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(54) **Method of making an abrasion resistant steel**

Verfahren zur Herstellung abriebfester Stähle

Procédé de fabrication d'aciers résistant à l'abrasion

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Description

The invention relates to the field of metallurgy and particularly relates to the field of a method of making an abrasion resistant steel utilized in the field of construction, civil engineering and mining.

Abrasion resistant steels are utilized in the field of construction, civil engineering and mining such as in power shovel, bulldozer, hopper and bucket to keep the lives of these machines or their parts. It is well known that the steel having high hardness possesses high abrasion resistance property.

For this purpose a high alloyed steel treated by quenching has commonly been utilized. The maximum value of the Brinell Hardness of such abrasion resistant steel in practical use is about 500. There are some other steels which have the Brinell Hardness higher than 500 to further enhance the abrasion resistance property.

However in the above-mentioned abrasion resistant steel the workability of the steel such as the bending workability may be required. To enhance the bending workability it is effective to lower the hardness of steel. As the result, in this kind of steel, the most important characteristic of the abrasion resistant steel, that is, the abrasion resistance property may be deteriorated.

Japanese Patent laid open Publication Nos. 142726/1987, 169359/1988 and 142023/1989 disclose the information about the production of the conventional abrasion resistant steel.

In these inventions the Brinell Hardness of steel is more than 300. These inventions aim at the improvements in the weldability, the toughness and the workability in bending of steel. However the abrasion resistance property is realized by increasing the hardness of steel.

The property required for the abrasion resistant steel has recently become severer and the essential solution to higher abrasion resistance of steel may not be obtained by simply enhancing the hardness of steel. When the hardness of steel is significantly enhanced, the weldability and the workability of steel are deteriorated due to the high alloying and the cost of producing such steels increases significantly. Accordingly in the practical point of view the significant increase of the hardness of abrasion resistant steel is facing with a difficulty with respect to the workability of steel.

Summarizing the above-mentioned facts in the conventional abrasion resistant steel, the followings are the points of problems.

(1) The abrasion resistance property of steel is improved by increasing the hardness of steel. Therefore it is necessary to increase the hardness to obtain the abrasion resistance.

However in the steels having high hardness the workability of the steel such as that in bending becomes difficult and the working may cause defects such as crack during the working operation.

(2) To enhance the hardness of steel, the carbon content of steel has to be increased and the alloying elements such as chromium and molybdenum have to be added to the steel. As the result the production cost is increased and the weldability and gas cutting property of steel are considerably deteriorated.

Japanese Patent laid open Publication No. 142726/1987 discloses that the weldability of steel is improved by controlling the carbon content of steel to a lower level. However the hardness of the steel is at most the level of 400 in Brinell Hardness. Therefore the steel has the practical weldability but the hardness of the steel is limited which gives rise to the low abrasion resistance property under severe abrasion atmosphere.

Japanese Patent laid open Publication No. 169359/1988 suggests the abrasion resistant steel having the improved toughness. However the point of the invention is in the improvement of the toughness of steel and the hardness of steel is 400 in Brinell Hardness which is insufficient as the abrasion resistance property under severe abrasion condition.

Japanese Patent laid open Publication No. 142023/1989 discloses that the bending workability may be improved by the reduction of the quantity of the inclusion in steel and the restriction of the process of making the steel. However the bending workability is improved only by limiting the hardness of steel under 400 in Brinell Hardness.

In short, in the conventional engineering the abrasion resistance property of steel is sacrificed in satisfying the requirement of the workability, the weldability and the toughness of steel.

Japanese unexamined patent publication 57-89426 discloses a method for manufacturing high-hardness and wear resistant steel having excellent weldability. The steel contains 0.08-0.25% C, 0.10-0.60% Si, 0.50-2.00% Mn and the balance Fe, optionally contains at least one of 0.10% or less Al, 1.0% or less Cu, 1.0% or less Ni, 1.0% or less Cr, 0.6% or less Mo, 0.10% or less V, 0.10% or less Nb, 0.15% or less Ti and 0.005% or less B. The steel is heated to 1000°C or more, rolled at a temperature of 850°C or more, and cooled from 800°C or more to a temperature of 150°C or less at a cooling rate of 20°C/sec or more. In this method, wear resistant steel having excellent weldability is obtained by controlling the rolling and cooling conditions whilst maintaining high hardness.

It is an object of the invention to provide a method of making an abrasion resistant steel.

It is an object of the invention to provide a method of making an abrasion resistant steel having an excellent abrasion resistance property without deteriorating the workability of steel in bending.

According to the invention a method of making an abrasion resistant steel is provided comprising the steps of:

heating to a temperature in a range of from 1000 to 1300 °C a slab of steel comprising from 0.05 to 0.45 wt.% C, 0.1 to 1.0 wt.% Si, 0.1 to 2.0 wt.% Mn, 0.3 to 1.5 wt.% Ti

the balance Fe having the carbon equivalent C^* , that is: $C^* = (C \text{ wt.}\%) - (Ti \text{ wt.}\%) (12/48)$,

(where (C wt.%) is the carbon content of said abrasion resistant steel and (Ti wt.%) is the titanium content of said abrasion resistant steel);

hot rolling said slab into a hot rolled product, with the temperature upon termination of hot rolling being within a range of from the Ar_3 point of the abrasion resistant steel to 1000 °C ; and

heat treating the hot rolled product according to the carbon equivalent C^* of $C^* \leq 0.20$ wt.% the heat treatment being carried out by one process selected from the following (a) to (e), that is:

(a) directly quenching the hot rolled product,

(b) air cooling the hot rolled product;

reheating the air cooled product to a temperature at least as high as the Ac_3 point of the abrasion resistant steel; and

quenching the reheated product,

(c) air cooling the hot rolled product,

(d) directly quenching the hot rolled product; and

tempering the quenched product at a temperature which is, at most, the Ac_1 point of the abrasion resistant steel,

(e) air cooling the hot rolled product;

reheating the air cooled product to a temperature at least as high as the Ac_3 point of the abrasion resistant steel;

quenching the reheated product; and

tempering the hot rolled product at a temperature which is, at most, the Ac_1 point of the abrasion resistant steel.

Further preferred embodiments of the process defined in claim 1 are given in the dependent claims 2 and 3.

The following are the processes of the hot rolled product having the chemical composition specified above.

(1) air cooling the hot rolled product,

(2) directly quenching and tempering the hot rolled product at the temperature at most the Ac_1 point of the steel,

(3) air cooling and reheating the hot rolled product at the temperature at least the Ac_3 point of the steel followed by quenching and tempering the hot rolled product at the temperature of at most the Ac_1 point of the steel.

In addition to the basic-elements, at least one element selected from the group consisting of 0.1 to 2.0 wt.% Cu, 0.1 to 10.0 wt.% Ni, 0.1 to 3.0 wt.% Cr, 0.1 to 3.0 wt.% Mo and 0.0003 to 0.01 wt.% B may be added to enhance the quenching hardenability of the steel, and at least one element selected from the group consisting of 0.005 to 0.5 wt.% Nb, 0.01 to 0.5 wt.% V may be added to enhance the precipitation hardenability of the steel.

A more preferable range with respect to the balance of the stable abrasion resistance and the economy of the steel is 0.3 to 1.0 wt.% in Ti content. A more preferable range for the stable abrasion resistance is 1.0 to 1.5 wt.% in Ti content.

Figure 1 is a graph showing the relationship between the hardness and the bending workability of steel. Figure 2 is a graph showing the relationship between the added quantity of titanium and the ratio of resistance to abrasion. Figure 3 is a graph showing the relationship between the Brinell Hardness of steel and the ratio of resistance to abrasion thereof. Figure 4 is a graph showing the relationship between the carbon equivalent and the Brinell Hardness of steel.

The invention concerns with a steel having good abrasion resistance and also good bending workability. The important characteristic of the invention is the bending workability.

The hardness of steel has a close relationship with the bending workability thereof. When the hardness is lowered, the bending workability is improved.

Figure 1 is a graph showing the relationship between the hardness and the bending workability of steel. The abscissa denotes Brinell Hardness of steel and the ordinate denotes the critical bending radius. The critical bending radius is the smallest radius of the specimen for bending test wherein no crack is generated on the surface of the specimen. The smaller the critical bending radius the easier for the tested steel to be bent without cracking. The value of the ordinate is the critical radius divided by the thickness of the specimen. Therefore the unit of the ordinate is the thickness of the specimen. The thickness of the specimen is 15 to 25 mm and the width thereof is 150 to 200 mm. In

Figure 1 the domain under the curve "a" is the area where the specimen cracks by the test of bending and the domain above the curve "b" is the area where the specimen does not crack, the domain between the curves "a" and "b" being a transitional area.

In this invention the target of the maximum critical bending radius is 3.0 in terms of the thickness of the specimen.

To satisfy the given condition the Brinell Hardness of the specimen has to be 401 at most.

Accordingly the hardness of the invented steel is determined to be at most 400 in Brinell Hardness. Therefore the domain of the invented steel complying with the above-mentioned requirement is the area encircled by the points A, B, C and D.

The significant characteristic of the invented steel is effectively utilizing of very hard TiC. In this invention it is not necessary to enhance the hardness of the abrasion resistant steel only by transforming the microstructure of the steel to a martensite which is the conventional way to enhance the abrasion resistance of steel.

In the conventional way the purpose of the addition of titanium to steel is to react with the nitrogen so that the nitrogen is stabilized as TiN. As the result boron does not react with nitrogen since there is not enough nitrogen in the steel, and retained in the steel as a soluble boron, which enhances the quenching hardenability of steel. The quantity of the addition in this case is about 0.02 wt.% of the steel. The addition of a large quantity of titanium to steel is limited by the oxidation of the titanium in the steel melting stage, the clogging of the nozzle and the reaction with the oxidation preventing powder in the casting stage. Therefore the effect of the addition of a large quantity of titanium is not yet known.

The inventors after detailed examination found that the addition of titanium in a large quantity realizes the improvement of steel with respect to the abrasion resistance property.

Figure 2 is a graph showing the relationship between the added quantity of titanium and the ratio of resistance to abrasion. The abscissa denotes the added quantity of titanium and the ordinate denotes the ratio of resistance to abrasion. The ratio of resistance to abrasion is an index wherein the resistance to abrasion of an abrasion resistant steel is divided by that of a mild steel. The resistance to abrasion is measured according to ASTM Standard G 65-85 wherein an abrasive is introduced between the test specimen and a rotating wheel with achlorobutyl rubber tire. The abrasive is a sand composed of 100% silica and of controlled size. The C content of test specimen is 0.3 wt.% and the specimen is heat treated by quenching.

The Brinell Hardness is at most 500. In Figure 2 the area below the curve "c" and above the curve "d" is where the test results of the steel is distributed. As shown in Figure 2, the ratio of resistance to abrasion linearly increases with the increase of the added quantity of titanium up to 0.5 wt.%.

The addition of titanium is effective when the added quantity of titanium is 0.05 wt.%. When the added quantity is 1.5 wt.%, the ratio of resistance to abrasion reaches about 10, which shows the remarkable improvement in the abrasion resistance property.

Figure 3 is a graph showing the relationship between the Brinell Hardness of steel and the ratio of resistance to abrasion thereof. The abscissa denotes the Brinell Hardness and the ordinate denotes the ratio of resistance to abrasion.

The area below the curve "f" and above the curve "g" is where the test results of the conventional steel having the Ti content of at most 0.05 wt.% are distributed. In the area on the right hand side of the line "e", wherein the Brinell Hardness is 401, and above the curve "f", the test results of the conventional steel having Ti content of 0.05 to 0.15 is distributed. In the area on the left side of the line "e" the test results having Ti content of 0.05 to 0.15 is distributed, being encircled by the dotted curve "h". Even if the ratio of resistance to abrasion is in the same range with that of the conventional steel, the Brinell Hardness of the invented steel is significantly lower than that of the conventional steel.

As mentioned above the invented steel satisfies the requirement of the bending workability without sacrificing the resistance to abrasion. The invented steel solves the problem by the precipitation and the dispersion of TiC in steel. Thus the invented steel satisfies the limitation of the bending workability by limiting the Brinell Hardness to at most 400, and still retains the resistance to abrasion due mainly to the precipitated TiC.

The followings are the reason why the contents of the elements of the invented steel is specified.

C is an indispensable element in forming TiC and also enhances the hardness of the matrix of steel. However when C is increased too much, the weldability and the workability are deteriorated. Therefore the upper limit of C is determined to be 0.45 wt.%. As for the lower limit of C the minimum quantity of C wherein the effect of TiC is shown is 0.05 wt.%.

Si is an element effective in deoxidation process of steel making and a minimum addition of 0.1 wt.% is required for this purpose. Si is also an effective element for solution hardening. However when the Si content exceeds 1.0 wt.%, the toughness of steel is lowered and the inclusion in steel is increased. Therefore the Si content is determined to be 0.1 to 1.0 wt.%.

Mn is an element effective in quenching hardenability. At least 0.1 wt.% is required for this purpose. When the Mn content exceeds 2.0 wt.%, the weldability of steel is deteriorated. Therefore the Mn content is determined to be 0.1 to 2.0 wt.%.

In this invention Ti is one of the most important elements as is C. The addition of at least 0.3 wt.% of Ti is required to stably form a large quantity of TiC. When the Ti content exceeds 1.5 wt.%, the steel possesses good abrasion resistance property but high cost is required for the production, also the weldability and the workability of steel are lowered. Therefore the Ti content is determined to be 0.3 to 1.5 wt.%.

A more preferable range with respect to the balance of the stable abrasion resistance and the economy of the steel is 0.3 to 1.0 wt.% in Ti content. A more preferable range for the stable abrasion resistance is 1.0 to 1.5 wt.% in Ti content.

In this invention, in addition to the above basic elements, at least one element selected from the group consisting of Cu, Ni, Cr, Mo and B may be added to enhance the quenching hardenability and at least one element selected from the group consisting of Nb and V may be added to enhance the precipitation hardening.

Cu is an element for enhancing the quenching hardenability and effective in controlling the hardness of steel. When the Cu content is below 0.1 wt.%, the effect is not sufficient. When the Cu content exceeds 2.0 wt.%, the hot workability is lowered and the production cost is increased. Therefore the Cu content is determined to be 0.1 to 2.0 wt.%.

Ni is an element which enhances the quenching hardenability and the low temperature toughness. When the Ni content is below 0.1 wt.%, the effect is not sufficient. When the Ni content exceeds 10.0 wt.%, the production cost is increased significantly. Therefore the Ni content is determined to be 0.1 to 10.0 wt.%.

Cr is an element which enhances the quenching hardenability. When the Cr content is below 0.1 wt.%, the effect is not sufficient. When the Cr content exceeds 3.0 wt.%, the weldability is deteriorated, and the production cost is increased. Therefore the Cr content is determined to be 0.1 to 3.0 wt.%.

Mo is an element which enhances the quenching hardenability. When the Mo content is below 0.1 wt.%, the effect is not sufficient. When the Mo content exceeds 3.0 wt.%, the weldability is deteriorated, and the production cost is increased. Therefore the Mo content is determined to be 0.1 to 3.0 wt.%.

B is an element which enhances the quenching hardenability by the addition to steel even by a small amount.

When the B content is below 0.0003 wt.%, the effect is not sufficient. When the B content exceeds 0.01 wt.%, the weldability is deteriorated, and the quenching hardenability is also deteriorated. Therefore the B content is determined to be 0.0003 to 0.01 wt.%.

Nb is an element effective in the precipitation hardening and can control the hardness of steel according to the purpose of steel. When the Nb content is below 0.005 wt.%, the effect is not sufficient. When the Nb content exceeds 0.5 wt.%, the weldability is deteriorated. Therefore the Nb content is determined to be 0.005 to 0.5 wt.%.

V is an element effective in the precipitation hardening and can control the hardness of steel according to the purpose of steel. When the V content is below 0.01 wt.%, the effect is not sufficient. When the V content exceeds 0.5 wt.%, the weldability is deteriorated. Therefore the V content is determined to be 0.01 to 0.5 wt.%.

The method of making, or working and heat treating of the invented steel is explained below.

The slabs having the chemical composition described above are heated to the temperature of 1000 to 1300 °C, and hot rolled. The finishing temperature of the rolling is from the Ar₃ point to 1000 °C.

In this invention an excellent abrasion resistance property is obtained when TiC is stabilized. Therefore the heating temperature is desirable to be below the temperature wherein TiC is dissolved into steel, which is considerably high. However in practical point of view the upper limit of the heating temperature is determined to be 1300 °C considering the heating cost. The lower limit of the heating temperature is determined to be 1000 °C considering the rolling efficiency.

When the finishing temperature is below the Ar₃ point, the hardness of steel is significantly lowered since the ferrite is generated in the steel.

Therefore the lower limit of the finishing temperature is determined to be the Ar₃ point. The upper limit of the finishing temperature is determined to be 1000°C considering the temperature of the heated slabs.

The process after the rolling is classified according to C*, or the carbon equivalent to limit the Brinell Hardness to at most 401.

The carbon equivalent is defined by the following equation;

$$C^* = [C\%] - [Ti\%] \times (12/48),$$

where [C %] is the C content and [Ti %] is the Ti content.

The carbon equivalent almost corresponds with the soluble carbon of steel. When the carbon equivalent is high, so is the hardness of steel. Therefore in this invention the processes after the rolling are classified according to the carbon equivalent.

Figure 4 is a graph showing the relationship between the carbon equivalent and the Brinell Hardness of steel. The abscissa is the carbon equivalent and the ordinate is the Brinell Hardness of steel. In Figure 4 the open marks denote the invented steel and the solid mark denotes the steel in comparison or the conventional steel. The circular mark denotes the process RQ or DQ while the triangular mark denotes the processes RQT, DQT and AR. RQ signifies the

process wherein the material is air cooled after finish rolling followed by reheating and quenching. DQ signifies the process wherein the material is directly quenched just after finish rolling. RQT signifies the process wherein the material is tampered after RQ. DQT signifies the process wherein the material is tempered after DQ. AR signifies as rolled. In Figure 4, line "j" signifies the line wherein the Brinell Hardness is 401. The area wherein the data of the invented steel; open circle marks, are generally distributed between the curves "k" and "l". The area wherein the data of the invented steel; open triangular marks, are generally distributed between the curves "m" and "n". The area wherein the data of the conventional steel, or steel in comparison; solid circular marks, are generally distributed between the curves "o" and "p".

When the carbon equivalent C^* is at most 0.20 wt.%, the Brinell Hardness is at most 401 in spite of the processes after finish rolling. However when the carbon equivalent C^* exceeds 0.20 wt.%, whether the Brinell Hardness of the steel is at most 401, depends on the processes. When the process is DQ or RQ, the Brinell Hardness of the steel exceeds 401. When the process is DQT or RQT or AR, the Brinell Hardness of the steel is at most 401.

As the result of the aforementioned description the processes after finish rolling are classified as follows by the carbon equivalent.

In case of $C^* \leq 0.20$ wt %,
the steel may be treated by the following processes;

- ① directly quenching just after finish rolling,
- ② quenching after the steel is reheated to at least the temperature of the Ac_3 point following finish rolling and air cooling.
- ③ air cooling after finish rolling,
- ④ directly quenching after finish rolling, followed by tempering at the temperature of at most the Ac_1 point,
- ⑤ air cooling after finish rolling, reheating to at least the temperature of Ac_3 , quenching, followed by tempering at the temperature of at most the Ac_1 point.

In this invention the abrasion resistance is obtained by adding a large quantity of TiC. However the harder the matrix of the steel, the better the abrasion resistance property.

Sufficient hardness is obtained in the processes ① and ②. In case of the process ② the steel is reheated to at least the temperature of the Ac_3 point since the structure of the steel is not homogeneously austenitic when the steel is reheated below the temperature of the Ac_3 point, whereby the elevation of the hardness is not expected.

The hardness of the steel should be at most 401 in Brinell Hardness in order to obtain the bending workability. When the carbon equivalent is at most 0.20 wt.%, the hardness of the steel is at most 401 in case of the process of ① or ②.

In case of the process ④ or ⑤ the steel is tempered after quenching which gives rise to the lowering of the hardness and enhancing the bending workability. In case of ④ or ⑤ when the tempering temperature exceeds the Ac_1 point, the structure of steel becomes partially austenite. Hence the tempering temperature is determined to be at most the Ac_1 point.

In case of the process ③ the hardness of steel is low and good abrasion resistance property is obtained.

In this invention the steel treated by the processes specified above can satisfy the required property even if the steel is further treated by aging or stress relief tempering.

EXAMPLE

Table 1 shows the chemical compositions of the samples of the invented and conventional steel.

Samples B to H, N and O are made of the invented steel, whereas samples A, I to M and P to R are made of the steel for comparison. The chemical composition of the samples from P to R varies with respect to Ti and other alloying elements.

The chemical composition of the samples P and Q are within the same range with those of the invented steel except that of Ti.

The chemical composition of the sample R is within the same range of the invented steel with respect to Ti, but out of the range with respect to C.

Table 1

Kind of Steel	C	Si	Mn	Cu	Ni	Cr	Mo	Nb	V	Ti	B	N
A	0.30	0.36	0.70	-	-	-	-	-	-	0.09	-	33
B	0.28	0.37	0.73	-	-	-	-	-	-	0.37	-	38
C	0.29	0.37	0.74	-	-	-	-	-	-	0.98	-	36

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Table 1 (continued)

Kind of Steel	C	Si	Mn	Cu	Ni	Cr	Mo	Nb	V	Ti	B	N
D	0.29	0.36	0.71	-	-	-	-	-	-	1.41	-	30
E	0.28	0.36	0.71	0.24	0.29	-	-	-	-	0.40	-	31
F	0.31	0.33	0.73	-	-	1.02	0.23	-	-	1.08	10	32
G	0.19	0.33	1.44	-	-	0.27	-	-	-	0.65	9	22
H	0.14	0.34	1.40	-	-	-	-	0.025	-	0.40	-	24
I	0.32	0.34	0.72	-	-	-	-	-	0.045	0.41	-	21
J	0.34	0.26	1.01	0.35	0.55	-	-	0.028	0.041	0.54	-	42
K	0.31	0.38	0.71	-	-	0.99	0.23	0.022	0.044	0.06	8	24
L	0.29	0.38	0.70	-	-	0.99	0.23	-	0.044	0.08	9	23
M	0.30	0.36	0.71	0.25	-	0.55	0.23	-	0.045	0.19	8	30
N	0.31	0.36	0.71	-	-	1.02	0.23	-	0.045	0.38	8	31
O	0.31	0.33	0.73	-	0.36	0.63	0.34	-	-	1.28	-	32
P	0.30	0.30	0.75	-	-	-	-	-	-	0.02	-	37
Q	0.30	0.30	0.96	-	-	1.03	0.21	-	0.045	0.01	11	47
R	0.03	0.30	0.75	-	-	-	-	-	-	0.47	-	37

Note: The values are in wt.% except B and N. The values of B and N are in ppm.

Table 2

			Process	Ratio of Resistance	HB	C*
Invented Steel	1	B	RQ	8.3	393	0.188
	2	B	RQT (400 °C)	6.1	277	0.188
	3	C	DQ	9.7	335	0.045
	4	C	DQT (400 °C)	6.8	245	0.045
	5	D	RQ	9.3	242	-0.063
	6	E	RQ	8.6	390	0.180
	7	F	RQ	9.1	321	0.040
	8	G	RQ	4.7	302	0.028
	9	H	DQ	3.4	253	0.040
	13	O	AR	7.3	246	-0.010
	14	O	RQ	11.1	275	-0.010

* This sample has a C* value greater than 0.2. Hence, RQ is an inappropriate heat treatment for compliance with the present invention.

Table 2 (continued)

			Process	Ratio of Resistance	HB	C*
Steel in Comparison	1	A	RQ	6.5	474	0.278
	2	I	RQ	10.1	451	0.218
	3	J	DQ	8.9	417	0.205
	4	K	RQ	6.4	503	0.295
	5	L	AR	4.5	293	0.270
	6	L	DQ	8.2	507	0.270
	7	M	AR	4.7	286	0.253
	8	M	RQ	9.1	454	0.253
	9	N*	RQ	11.6	448	0.215
	10	P	RQ	4.9	464	0.295
	11	Q	AR	2.8	326	0.298
	12	Q	RQ	5.2	481	0.298
	13	R	RQ	1.2	122	-0.088
	14	N	AR	6.1	274	0.215

* This sample has a C* value greater than 0.2. Hence, RQ is an inappropriate heat treatment for compliance with the present invention.

Table 2 shows the process of making the samples, the ratio of the resistance to abrasion, Brinell Hardness and the equivalent carbon of the samples. The alphabetical notations at the left parts of Tables 1 and 2 denote the same kind of steels. The abrasion test is carried out according to ASTM G 65-85 as described before. The measurement of the abrasion is done by the change of the weight of the sample. As described before the ratio of resistance to abrasion is the ratio of the weight change of the specimen versus that of the specimen made of a mild steel.

The processes in the table are classified as follows; AR, as rolled; RQ, as quenched after reheating; RQT, as tempered after RQ treatment; DQ, as directly quenched; DQT, as tempered following DQ. The kind of steel in Table 1 corresponds with those in Table 2.

The cases numbered 1 to 9, 13 and 14 in the upper section are of the invented steel, and the cases of which numbering are 1 to 14 on the lower lines, are of the conventional steel, or steel in comparison.

Case No. 8 of the steel for comparison corresponds with the cases of invented steel Nos. 1 and 5 but in case No. 8, Ti content is below the range of the invented steel. Examining the ratio of the resistance to abrasion, it is found that the ratio is 4.9 in case No. 8 of the steel for comparison, whereas the ratio of No.1 of the invented steel is 8.3, that of case 5 of the invented steel is 9.3. This is to say that the ratio of the invented steel can be enhanced about twice as much as that of the steel for comparison which is a conventional abrasion resistant steel. Moreover the hardness of the invented steel is lower than 401 in Brinell Hardness.

This result agrees with the purpose of the invention wherein the invented steel treated by the invented process possesses high resistance to abrasion and low hardness.

The hardness of steel of case 9 of the steel for comparison satisfies the condition wherein the Brinell Hardness is at most 401, but the ratio of resistance to abrasion is lower than in the invented steel.

Case 11 of the steel for comparison corresponds with case 1 of the invented steel. However the carbon content of the steel in case 11 of the steel for comparison is below the half of the lower limit of prescription in invented steel. Therefore the hardness of steel in case 11 of the steel for comparison is sufficiently low but the abrasion resistance is much lower than that of the invented steel.

The chemical composition of the steel in cases Nos. 1 to 7 is in the range of the invented steel and these steels possess the excellent abrasion resistant property. However these samples are as directly quenched or as quenched after reheating in spite of the fact wherein the carbon equivalents of these samples exceeds 0.20 wt.%. Accordingly the Brinell Hardness of these samples is above 401, which deteriorates the bending workability of steel.

Claims

1. A method of making an abrasion resistant steel comprising the steps of:

heating to a temperature in the range from 1000 to 1300 °C a slab of steel comprising from 0.05 to 0.45 wt. % C, 0.1 to 1.0 wt.% Ni, 0.1 to 2.0 wt.% Mn, 0.3 to 1.5 wt.% Ti, optionally comprising at least one of 0.1 to 2.0 wt.% Cu, 0.1 to 10.0 wt.% Ni, 0.1 to 3.0 wt.% Cr, 0.1 to 3.0 wt.% Mo and 0.0003 to 0.01 wt.% B, and further optionally comprising at least one of 0.005 to 0.5 wt.% Nb and 0.01 to 0.5 wt.% V, and the balance Fe having the carbon equivalent C^* , that is: $C^* = (C \text{ wt.} \%) - (Ti \text{ wt.} \%) (12/48)$,
(where (C wt. %) is the carbon content of said abrasion resistant steel and (Ti wt. %) is the titanium content of said abrasion resistant steel);
hot rolling said slab into a hot rolled product, with the temperature upon termination of hot rolling being within a range of from the Ar_3 point of the abrasion resistant steel to 1000 °C; and
heat treating the hot rolled product according to the carbon equivalent C^* of $C^* \leq 0.20$ wt.% the heat treatment being carried out by one process selected from the following (a) to (e), that is:

- (a) directly quenching the hot rolled product;
- (b) air cooling the hot rolled product;

reheating the air cooled product to a temperature at least as high as the Ac_3 point of the abrasion resistant steel; and
quenching the reheated product;

- (c) air cooling the hot rolled product;
- (d) directly quenching the hot rolled product; and tempering the quenched product at a temperature which is, at most, the Ac_1 point of the abrasion resistant steel;
- (e) air cooling the hot rolled product;

reheating the air cooled product to a temperature at least as high as the Ac_3 point of the abrasion resistant steel;
quenching the reheated product; and
tempering the hot rolled product at a temperature which is, at most, the Ac_1 point of the abrasion resistant steel.

- 2. A method according to claim 1, wherein the Ti content is from 0.3 to 1.0 wt.%.
- 3. A method according to claim 1, wherein the Ti content is from 1.0 to 1.5 wt.%.

Patentansprüche

- 1. Verfahren zur Herstellung eines abriebfesten Stahls, umfassend die Schritte:

Aufheizen eines Stahlwalzblocks, umfassend 0,05 bis 0,45 Gew.% C, 0,1 bis 1,0 Gew.% Si, 0,1 bis 2,0 Gew.% Mn, 0,3 bis 1,5 Gew.% Ti, wahlweise umfassend mindestens ein Element aus 0,1 bis 2,0 Gew.% Cu, 0,1 bis 10,0 Gew.% Ni, 0,1 bis 3,0 Gew.% Cr, 0,1 bis 3,0 Gew.% Mo mit 0,0003 bis 0,001 Gew.% B, und mindestens eines Elements aus 0,005 bis 0,5 Gew.% Nb und 0,01 bis 0,5 Gew.% V, und Rest-Fe mit einem Kohlenstoffäquivalent C^* , welches beträgt: $C^* = (C \text{ Gew.} \%) - (Ti \text{ Gew.} \%) (12/48)$, (worin (C-Gew.%) der Kohlenstoffgehalt des abriebfesten Stahls und (Ti-Gew.%) der Titangehalt des abriebfesten Stahls ist), auf eine Temperatur im Bereich von 1000 bis 1300°C;

Warmwalzen des Walzblocks in ein warmgewalztes Produkt mit einer Temperatur bei Beendigung des Warmwalzens in dem Bereich zwischen dem Ar_3 -Punkt des abriebfesten Stahls und 1000°C; und

Wärmebehandlung des warmgewalzten Produkts entsprechend dem Kohlenstoffäquivalent C^* , von C^* mit $C^* \leq 0,20$ Gew.%, wobei die Wärmebehandlung nach einem der folgenden Verfahren (a) bis (e) ausgeführt wird:

- (a) direktes Abschrecken des warmgewalzten Produkts;
- (b) Luftkühlen des warmgewalzten Produkts;

Wiederaufheizen des luftgekühlten Produkts auf eine Temperatur von mindestens dem Ac_3 -Punkt des abriebfesten Stahls; und

Abschrecken des wiederaufgeheizten Produkts;

(c) Luftkühlen des warmgewalzten Produkts;

(d) direktes Abschrecken des warmgewalzten Produkts; und
Temperieren des abgeschreckten Produkts auf eine Temperatur von maximal dem Ac_1 -Punkt des abriebfesten Stahls; oder

(e) Luftkühlen des warmgewalzten Produkts;

Wiederaufheizen des luftgekühlten Produkts auf eine Temperatur von mindestens dem Ac_3 -Punkt des abriebfesten Stahls;

Abschrecken des wiederaufgeheizten Produkts; und

Temperieren des warmgewalzten Produkts auf eine Temperatur von maximal dem Ac_1 -Punkt des abriebfesten Stahls.

2. Verfahren gemäss Anspruch 1, worin der Ti-Gehalt zwischen 0,3 und 1,0 Gew.% beträgt.

3. Verfahren gemäss Anspruch 1, worin der Ti-Gehalt zwischen 1,0 und 1,5 Gew.% beträgt.

Revendications

1. Procédé de fabrication d'un acier résistant à l'abrasion comprenant les étapes consistant à:

chauffer à une température dans le domaine de 1000 à 1300°C une brame d'acier comprenant de 0,05 à 0,45% en poids de C, 0,1 à 1,0% en poids de Si, 0,1 à 2,0% en poids de Mn, 0,3 à 1,5% en poids de Ti, comprenant éventuellement au moins l'un parmi 0,1 à 2,0% en poids de Cu, 0,1 à 10% en poids de Ni, 0,1 à 3,0% en poids de Cr, 0,1 à 3,0% en poids de Mo et 0,0003 à 0,01% en poids de B, et comprenant en outre éventuellement au moins l'un parmi 0,005 à 0,5% en poids de Nb et 0,01 à 0,5% en poids de V, et le complément en Fe, ayant un équivalent en carbone C^* , à savoir: $C^* = (C \% \text{ en poids}) - (Ti \% \text{ en poids})(12/48)$, (où (C % en poids) est la teneur en carbone dudit acier résistant à l'abrasion et (Ti % en poids) est la teneur en titane dudit acier résistant à l'abrasion);

laminer à chaud ladite brame en un produit laminé à chaud, la température après achèvement du laminage à chaud étant dans le domaine allant du point Ar_3 de l'acier résistant à l'abrasion à 1000°C; et
traiter à chaud le produit laminé à chaud selon l'équivalent en carbone C^* , de $C^* \leq 0,20\%$ en poids, le traitement à chaud étant effectué par un procédé choisi parmi les procédés suivants (a) à (e), à savoir:

(a) la trempe directe du produit laminé à chaud,

(b) le refroidissement à l'air du produit laminé à chaud;

le réchauffage du produit refroidi à l'air à une température au moins aussi élevée que le point Ac_3 de l'acier résistant à l'abrasion; et la trempe du produit réchauffé,

(c) le refroidissement à l'air du produit laminé à chaud;

(d) la trempe directe du produit laminé à chaud; et le revenu du produit trempé à une température qui est, au plus, le point Ac_1 de l'acier résistant à l'abrasion,

(e) le refroidissement à l'air du produit laminé à chaud;

le réchauffage du produit refroidi à l'air à une température au moins aussi élevée que le point Ac_3 de l'acier résistant à l'abrasion;

la trempe du produit réchauffé; et

le revenu du produit laminé à chaud à une température qui est, au plus, le point Ac_1 de l'acier résistant à l'abrasion.

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2. Procédé selon la revendication 1, dans lequel la teneur en Ti est de 0,3 à 1,0% en poids.
3. Procédé selon la revendication 1, dans lequel la teneur en Ti est de 1,0 à 1,5% en poids.

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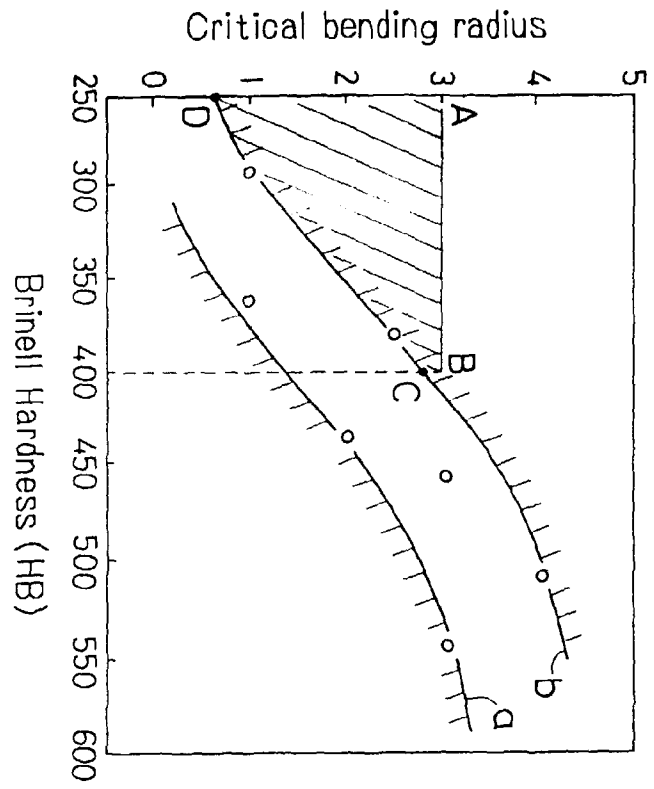


Fig. 1

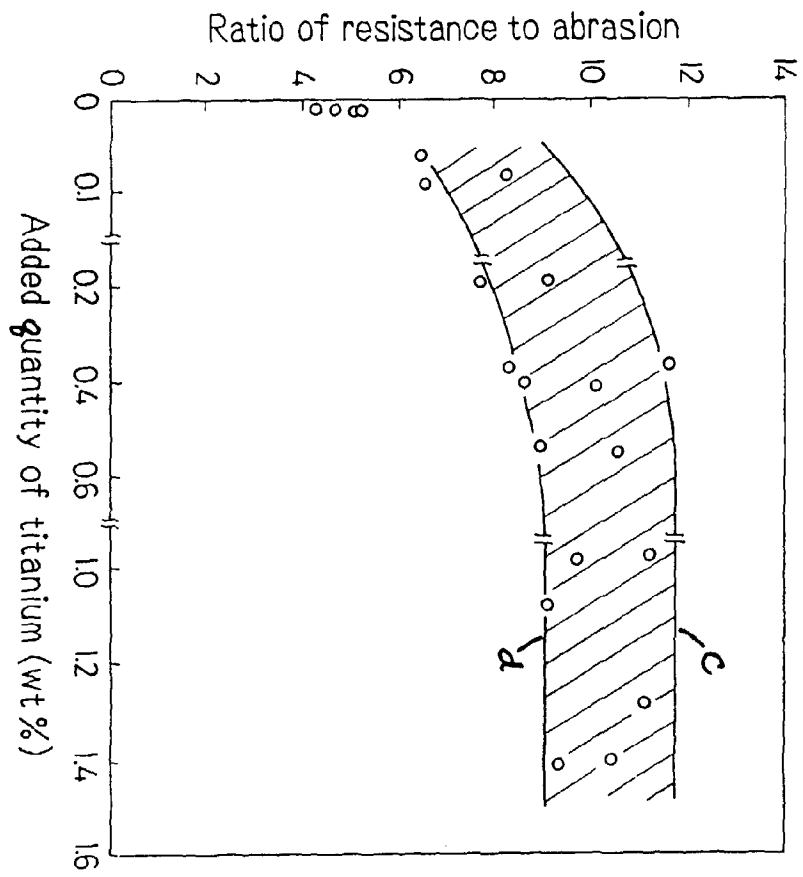


Fig. 2

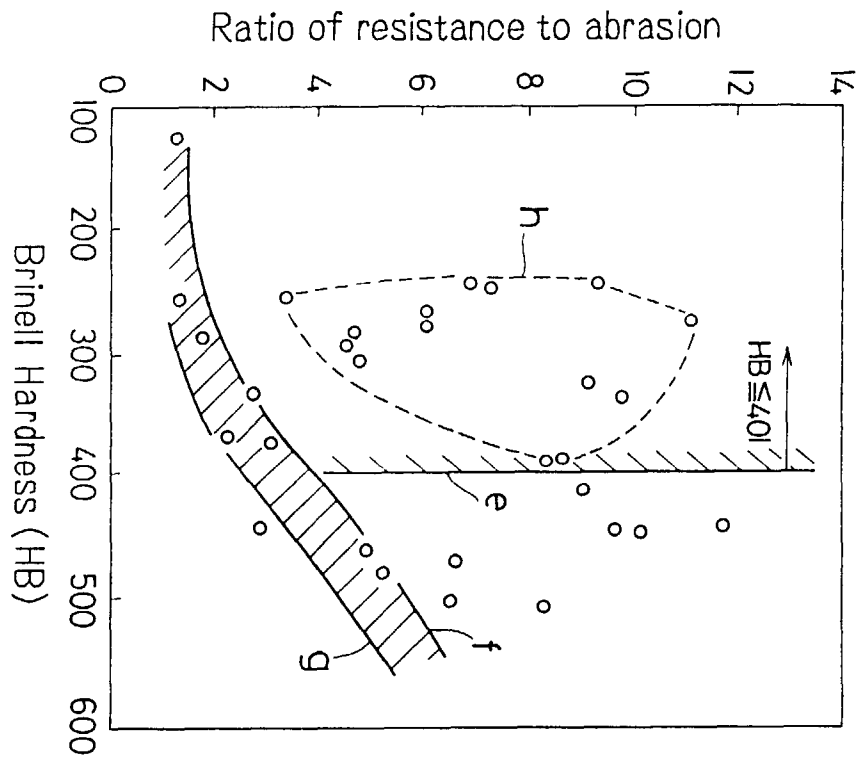


Fig. 3

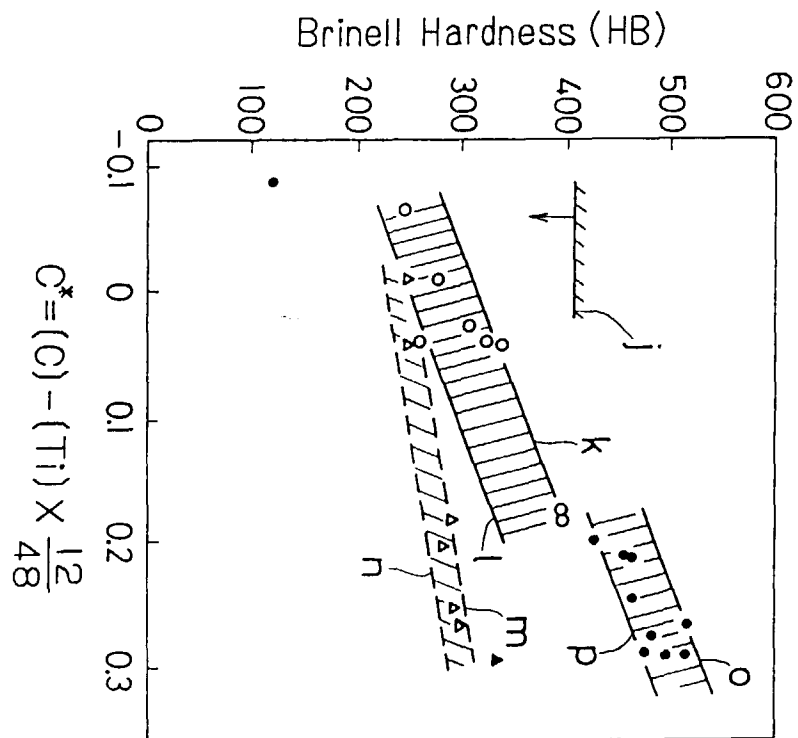


Fig. 4