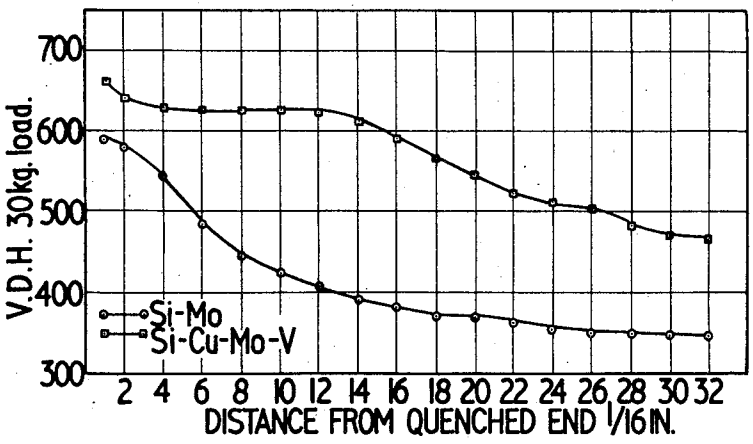
Dec. 25, 1962 A. S. KENNEFORD 3,070,438

HEAT TREATED ALLOY STEELS

Filed May 21, 1959 5 Sheets-Sheet 1

FIG. 1



EFFECT OF 2% Cu & 0.19% V. HARDENABILITY OF Si-Mo STEEL.

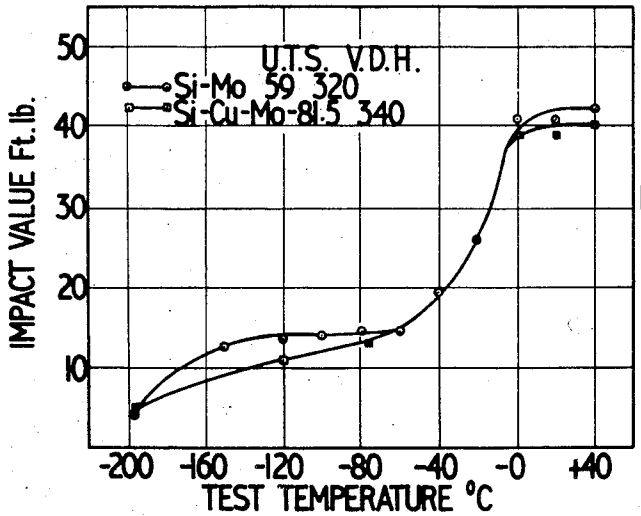


FIG. 6.

EFFECT OF TEMP. ON CHARPY IMPACT VALUE OF Si-Mo & Si-Mo-V STEELS. WATER QUENCHED 970° C. TEMPERED 700° C WATER QUENCHED.

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HEAT TREATED ALLOY STEELS

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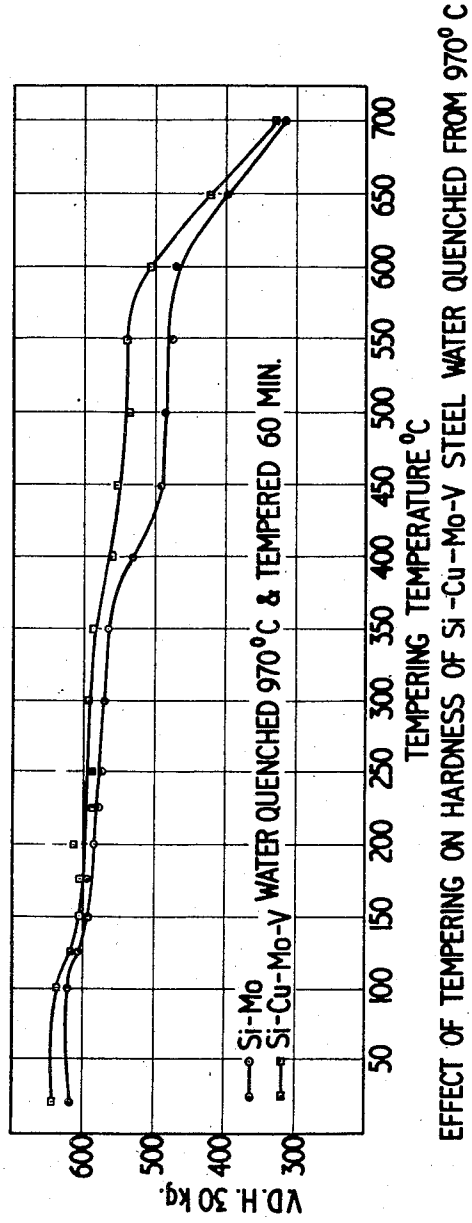


FIG. 2.

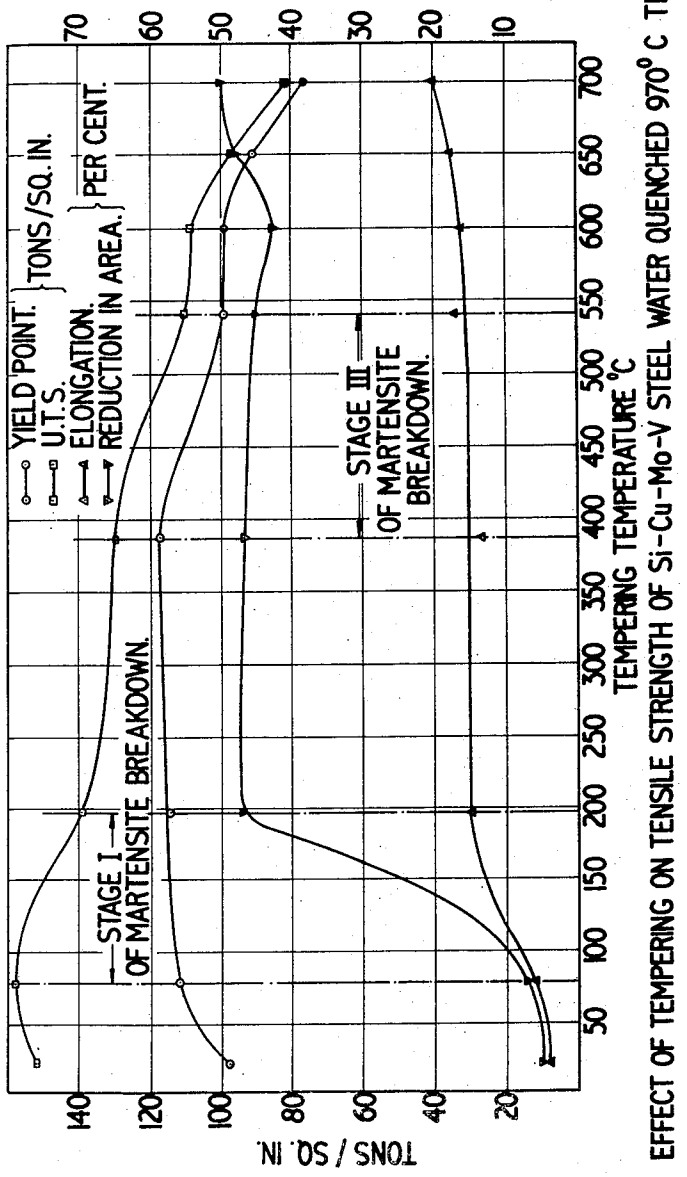
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HEAT TREATED ALLOY STEELS

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FIG. 3.



EFFECT OF TEMPERING ON TENSILE STRENGTH OF Si-Cu-Mo-V STEEL WATER QUENCHED 970° C TIME 1 HOUR.

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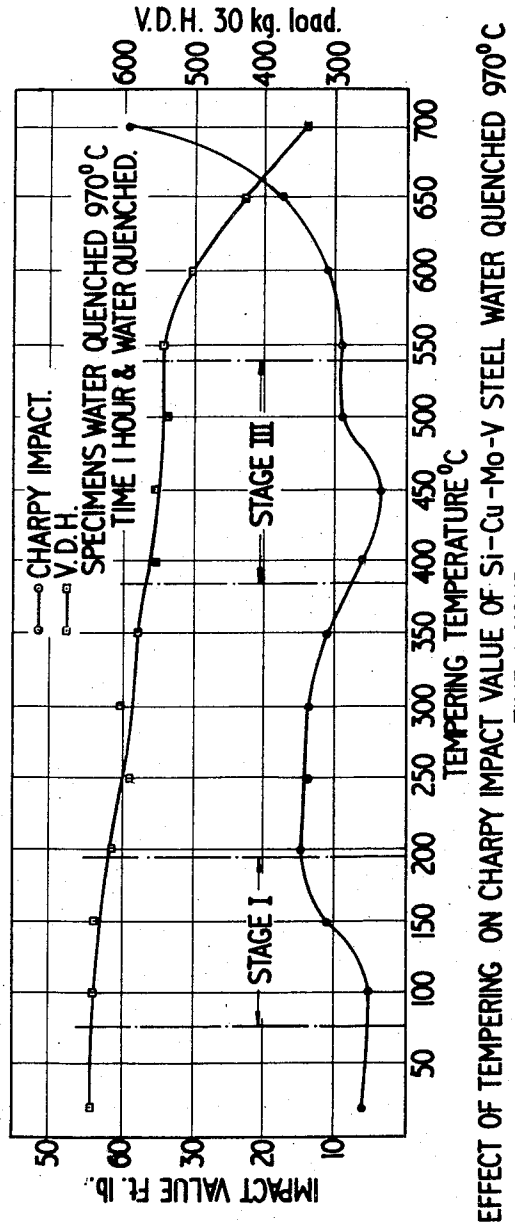


FIG. 4.

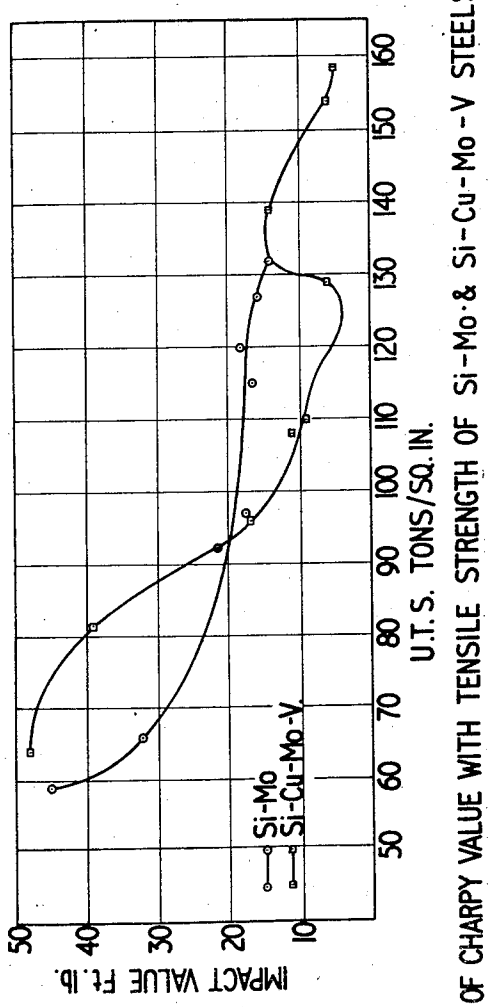
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HEAT TREATED ALLOY STEELS

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FIG. 5.



VARIATION OF CHARPY VALUE WITH TENSILE STRENGTH OF Si-Mo & Si-Cu-Mo-V STEELS.

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HEAT TREATED ALLOY STEELS

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Claims priority, application Great Britain May 22, 1958
4 Claims. (Cl. 75—125)

This invention relates to high-tensile alloy steels which are heat-treated by quenching followed by tempering or drawing.

It is concerned with the production of heat-treated steels of high tensile strength which are resistant to softening on tempering and quench cracking.

The invention provides new alloy steels having advantageous properties, in particular because they have high permissible tempering temperatures for a given tensile strength. 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 level. The use of higher tempering temperatures permits the steel to be subsequently used at higher temperatures and to be post-heated to higher temperatures for such purposes as welding, surface treatment and hydrogen removal.

The present invention provides an improved medium-carbon manganese steel having a carbon content of between 0.1 and 0.5% and a manganese content in the normal proportions to increase hardenability usually in the region of ½ to 1% but possibly up to about 3%.

In accordance with the invention an improved heat-treated medium-carbon manganese alloy steel contains about 1–2½% silicon, about ½ to 3% molybdenum and about 1–3% copper. Nickel and chromium and other impurities including the common non-metallic impurities may be present in the small proportions usual in commercial steels.

The molybdenum content is preferably between about 1 to 1½% and as the content increases above 2%, although there is no loss of tensile strength, the impact strength diminishes.

The copper content is preferably not more than 2 or 2½% as although there is a little improvement in hardenability as the copper content increases beyond 2% there may be copper segregation during the steel manufacture if these higher proportions are used.

The temperature of tempering or drawing specimens of these new alloy steels of a given tensile strength may be increased by incorporating into the steel, in addition to the molybdenum already present, a small amount of the order of about 1% of other carbide-forming element or elements such as vanadium, chromium, tungsten, titanium tantalum and niobium. Vanadium may be added in proportions up to about 1%, raising the temperature of tempering of these steels having a given tensile strength by the order of 100° C. with little effect on other properties. The preferred vanadium addition is about 0.2–0.3% as the effect decreases rapidly below about 0.2% and increases only slowly above about 0.3%.

It is possible to temper or draw at temperatures over 600° C. silicon-molybdenum-copper-vanadium alloy steels which have an ultimate tensile strength of more than 100 tons sq. in. An example of such a steel has a carbon content of about 0.3%, a silicon content of about 1½–2%, a molybdenum content of about 1% and a vanadium content of about 0.25%.

The properties of alloy steels in accordance with the invention will now be more fully described by the following results of tests carried out on various alloy steels by way of example.

Reference will be made to the accompanying drawings in which:

FIGURE 1 is a graph showing the hardenability of a silicon-molybdenum-copper-vanadium steel and a silicon-molybdenum steel;

FIGURE 2 shows the effect of tempering on the hardness of a silicon-copper-molybdenum-vanadium steel water quenched from 970° C.;

FIGURE 3 shows the effect of tempering on the tensile strength of a silicon-copper-molybdenum-vanadium steel water quenched at 970° C.;

FIGURE 4 shows the effect of tempering on the Charpy impact value of a silicon-copper-molybdenum-vanadium steel water quenched at 970° C. and tempered for 1 hour;

FIGURE 5 shows the variation of the Charpy impact value with tensile strength of silicon-molybdenum and silicon-copper-molybdenum-vanadium steel; while

FIGURE 6 shows the effect of temperature on Charpy impact values of silicon-molybdenum and silicon-copper-molybdenum-vanadium steels.

A high-frequency melt of a steel for experimental testing was obtained in the form of hot rolled ¾ in. diameter bars having the percentage composition 0.37 carbon, 2.16 silicon, 0.51 manganese, 0.022 sulphur, 0.036 phosphorus, 0.82 molybdenum, 0.19 vanadium, 1.85 copper. Residual nickel and chromium were each below 0.1%.

The temperatures of the critical range (α-γ transformation) and of the two stages of martensite breakdown were determined dilatometrically. The results, together with values of the volume changes accompanying the transformations, are shown below.

α-γ Transformation			Martensite Breakdown		
Temperature, ° C.		Volume Change, Percent	Temperature, ° C.		Volume Change, Percent
AC_1	AC_3		Stage I	Stage III	
768	805–895	0.067	77–195	383–540	0.37

These figures show the usual low transformation volume change and high martensite breakdown temperatures associated with silicon steels. Comparison with a silicon-molybdenum steel of similar carbon content shows that the end temperature of the third stage of martensite breakdown has been raised some 40° C. by the addition of 2% copper.

The hardenability of the test steel was determined under standard and quench conditions (S.A.E. Handbook 1947) after a soak of one hour at 970° C. in a controlled atmosphere. The results obtained are shown in FIGURE 1, which also include values for a comparable silicon-molybdenum steel.

The difference in initial hardness between the two steels is accounted for by a slight difference in carbon content which will also have affected the hardenability to some extent. The effect of the carbon content (0.37% for the Si—Cu—Mo—V steel against 0.31 for the Si—Mo steel) is not otherwise of great significance. These results illustrate that the presence of 2% copper and 0.19% vanadium increase the hardenability of silicon-molybdenum steels markedly, and to a far greater extent than would have been expected judging from their effect on plain carbon steels.

The effect of tempering on hardness of the experimental Si—Cu—Mo—V steel was determined by soaking samples of ¾ in. diameter bar material for 1 hour at 970° C. in a protective atmosphere and water quenching. Then after normal preparation of a cross-sectional face, Vickers diamond impressions were made along two mutually perpendicular diameters on the material in the quenched state, and after tempering for 1 hour at various temperatures up to 700° C. These results are shown plotted in FIGURE 2 which illustrates clearly the remarkable resistance of the new alloy steel to tempering (for 1 hour periods) at temperatures up to 600° C., and the superior result obtained by the presence of copper and vanadium in addition to silicon and molybdenum in the steel.

The effects of the separate alloying elements on the hardness of a 0.3% carbon steel after tempering for 1 hour show that the increase in hardness caused by the combination of the alloying elements in the one steel is at least equal to the sum of the increases brought about by the separate additions.

Tensile tests were carried out on Hounsfield No. 11 specimens (1/80 sq. in. cross-section) and consequently the values which will be given for elongation and reduction of area may be slightly higher than those which would have been obtained from normal sized test pieces.

Test pieces were heat-treated in the form of cylindrical blanks 0.284 in. diameter x 1 in. long, and were water quenched after soaking for 1 hour at 970° C. followed by tempering for 1 hour at the required temperature. Duplicate tensile test pieces were then wet ground to finish size from these blanks.

The results obtained are shown in FIGURE 3 and show that the presence of 2% copper and 0.19% vanadium in addition to the silicon and molybdenum in the alloy steel had a markedly beneficial effect on the tensile strength and yield ratio obtainable by quenching and tempering, and that the resultant steel had outstanding properties after being tempered at temperatures as high as 600° C. The yield ratio of the material after tempering at 385° C. or above was also exceptionally high.

The effect of tempering on the Charpy impact value (Standard Izod Notch) is shown in FIGURE 4. The Charpy blanks were heated at 970° C. for 1 hour in a controlled atmosphere, quenched, and tempered at the requisite temperature for 1 hour, followed by wet grinding to final dimensions (10 x 10 x 56 mm.). The efficacy of the heat treatment was checked by hardness measurements on each specimen before any impact testing was done.

These results show that the copper and vanadium additions reduced the Charpy impact value of the steel particularly in the tempering range 400–550° C. This range of tempering temperature is that over which copper is precipitated from solution, according to dilatometric measurements which have been carried out. From these experiments, it has been shown that copper precipitation commenced around 400° C. under continuous heating at a rate of 2.5° C./min. and continued to some temperature over 600° C. which may be as high as 645° C.

Table I and FIGURE 5 show the variation of Charpy impact values with tensile strength for silicon-molybdenum and silicon-molybdenum-copper-vanadium steels, and illustrates that the Charpy impact value of the copper and vanadium bearing steel at a tensile strength of 140 tons/sq. in. was about the same as that of the copper free steel at a tensile strength of 130 tons/sq. in. The ductility of the copper-vanadium material at this high tensile strength was also better than that of the copper free steel.

For a range of tensile strengths between 130 tons/sq. in. and 96 tons/sq. in., however, the Charpy impact values of the silicon-copper-molybdenum-vanadium steel were considerably inferior to those of the silicon-molybdenum steel. For tensile strengths below 96 tons/sq. in., the reverse situation applied.

Table I

Tempering Temp., ° C.	Si-Cu-Mo-V Steel		Si-Mo Steel	
	Impact, Ft. lb.	U.T.S., Tons/in.²	Impact, Ft. lb.	U.T.S., Tons/in.²
As quenched	6.0	154.2	14.3	132
Start Stage I	5.1	158.2	15.0	----------
End Stage I	14.5	139.2	18.0	119.7
Start Stage III	5.8	129.2	16.6	114.6
End Stage III	9.0	110	17.5	97.2
600	10.8	108.4	21.7	92.6
650	16.8	96	32.1	74.6
700	38.7	81.5	45.4	58.9
750	47.3	65.5	----------	----------

For the quarternary alloy stage I was from 77°–195° C. while for the Ci—Mo alloy stage I was from 75°–220° C. Stage III was from 383°–540° C. for the quaternary alloy and from 353°–502° C. for the Si—Mo alloy.

Tests at temperatures from +80° to −196° C. were carried out on Charpy impact test pieces water quenched from 970° C., tempered for 1 hour at 700° C., and water quenched from tempering temperature to avoid any possible temper brittleness in the material.

The results obtained are shown in FIGURE 5, and demonstrate that the impact transition temperature of the copper-vanadium bearing steel was the same as that of the silicon-molybdenum steel. For the same tempering temperatures (700° C.), however, the tensile strength of the test Si—Cu—Mo—V steel was 81.5 tons/sq. in., whereas that of the comparable silicon-molybdenum steel was 59 ton/sq. in.

From FIGURE 6 it will be seen that in each case the mean energy transition temperature is around −10° C., whilst the 20 ft. lb. transition temperature is at approximately −40° C.

The results show that a 0.37% carbon alloy steel produced according to the invention is capable of being heat-treated to a tensile strength of 140 tons/sq. in. with a reduction of area of 47% and a Charpy impact value of 14.5 ft. lb.

Even after tempering at 600° C. the tensile strength was 108 tons/sq. in. whilst after a 700° C. temper, it had dropped only to 81.5 tons/sq. in., the yield ratio in each case being extremely high, and the ductility as measured by the reduction of area being in the region of 45%.

The tensile strength and ductibility of the silicon-molybdenum-copper steels is largely dependent upon the carbon content. For comparison with the results already given in FIGURE 3 for a 0.37% carbon alloy steel, results are given in Table II for a 0.23% carbon steel containing 1.14% silicon, 0.33% manganese, 1.08% molybdenum, 0.24% vanadium, and 1.48% copper.

Table II

Tempering Temp., ° C.	0.1% P.S.	U.T.S.	E.	R.A.
	Tons/sq. in.		percent	
as quenched	56.2	102	17	55
100	61.2	101	20	53
200	73.3	98	20	56
400	72.5	89	18	57
515	76.2	88	20	54
600	83.7	89.5	18	56
650	77.3	81.2	20	56
700	63.5	69.5	22	60

It will be seen that a reduction in carbon content reduces the tensile strength and increases the ductility while the results shown in Table II demonstrate that there is increased resistance to softening on tempering, especially in the range from about 400° to 600° C. due to the increase in molybdenum and vanadium content.

Results of tests on thee ffects of various alloying elements on the fatigue properties of a steel containing

0.30% carbon, show that this new type of steel possesses high endurance limit and endurance ratio for a given tensile strength. Both major alloying elements are ferrite soluble, and with the high tempering temperatures permissible, internal stress remaining after heat-treatment should be almost entirely eliminated.

These new alloy steels have a wide field of use for structures where a high strength to weight ratio is required such as in aircraft and airborn missiles. Particular uses by way of examples are as a material for aircraft undercarriages and control rods. When the alloy steel is used at normal temperatures and very high strength is required the tempering temperature may advantageously be less then 300° C.

The new alloy steels when tempered at temperatures over 500° or 600° C. may still have high tensile strength and when these steels have ben so tempered they may be advantageously used at high temperatures, for example as engine components, or as structural materials for supersonic aircraft or missiles.

I claim:

1. A high strength heat treated medium carbon steel consisting of about 0.1–0.5% carbon, about 0.3–3.0% manganese, about 1.0–2.5% silicon, about 0.5–3.0% molybdenum, and about 1.0–3.0% copper, the balance being essentially iron.

2. A steel according to claim 1 wherein the molybdenum is present to the extent of about 1.0–2.0%, and the copper is present to the extent of about 1.0–2.5%.

3. A steel according to claim 1 consisting further of up to about 1.0% of a carbide-forming element from the group consisting of tungsten, titanium, tantalum, niobium, chromium, and vanadium.

4. A steel according to claim 3 wherein vanadium is present to the extent of about 0.2–0.3%.

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