Sept. 29, 1970 TADASHI SHIMEGI ET AL 3,530,703
QUENCH HARDENED ROLL OF FORGED STEEL CONTAINING COBALT
Filed June 10, 1966

FIG.1

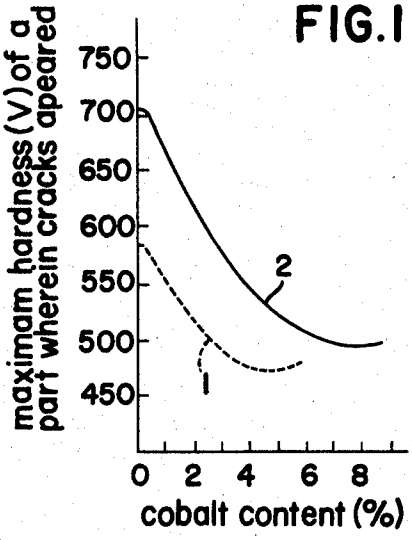


FIG.2

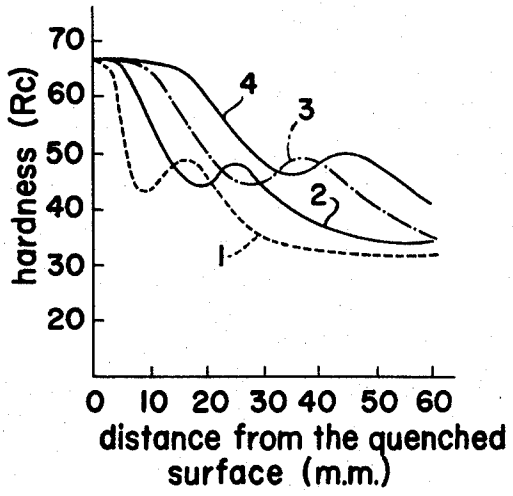


FIG.3

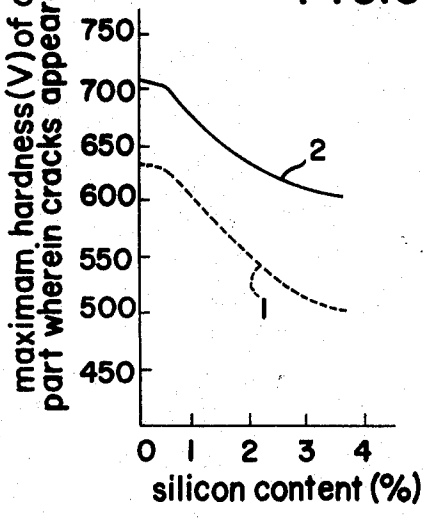


FIG.4

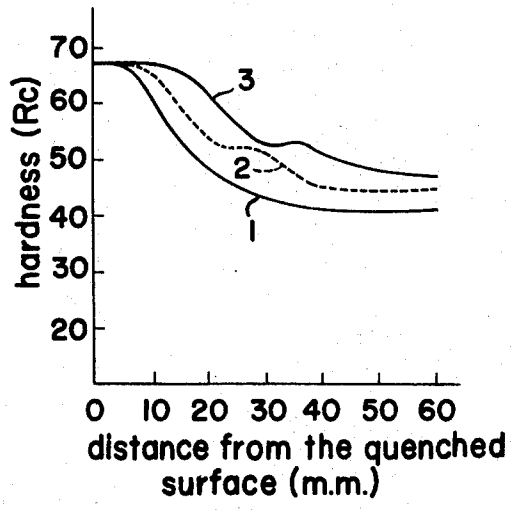
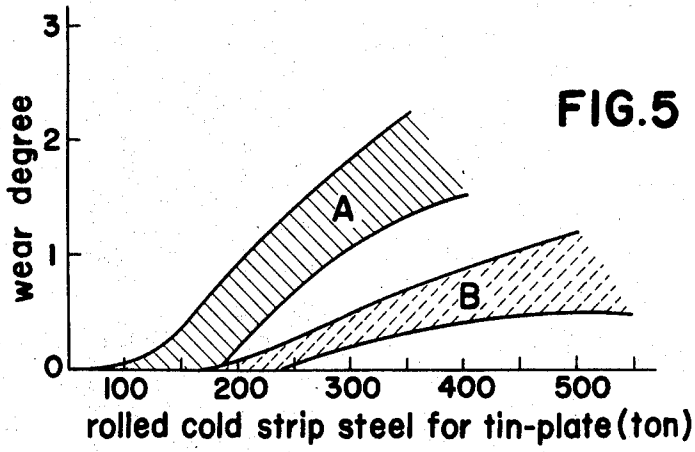


FIG.5



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3,530,703

QUENCH HARDENED ROLL OF FORGED STEEL CONTAINING COBALT

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Continuation-in-part of application Ser. No. 246,788, Dec. 24, 1962. This application June 10, 1966, Ser. No. 556,753

Int. Cl. B21b 1/00; C21d 9/38

U.S. Cl. 72—366 3 Claims

ABSTRACT OF THE DISCLOSURE

A method for cold rolling of metals utilizing a roll composed of roll steel having improved resistance against cracks and wear, a hardness of above Vickers hardness No. 700, and prepared by forging a roll steel consisting of 0.60 to 1.30% C., 0.25 to 3.50% Si, 0.15 to 1.60% Mn, 1.00 to 3.50% Cr, 0.30 to 8.0% Co, and the balance iron and impurities, and quenching the surface thereof.

This application is a continuation-in-part of application Ser. No. 246,788 filed Dec. 24, 1962, now abandoned.

The present invention relates to improvements in rolls for cold rolling, and particularly to forged steel hardened rolls for cold rolling, whose steel has improved resistance against crack and wear. In the production of sheets or strips of steel or nonferrous metals, a slab is generally hot rolled into a plate having a thickness of about 3 mm. To obtain a plate of less thickness than 3 mm., it is subjected to cold rolling, by which a tinplate can be rolled up to a thickness below 0.3 mm.

The modern cold rolling strip mill employs a hardened roll of forged steel having high hardness and wear resistance to meet the requirement that its rolling pressure is extremely high so as to effect heavy reduction and to produce the beautifully finished surface of the strip. This conventional roll is given high hardness by hardening, so that its portion is subjected to the heat generated by miss-rollings during cold rolling operation and tempered with the result that the hardness is lowered and crazy cracks appear. The cracks are developed due to rolling pressure until spallings occur. The conventional roll is very poor in crack-resistance.

Steel to be used for conventional rolls consists, in general, of 0.6 to 1.3% C, 0.25 to 0.50% Si, 0.15 to 1.60% Mn and 1.00 to 3.50% Cr, to which less than 2% each of Mo, V, W and Ni are often added. We have found that by adding Co or Co plus Si to the conventional roll steel, its crack-resistance and wear resistance is markedly improved.

A molten steel consisting of 0.60 to 1.30% C., 0.25 to 3.50% Si, 0.25 to 1.60% Mn, 1.00 to 3.50% Cr, 0.3 to 8.0% Co, and the balance iron and impurities is prepared by means of the basic electric furnace or acid open hearth. To the above steel components, less than 2% of a substance or more selected from the group consisting of Mo, V, W, and Ni may be added if necessary.

The molten steel is cast in an ingot having a suitable shape and size. The ingot is forged into roll, then heated at 800–900° C. and annealed for a long time. The annealed roll undergoes rough machining. The roll thus treated is surface-heated at 800 to 990° C. above transformation point of AC_3 by means of an electric resistance furnaces or induction heating or gas flame, thereafter quench-hardened with a jet of water, aged at 100 to 300° C. (conventional rolls aged at 100 to 200° C.) and processed into the finished shape to be used as roll for cold rolling.

The roll of the present invention has the desired mechanical properties as a consequence of the above-mentioned forging and heat-treatment, and a fine structure through forging and also a beautifully finished surface, so that a sheet or strip cold-rolled by this roll is much improved in quality.

Due to very high hardness, the surface of the roll is much improved in its wear resistance so that it is fit for a long time to be used for cold rolling. Furthermore, the roll containing Co or Co plus Si more than conventional roll has much improved crack-resistance and wear resistance in performing the cold rolling.

The forged quenched steel roll which is used for cold rolling of various metals has risk of collapse and damage owing to the extremely high rolling pressure during the operation, and therefore it is required to have high surface hardness and suitable thickness of quenched hardened layer. On the other hand, since the qualities of the hardness and structure of the surface, it is required that the surface hardness is high and such defect as crazy cracks are prevented.

Hitherto generally in order to obtain this high surface hardness high carbon alloy steel containing 0.60 to 1.30% of carbon has been used as the material of roll and further 1.00 to 3.50% by weight of chromium has been added to it in order to distribute hard carbide through the matrix to give wear resistance, and small amount of nickel, molybdenum, vanadium and wolfram and as impurities silicon and maganese are obtained in order to give sufficient thickness of the quench hardened layer. According to our experiences steels of the following range of compositions are understood to have the faculty as the roll steel:

0.60 to 1.30% by weight of carbon,
0.25 to 0.50% by weight of silicon,
0.15 to 1.60% by weight of manganese,
1.00 to 3.50% by weight of chromium,
0 to 1% by weight of molybdenum,
0 to 0.5% by weight of vanadium,
0 to 1% by weight of wolfam, and
less than 0.8% by weight of nickel.

The amount of carbon is most important for the forged, quench hardened roll steel in order to obtain high hardness above Vickers hardness 700 and in case carbon content is out of range of 0.60 to 1.30% by weight it is difficult to obtain such hardness.

The both elements, manganese and nickel, are effective to improve hardenability, but as the quantity of residual austenite increases in accordance with the increase of the amount thereof, they function as minus for the hardness. The addition of molybdenum improves the hardenability of steel and has the effect to restrain the occurrence of residual austenite to some extent, effecting favorably on hardness. Cr, Mo, V and W have tendency to make easily carbides, and addition of these elements makes carbides harder, thereby to improve the wear resistance. The roll of these compositions will, however, causes cracks or spallings due to the heat generated by miss-rollings such as skidings, weldings and overlappings during rolling operation, and which hurt the surface of the roll barrel and enormously shorten the life of the roll.

As a cause of cracks, there is volume contraction originated from the precipitation of carbides from martensite at 250–520° C., when the quenched surface of roll barrel is tempered through partial heating. This volume contraction is called secondary contraction.

In accordance with the recent development of rolling mills for metals, rolls are being used under increasingly severe circumstances, and therefore more frequently crazy cracks and spallings are appeared on the surface of the rolls. Thus the manufacturing of the rolls without these

defects is earnestly required. As described above the cause of such cracks are generated by volume change at the time of tempering, and most of spalling originate from such cracks.

Now it seems to be possible to improve crack resistance by control of the composition and improvement of heat-treating method, but since the forged hardened roll for rolling thin strip is required to have both high hardness of above Vickers hardeness 700 and hardened depth of more than ½ inch, it is extremely difficult to improve crack resistance of such rolls. In order to improve crack resistance by change of composition without sacrificing hardness and depth of hardness, the following means can be pointed out; namely, to contrive to yet better mechanical properties of the barrel's surface layer, to contrive to add an element which will elevate secondary contraction temperature and to produce such alloy composition that volume contraction created by secondary contraction is small. However anyone could not succeed to manufacture such rolls having good crack resistance.

An object of this invention is to provide an improved new quenched roll of forged steel which does not produce any cracks and spalling through heat generation due to miss-rolling.

Another object of this invention is to provide an improved roll having sufficient high hardness and thickness of quench hardened layer as well as good crack resistance and superior wear resistance.

This invention relates to a forged hardened roll manufactured from a steel having ordinary forged hardened roll steel composition with Co annex of 0.3–8.0 wt. percent.

It is composed of

C—0.60–1.30 wt. percent
Si—0.25–0.50 wt. percent or 0.50–3.50 wt. percent
Mn—0.15–1.60 wt. percent
Cr—1.00–3.50 wt. percent
Mo—0–2 wt. percent
V—0–2 wt. percent
W—0–2 wt. percent
Ni—0–2 wt. percent
Co—0.3–8 wt. percent

The purpose of the present invention is to get rolls that can sufficiently suppress cracks which is caused by the heat generated during grinding or during the metal rolling operation as well as to have high surface hardness and with necessary and sufficient thickness of hardened layer.

According to this invention, suitable quantity as mentioned above of cobalt is quite effective in restraining cracks. Thus in conventional quenched hardened steel roll, there develop cracks on the surface of the roll when it is tempered by partial and unusual generation of heat. In case of the present cobalt containing steel roll, however, the crack does not occur on the surface, unless it is tempered at higher temperature than the rolls heretofore in use, which means that cobalt containing steel roll is effective in repressing cracks. Accordingly kinds of rolls, however, it is not desirous that large amount of cobalt is added since such amount of cobalt with deteriolate hardenability.

We found also that such defects may be eliminated by adding 0.5–3.5% of silicon which is more than what is originally contained as impurity in the steel. Thus the hardened roll has been successfully obtained, that has the advantage to effectively suppress cracks and is by no means inferior in its hardenability. These are other characteristics of the present invention.

Thus composition of steel used for the roll of the present invention is as follows:

C—0.60–1.30 wt. percent
Si—0.50–3.50 wt. percent
Mn—0.15–1.60 wt. percent
Cr—1.00–3.50 wt. percent

Co—0.3–8.0 wt. percent
Mo—0–2 wt. percent
V—0–2 wt. percent
W—0–2 wt. percent
Ni—0–2 wt. percent

The amount of Co or Co, Si annex should be more or less varied in accordance with the size of roll, desired depth of hardness or degree of heat generated during cold rolling operation. But, as mentioned above, the amount should be within C: 0.60–1.30%, Co: 0.3–8.0% and Si: 0.5–3.5%, in case it is contained. The reasons for such limitations are as follows: with less than 0.60% of carbon, required hardness of Vickers hardness 700 is not obtained whereas with more than 1.30% of carbon, required depth (about more than 10 mm.) is not obtained either. Furthermore, the relationship between the amount of cobalt and cracks as well as thickness of hardened layer are illustrated in the attached drawing **1** and **2**. FIG. 1 shows the relationship between the amount of cobalt and the hardness when the roll begins to crack owing to tempering; Curve **1** corresponds to the steel containing 0.67% of carbon, 0.26% of silicon, 0.38% of manganese, 2.2% of chromium, 0.26% of molybdenum, and 0.15% of vanadium, Curve 2 corresponds to a steel containing 1.15% of carbon, 0.26% of silicon, 0.39% of manganese, 3.5% of chromium, 0.35% of molybdenum and 0.05% of vanadium.

As is clear in the figures, the more increased the amount of cobablt, the better crack can be suppressed. When more than 8% of cobalt is contained, however, the roll begins to lose its hardenability, and becomes less resistant against thermal shock. Moreover, no improvements in crack resistance are obtained. Therefore, the present invention has set the maximum of Co content at 8%. The minimum has been set at 0.3%, because, as also clear in the figures, less than 0.2% of cobalt shows no effect. FIG. 2 illustrates the influence of amount of cobalt upon the hardenability through Jominy's end-quench test. The each curve corresponds to each steel having following compositions.

	Percent				
	C	Si	Mn	Cr	Co
Curve:					
1	0.75	0.24	0.36	1.80	2.5
2	0.75	0.24	0.41	1.80	1.5
3	0.75	0.22	0.36	1.80	1.0
4	0.75	0.25	0.38	1.85	0.5

That is, there is a tendency that the more Co is contained, the lower becomes hardenability. The curves in FIG. 3 are the same as those illustrated in FIG. 1, which shows the influence exerted by the amount of silicon in the steel upon the control of occurrence of cracks. Curve **1** corresponds the steel containing C: 0.66%, Si: 0.28%, Mn: 0.40%, Cr: 2.3%, Mo: 0.30% and V: 0.13%, while curve **2** corresponds to the steel containing C: 1.18%, Si: 0.25%, Mn: 0.35%, Cr: 2.2%, Mo: 0.31% and V: 0.10% respectively. That is, although silicon will increase the effect to control the development of cracks when the amount is more than 0.5%, that is more than the amount generally found in the steel as impurities, whereas when the amount of silicon is more than 3.5%, it impairs not only the heat conductivity and resistance against thermal shock, but also the increase of crack resistance becomes unrecognizable. In the present invention, therefore, the maximum amount of silicon is 3.5%. As illustrated in FIG. 3, although even the addition of proper amount of silicon to the general roll steel improves the crack resistance, the reason of this seems that silicon in the amount of afore-mentioned range together with suitable amount, i.e. 0.3–8.0% of cobalt cannot only improve the crack resistance but also the defect of lowering the hardenability can thereby be controlled.

FIG. 4 shows the result of Jominy's end-quench test which illustrates the effect of adding silicon to the hardenability to steel containing cobalt.

Each curve corresponds steels having the following compositions:

	Percent				
	C	Si	Mn	Cr	Co
Curve:					
1	0.83	0.5	0.36	1.85	2.0
2	0.83	1.5	0.36	1.85	2.0
3	0.83	3.0	0.36	1.85	2.0

As is clear from the figure, when the amount of silicon of the roll steels containing same contents of C, Cr and Co, the increase in the amount of the silicon raises the hardenability. However, in the present invention the maximum amount of the silicon is limited at 3.5% for the above mentioned reason. Thus, this newly invented roll containing a suitable amount of cobalt, could further improve its properties, by adding also a suitable amount of silicon.

The followings are the practical examples, in which the novel roll according to this invention is compared with the conventional one.

EXAMPLES

The roll steels composed of the following compositions were melted, casted and forged into shape of a roll. And after rough machining to the defined size, it was quenched.

Example 1 is the steel roll containing cobalt, Example 2 contains both cobalt and added silicon, and Example 3 is the conventional roll steel.

	Percent		
Example	1	2	3
C	0.80	0.80	0.81
Si	0.28	0.75	0.28
Mn	0.26	0.26	0.35
Cr	2.51	2.38	2.50
Mo	0.32	0.32	0.29
V	0.09	0.15	0.13
Co	2.70	2.70	0
Ni	0.18	0.25	0.19

The new roll of the present invention is heat-treated by keeping it for suitable time, above transformation point of Ac_3, and then quenched.

The roll of Example 1 and the roll of Example 2 were both maintained for more than five minutes at the temperature of 940° C., and then quenched by water jet.

These rolls are one for 4 high cold rolling mill, and it has the barrel-diameter of 100 mm. and barrel-length of 330 mm. in its finished size.

The surface hardness of barrel after quenching was Vickers hardness 865–925 in all of these examples. As to the thickness of hardened layer, Example 2 was about 14–16 mm., and the rest were 10–12 mm.

In the case of Example 1, the quenching temperature was 30° C. higher than that of Example 3 in order to improve the thickness of hardened layer.

Steel stripes were manufactured by using these three kinds of rolls, and after that the hardness of the heat generated parts of the rolls were observed. The result was as follows: in the case of old roll steel, many cracks were obviously found in the part tempered to Vickers hardness 674 through the generation of heat, but in the case of the Examples 1 and 2 according to the invention cracks was found only in the part of the roll below Vickers hardness 554. Consequently, it is confirmed that the roll of this invention had conspicuously strong resistance against the occurrence of cracks.

It has hitherto been demanded that forged hardened steel roll must have resistance against premature failures. Premature failure is generally effected in a short time after quenching, and it occurs also during transportation or use of the roll. Its pattern of premature failure which frequently occurs is the roll body fractured transversely. Premature failures are due to residual stress given to steel by heat-treatment and they are very dangerous because of an explosive power involved therein. Since the cause of breakage is residual stress, it is necessary to decrease residual stress by aging (tempering) after hardening. The higher the aging (tempering) temperature, the greater the stress relief. When a roll of 540 mm. in diameter and 1067 mm. in barrel length was hardened and then aged (tempered) at 130, 150, 200, 250 or 300° C. for 48 hours, the decrease of residual stress and the change in surface hardness were as follows:

Aging temperature (° C.)	130	150	200	250	300
Stress relief (percent)	29	33	43	56	69
Roll of the present invention in hardness (D.P.H.)	875	862	812	761	723
Conventional roll in hardness (D.P.H.)	862	825	748	685	558

The composition was as follows:

	Percent						
	C	Si	Mn	Cr	Mo	V	Co
Roll of the present invention	0.81	1.04	0.34	2.32	0.28	0.12	1.60
Conventional roll	0.81	0.30	0.35	2.25	0.25	0.09	

The respective rolls were maintained at 860° C. for 4 hours, quenched with water jet and hardened.

As shown, the roll of the present invention is much less in the decrease of hardness caused by tempering than conventional roll, so that it is possible to elevate the tempering temperature higher than in conventional roll in order to effect tempering up to the desired hardness, with the advantage that residual stress, the cause of premature failures, becomes smaller.

The roll of the present invention is also characterized by great wear resistance. A roll of 585 mm. in diameter and 1422 mm. in barrel length was used for a six tandem cold strip mill by which strip steel for tin plate was rolled. The rolling result of 14 rolls of the present invention was 89,264 t. in average, while that of conventional rolls was 59,266 t. For the rolling, the roll of the present invention (C: 0.79–0.86%, Si: 1.02–1.20%, Mn: 0.30–0.50%; Ni: 0.15–0.37%, Cr: 2.38–2.40%, Mo: 0.26–0.29%, V: 0.11–0.12%, Co: 1.56–2.08%) and conventional roll (C: 0.77–0.85%, Si: 0.25–0.35%, Mn: 0.30–0.40%, Ni: 0.15–0.25%, Cr: 2.10–2.30%, Mo: 0.22–0.27%, V: 0.05–0.12%) were used for comparison. In this rolling, there occurred often cracks on the barrel surface due to miss-rolling. The depth of the crack produced was a maximum 1.8 mm. in the roll of the present invention, and a maximum 16.0 mm. frequently about 5.0 mm. in conventional roll, which shows that there is a wide difference in crack-resistance between the rolls. At the same time, wears on the surface of the barrels were compared. The result is shown in FIG. 5.

In FIG. 5 the abscissa indicates rolled tons of a cold strip steel for tin plates, and the ordinate shows the extent of wear. A represents conventional rolls (a set of 14 rolls), while B indicates the relation between rolled tons of rolls of the present invention (a set of 7 rolls) and wear. As shown, even after 500-ton rolling, there is almost no wear on the surface of the roll according to the present invention, while on the other hand, after 300-ton rolling, fairly clear wear appears on conventional roll, and after 400-ton rolling, the quality of the strip steel for tin plates becomes worse due to wear, so that further rolling is impossible.

As is clear from the foregoing, the forged hardened roll having the composition of the present invention is excellent in crack resistance and also wear resistance. Furthermore, since it is possible to make residual stress smaller, the resistance against premature failures can be larger.

What is claimed is:

1. In a process of cold-rolling metals by means of a rolling mill having forged rolls which contact the metal, the improvement comprising contacting said metals with rolls consisting essentially of from about 0.60 to about 1.30% by weight carbon, from about 0.25 to about 0.50% by weight silicon, from about 0.15 to about 1.60% by weight manganese, from about 1.00 to about 3.50% by weight chromium, from about 0.30 to about 8.0% by weight cobalt and the balance except for impurities being iron, said rolls having a surface hardness of above Vickers hardness No. 700.

2. A process according to claim 1 wherein the roll steel of said forged rolls contains less than about 2.00% by weight of a metal selected from the group consisting of molybdenum, vanadium, tungsten and nickel.

3. A process according to claim 1 wherein the surface of said forged roll is hardened by heating at a temperature between about 800° C. and about 990° C., then quenching with water and then aging at a temperature between about 100° C. and about 300° C.

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CHARLES N. LOVELL, Primary Examiner

U.S. Cl. X.R.

29—132; 75—126, 128; 148—31