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STEEL ROLL COMPOSITION

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The invention relates to rolls for use in hot-mills; that is, mills for the hot rolling or hot forming of strips, sheets, and other things of ferrous metals. More specifically the invention lies in a steel composition which is particularly susceptible to the well-known nitriding process, whereby a roll forged of such steel may be provided with a surface which is especially efficient in such service. The method of heat treating and nitriding the steel, to provide a roll or other metal-shaping tool of superior characteristics, also finds place in the invention.

According to present practice, it is customary to employ chilled cast iron rolls in hot-mills, or to use quenched and tempered steel rolls. The metal grain structure of rolls of each of these types is unstable at the temperatures developed in the roll body during service. Such instability is particularly to be found in the working faces of the rolls. In endeavoring to overcome this objection, recourse has hitherto been had to water cooling; that is to say, the rolls were hollow cast, or channeled, and provided with a circulation of cooling water.

The surface of a roll in contact with the hot metal being rolled becomes exceedingly hot, and such heat, together with the rolling pressures, tends to destroy the roll. This objection has been encountered for years in the hot rolling of mild steels, and it will be understood that, with the relatively recent advent of alloy steels for structural parts, the rolls are subjected to increased roll-operating pressures and temperatures. That is to say, in rolling alloy steels, greater stresses are developed in the rolls, resulting in cracking, distorting, surface scoring, and other roll defects. Thus, the problems confronting the operators have increased, and the maintenance of hot-mills has been rendered more difficult. Cast steel rolls, and water-cooled forged steel rolls have failed to meet the requirements of to-day, and an improved roll material is much needed in the art—a material providing stability at the temperatures developed during hot rolling, as well as adequate physical strength and abrasive hardness.

The object of my invention is to provide an alloy steel which is particularly adapted to receive a nitride hardened surface, and which will provide a roll of structural, physical, and chemical stability at the temperatures and pressures developed during hot rolling. I aim to provide a material having permanent hardness and wear-resisting characteristics.

An alloy steel having the following analysis has

been found to provide advantages of the nature indicated:

Carbon	.50 to .85 per cent	
Chromium	3.5 to 8.0 per cent	
Vanadium	.30 to 1.00 per cent	5
Molybdenum	.80 to 1.20 per cent	
Silicon	.10 to .20 per cent	
Sulphur	.04 per cent. maximum	
Phosphorus	.04 per cent. maximum	10
Remainder	iron	

Of course, the silicon, sulphur and phosphorus constituents of the alloy may be varied in accordance with usual open-hearth or electric practice.

Possibly the carbon and chromium proportions may be varied to either side of the ranges specified, and still provide a composition of superior quality, although, for the best results, I have found that these elements should be within the specified ranges. The elements of the alloy steel with which I am particularly concerned are vanadium and molybdenum.

The steel best suited for the practice of the invention includes carbon .70%, chromium 5.5%, vanadium .60%, and molybdenum 1.10%.

Good results are obtained in using a composition in which the ingredients include carbon .50%, chromium 3.5%, vanadium .35%, and molybdenum .80%. It may be said of this formula, however, that the steel does not have so high a resistance to shocks, nor such thermal and chemical stability under operating conditions, as the roll made of steel of the preferred formula noted above.

A steel including carbon .85%, chromium 7.5%, vanadium .75% and molybdenum 1.20% also was found to give good results, but not to the same high degree that such results are obtained when the carbon lies between .50 and .80%, chromium between 4.0 and 5.5%, vanadium between .45 and .60%, and molybdenum between .90 and 1.10%.

A steel including carbon .40%, chromium 3.0% vanadium .25%, and molybdenum .70%, was found to be unsatisfactory. Steel including the ingredients in such proportions did not have adequate strength; it changed structurally at rolling temperatures; and fissures and exfoliation appeared in the surface of the steel. In another case I found that steel including carbon 1.0%, chromium 9.0%, vanadium 1.0%, molybdenum 1.25% was unsatisfactory. The grain structure of such steel was coarse, and the steel was of a brittle nature at relatively low temperatures, this characteristic being known as blue brittleness. It is well known that the molybdenum content of

the steel tends to counteract the chromium content which produces the blue brittleness, but when the chromium exceeds 8.0% the molybdenum is ineffective to neutralize its objectionable effect.

A steel made and treated in accordance with my invention will give the desired service in hot-rolling practice, or in any other severe hot-forming operation. In making a roll of such steel I proceed as follows: First, the roll is forged according to well known methods, and then it is annealed. After annealing it is reheated to from 1600 to 1675 degrees Fahrenheit (between 1600° F. and 1650° F. is preferred), and then it is quenched in oil. During the quenching the roll-necks are muffled in a manner well known to the art, to keep them at a relatively low degree of hardness. The chilling in the quenching bath is interrupted when the roll reaches a temperature of from 300 to 600 degrees Fahrenheit (between 350° F. and 500° F. is preferred), and immediately tempering is performed at from 800 to 1100 degrees Fahrenheit. I have found it desirable to conduct the tempering for a period of two hours, so as to give the faces of the roll body a Brinell hardness of from 475 to 525, and a Scleroscope hardness reading of from 68 to 75. Manifestly, the duration of the tempering is varied in accordance with the weight and diameter of the rolls, two hours being the approximate tempering interval for a roll 8 inches in diameter.

The roll-necks are kept at from 375 to 400 Brinell hardness, and from 56 to 60 Scleroscope hardness.

After tempering, the rolls are subjected to an atmosphere of ammonia, and therein they are maintained at a temperature of from 850 to 900 degrees Fahrenheit. This is known as the nitriding step, and the time of nitriding is about fifteen hours. The nitriding process is conducted in accordance with the teachings of Adolf Machlet and Adolf Fry, well known investigators of the nitriding process. Inasmuch as I do not concern myself with the nitriding process, other than to the extent herein disclosed, I shall not dwell particularly upon the nitriding of the rolls, for, as said, Fry, as well as others before and after him, have disclosed the principles of the nitriding process to the art.

As a result of the nitriding, I provide on the roll of my composition a permanent surface hardness of approximately 1000 Brinell reading, to a depth of approximately .02 of an inch.

Rolls made in accordance with this method and of the above-described composition are found to retain their hardness, and to resist frictional wear and highly-concentrated surface straining. Otherwise expressed, the thermo-physical-chemical characteristics of the rolls are, during hot-rolling service, stable up to and beyond the heat or temperatures developed in the roll bodies, and the temperatures which are developed at the surfaces of the rolls. The aggregate grain structure of the rolls is of physical and chemical permanence or stability at the temperatures and pressures to which the rolls are subjected. By "aggregate grain structure" I means the relation of the grains as a unit—the positions of the grains of the metal with respect to each other, and when I say that the aggregate grain structure is physically and chemically permanent or stable, I mean that the relative positions and the physical and chemical char-

acteristics of the grains of the metal remain practically unchanged.

Chromium and vanadium are present in the composition to preserve the physical strength and structural uniformity of the metal at elevated temperatures; the chromium and vanadium are valuable in producing stabilization of the core or base metal, in addition to their usual strength-inducing characteristics. Chromium and vanadium are the elements which, during the forging and heat-treating operations, limit the grain size of the metal. Chromium and vanadium are of value in maintaining the desired grain structure of the metal during the forging of the ingot, and up to and until the roll has been completely prepared for service.

While vanadium is of great value in the above-mentioned capacity, it is also of value in still another capacity; it serves not only for the prevention of grain growth, as a toughening agent, and as an element which lessens the temper brittleness of the steel, but it also acts as a hydrogen reactivity neutralizing agent, during the nitriding process.

It will be understood that in the nitriding process the heated rolls are subjected to ammonia. The ammonia breaks up into its components, nitrogen and hydrogen, and nascent nitrogen is thus provided. The nitrogen combines chemically with certain alloys of the steel. In this case I have reason to believe that the nitrogen combines with the molybdenum, forming molybdenum nitride. There is a possibility that the molybdenum nitride may form a solid solution with alpha iron, or may combine with iron or other elements of the steel, to provide complex molybdenum nitrides, which form the exceedingly hard and stable surface desired for the rolls. The nitriding of the metal is the action desired, but unfortunately, the hydrogen which is also liberated upon the breaking down of the ammonia, tends to impede the nitriding action. The free hydrogen characteristically decarburizes the steel, attacks the nitride case formed on the steel and in general impedes or interferes with the process.

I am not prepared to say positively how the vanadium in my composition acts to restrain catalytically the undesired activity of hydrogen, but I can and do say that rolls made in accordance with this specification have an internal grain structure which is stable at hot-mill temperatures and rolling pressures, and evidence a nitrided surface which is adequate to withstand the extreme conditions of hot-mill service, whereas the nitrided steel rolls tried in service hitherto have not evidenced such stability of grain structure nor durability of surface as to admit of their general use in the art. In endeavoring to account for the superiority of my product, I shall state what I have reason to believe occurs during the nitriding process. In the case of the steels nitrided hitherto, it is thought that the hydrogen liberated during the nitriding process tends to combine with the chromium and other hydride-forming ingredients of the steel, to form stable metallic hydrides which are probably deposited along the grain boundaries of the metal. Such metallic hydrides produce brittleness which causes the surface of the steel to crack and spall in service. In addition to this objection, the activity of the hydrogen in slowly forming stable metallic hydrides seems to retard or inhibit the activity of nitrogen in combining with molybdenum and the other nitride-forming elements in

the steel, to provide the desired metallic nitrides.

It seems that the liberated hydrogen has greater affinity for the vanadium than for the other alloying elements of the steel, and that in the nitriding of my steel the hydrogen is relatively quickly absorbed to form vanadium hydride, thereby increasing the effectiveness of the nitrogen for the formation of the desired metallic nitrides. The vanadium hydride thus formed during the nitriding process is an unstable hydride, that is, the hydrogen is given up by the vanadium when the process is completed and the steel allowed to cool. It will be understood, therefore, that apparently during the nitriding process the hydrogen is quickly absorbed to form unstable vanadium hydride, thus preventing in greater degree the formation of the undesired stable metallic hydrides, and enhancing the action of nitrogen in forming the desired metallic nitrides. It may be, however, that the hydrogen is adsorbed by the vanadium, so that the hydrogen becomes inert, and thus does not interfere with activity of nitrogen in forming the desired metallic nitrides.

As indicated above the molybdenum is the element which I believe has the greatest affinity for nitrogen, and accordingly, molybdenum nitride is the primary metallic nitride formed in the surface of the roll. Naturally there is a tendency to form complex nitrides, analogous to carbide formations and complex alloy carbides formed in certain alloy steels; nevertheless, the potent nitriding element is molybdenum, and molybdenum nitride is the primary hardening compound formed, to produce the characteristics desired in rolls for hot-mills. The nitrided steel also finds application in guides, dies, punches and other tools and machine parts employed in the hot working and shaping of metal.

It may be repeated that chromium and vanadium are the most effective elements for limiting the grain size of the metal, and, consequently, are the strength-inducing alloys. In addition to the characteristics above mentioned, I have found that the steel is of a corrosion-resisting nature, both at room temperature and at elevated rolling temperatures.

This application constitutes in part a continuation of application Serial No. 563,359, filed September 17, 1931.

I claim as my invention:

1. As a new article of manufacture, a machine part forged of a ferrous body containing carbon from .55 to .70 per cent., chromium above 4.0 and below 5.5 per cent., vanadium from .45 to .60 per cent., and molybdenum from .90 to 1.10 per cent., said machine part having a nitride-hardened surface.

2. A hot-mill roll of physical and chemical stability at the pressures and temperatures incident to and developed during the hot rolling of metal, which roll comprises a heat-treated forging of a ferrous body containing carbon from .55 to .70 per cent., chromium above 4.0 and below 5.5 per cent., vanadium from .30 to .60 per cent., and molybdenum from .90 to 1.10 per cent., said forging having a nitride-hardened surface.

3. A machine part of physical and chemical stability at the pressures and temperatures incident to and developed during the hot working of metal, which part comprises a heat-treated forging of steel containing carbon from .50 to .85 per cent., chromium above 4.0 and below 8.0 per cent., vanadium from .30 to .70 per cent., molybdenum from .80 to 1.20 per cent., and the principal

portion of the remainder iron, said forging have a nitride-hardened surface.

4. A hot-mill roll of physical and chemical stability at the pressures and temperatures incident to and developed during hot rolling, which roll comprises a ferrous body containing carbon from .50 to .85 per cent., chromium above 4.0 and below 8.0 per cent., vanadium from .30 to .70 per cent., and molybdenum from .80 to 1.20 per cent., said roll being further characterized as a heat-treated forging having a nitrided surface which includes within practical limits a maximum of metallic nitrides, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said forging.

5. A hot-mill roll of physical and chemical stability at the pressures and temperatures developed during hot rolling, which roll comprises a ferrous body containing carbon between .50 and .85 per cent., chromium above 4.0 and below 8.0 per cent., molybdenum between .80 and 1.20 per cent., and vanadium between .30 and 1.00 per cent., said roll being further characterized as a heat-treated forging having a nitrided surface which includes within practical limits a maximum of metallic nitrides, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said forging.

6. An article of manufacture formed of a ferrous body containing carbon between .50 and .85 per cent., chromium above 4.0 and below 8.0 per cent., molybdenum between .80 and 1.20 per cent., and vanadium between .30 and 1.00 per cent., said article being further characterized as an annealed, reheated, quenched, and tempered forging having a stabilized grain structure, and having a nitrided surface including within practical limits a maximum of metallic nitrides, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said surface.

7. A machine part or tool comprising a ferrous body containing carbon above .40 and below 1.00 per cent., chromium above 4.0 and below 9.0 per cent., molybdenum between .80 and 1.20 per cent., and vanadium between .30 and 1.00 per cent., said machine part being further characterized as a heat-treated forging having a nitrided surface which includes within practical limits a maximum of metallic nitrides, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said forging.

8. A machine part or tool comprising a ferrous body containing carbon above .40 and below 1.00 per cent., chromium above 4.0 and below 9.0 per cent., molybdenum between .80 and 1.20 per cent., and vanadium between .30 and 1.00 per cent., said machine part being further characterized as an annealed, reheated, quenched, and tempered forging having a stabilized grain structure, and having a nitrided surface in which within practical limits a maximum of metallic nitrides is included, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said forging.

9. A hot-mill roll of physical and chemical stability at the pressures and temperatures incident to and developed during hot rolling, which roll comprises a ferrous body containing carbon above .40 and below 1.00 per cent., chromium above 4.0

and below 9.0 per cent., vanadium between .30 and 1.00 per cent., and molybdenum between .80 and 1.20 per cent., said roll being characterized as a forging which has been annealed, reheated to 5 from 1600° to 1675° F., quenched to from 300° to 600° F., and tempered between 800° and 1100° F., said forging having a nitrided surface which includes within practical limits a maximum of metallic nitrides, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said forging.

10 10. A machine part or tool formed of a ferrous body containing carbon between .50 and .85 per cent., chromium above 4.0 and below 8.0 per cent., 15 molybdenum between .80 and 1.20 per cent., and vanadium between .30 and 1.00 per cent., said roll being characterized as a forging which has been annealed, reheated to a temperature from 1600° 20 to 1675° F., quenched from substantially the temperature of reheating to a temperature ranging from 300° to 600° F., and tempered between 800° and 1100° F., said forging having a nitrided surface which includes within practical limits a

maximum of metallic nitrides, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said forging.

5 11. A machine part or tool formed of a ferrous body containing carbon above .40 and below 1.00 per cent., chromium above 4.0 and below 9.0 per cent., molybdenum between .80 and 1.20 per cent., and vanadium between .30 and 1.00 per cent., 10 said machine part being further characterized as a forging which has been annealed, reheated to a temperature of from 1600 to 1675° F., quenched to a temperature between 300° and 600° F., and 15 tempered between 800° and 1100° F., said forging having a stabilized grain structure and having a nitrided surface in which within practical limits a maximum of metallic nitrides is included, due to the vanadium which is present in the ferrous body in sufficient quantity to counteract the objectionable activity of hydrogen during the nitriding of said forging. 20

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