high strength heat treated alloy steel according to claim 5 wherein the quenched alloy is tempered at a temperature of up to 550° C.

7. A method of making a high strength heat treated alloy steel according to claim 5 wherein the quenched alloy is tempered at a temperature of at least 500° C.

8. A method of making a high strength heat treated alloy steel according to claim 5 comprising the further step of nitriding the tempered alloy at a temperature lower than said tempering temperature.

9. A heat-treated high tensile medium carbon alloy steel having a structure which is essentially tempered martensite and consisting essentially of about 0.15 to 0.5% carbon, about 0.25 to 3% manganese, about 1 to 2.5% silicon, about 0.5 to 2% aluminium, about 0.25 to 3% molybdenum, about 1 to 3% copper, and about 0.2 to 1% vanadium, the remainder being essentially iron.

References Cited

UNITED STATES PATENTS

1,896,889	2/1933	French	148—16.6
3,070,438	12/1962	Kenneford	75—125

FOREIGN PATENTS

386,665	1/1933	Great Britain.

DAVID L. RECK, *Primary Examiner.*

P. WEINSTEIN, *Assistant Examiner.*