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(54) ABRASION-RESISTANT STEEL SHEET HAVING EXCELLENT PROCESSABILITY, AND METHOD FOR PRODUCTION THEREOF

ABRIEBFESTES STAHLBLECH MIT HERVORRAGENDER VERARBEITBARKEIT UND HERSTELLUNGSVERFAHREN DAFÜR

TÔLE D'ACIER RÉSISTANTE À L'ABRASION EXTRÊMEMENT FACILE À METTRE EN UVRE ET SON PROCÉDÉ DE PRODUCTION

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Description

Technical Field

[0001] The present invention relates to an abrasion resistant steel suitable for members, which have issues in wear or abrasion resulting from contact with earth and sand, of industrial machines and transporting machines, e.g., power shovels, bulldozers, hoppers, and buckets, used in the fields of construction, civil engineering, mining, and the like and a production method thereof. In particular it relates to an abrasion resistant steel excellent in bending formability.

Background Art

[0002] Steels having an excellent abrasion resistant property are used for members which are worn and abraded by earth and sand, in order to obtain its prolonged service life. It is known that the abrasion resistant property of the steel is improved by increasing hardness. Therefore, steels having a hardness increased by subjecting the steel containing large amounts of alloy elements, e.g., Cr and Mo, to a heat treatment, e.g., quenching, has been used for a member required to have the abrasion resistant property.

[0003] For example, Japanese Unexamined Patent Application Publication No. 62-142726 proposes a method for producing an abrasion resistant steel plate, wherein a steel containing 0.10% to 0.19% of C and appropriate amounts of Si and Mn and having Ceq limited to 0.35% to 0.44% is hot rolled and, thereafter, is quenched directly or is reheated to 900°C to 950°C and quenched, followed by tempering at 300°C to 500°C so as to have a steel surface hardness of 300 HV (Vickers hardness) or more.

[0004] Japanese Unexamined Patent Application Publication No. 63-169359 proposes a method for producing an abrasion resistant thick steel plate, wherein a steel containing 0.10% to 0.20% of C and appropriately adjusted amounts of Si, Mn, P, S, N, and Al, or further containing at least one element of Cu, Ni, Cr, Mo, and B is hot rolled, followed directly by quenching or above steel is hot rolled, cooled through standing, reheated, and quenched, so as to be provided with a hardness of 340 HB (Brinell hardness) or more.

[0005] Japanese Unexamined Patent Application Publication No. 1-142023 proposes a method for producing an abrasion resistant steel, wherein a steel containing 0.07% to 0.17% of C and appropriately adjusted amounts of Si, Mn, P, S, N, and Al, or further containing at least one element of Cu, Ni, Cr, Mo, and B is hot rolled, followed directly by quenching or above steel is hot rolled, air cooled to the room temperature, reheated, and quenched, so as to produce a steel having a surface hardness of 321 HB or more and exhibiting excellent bending formability.

[0006] In the technologies described in Japanese Unexamined Patent Application Publication No. 62-142726, Japanese Unexamined Patent Application Publication No. 63-169359, and Japanese Unexamined Patent Application Publication No. 1-142023, the hardness is increased taking advantage of solid solution hardening, transformation hardening, precipitation hardening, and the like by addition of large amounts of alloy elements and, thereby, the abrasion resistant characteristic is improved. However, in the case where the hardness is increased taking advantage of solid solution hardening, transformation hardening, precipitation hardening, and the like by addition of large amounts of alloy elements, the weldability and the formability deteriorate and, furthermore, the production cost increases.

[0007] Regarding the member required to have the abrasion resistant property, in some cases, merely an increase in hardness of only a surface and the vicinity of surface to improve the abrasion resistant property is good enough depending on the use condition. Regarding the steel used in such a case, it is believed that addition of large amounts of alloy elements, e.g., Cr, Mo, and the like is not necessary, but a heat treatment, e.g., quenching, is conducted so as to allow only a surface and the vicinity of surface to have a hardened structure.

[0008] In general, an increase in the amount of solid solution C in the steel is required to increase the hardness of the hardened structure. However, the increase in the amount of solid solution C causes deterioration of the weldability, deterioration of the bending formability, and the like. In particular, the deterioration of the bending formability limits the bending which is required of the member and, therefore, the use condition is limited.

[0009] Consequently, an abrasion resistant steel with the abrasion resistant property of which can be improved without increasing the hardness excessively, has been desired. Japanese Patent No. 3089882 proposes an abrasion resistant steel containing 0.10% to 0.45% of C, appropriately adjusted amounts of Si, Mn, P, S, and N, and 0.10% to 1.0% of Ti, including 400 particles/mm^2 or more of TiC precipitates or complex precipitates of TiC and TiN or TiS, which have an average particle diameter of 0.5 μm or more, having 0.05% or more, and less than 0.4% of Ti*, and exhibiting improved surface properties.

[0010] Furthermore, Japanese Unexamined Patent Application Publication No. 4-41616 proposes a method for producing an abrasion resistant steel, wherein 0.05% to 0.45% of C, 0.1% to 1.0% of Si, 0.1% to 1.0% of Mn, and 0.05% to 1.5% of Ti are contained and the bending formability is improved by specifying a surface hardness to be 401 or less on a Brinell hardness basis.

[0011] According to the technologies described in Japanese Patent No. 3089882 and Japanese Unexamined Patent

Application Publication No. 4-41616, coarse precipitates primarily containing TiC are produced in solidification and, thereby, the abrasion resistant property can be improved inexpensively without increasing the hardness excessively.

[0012] However, in the technology described in Japanese Patent No. 3089882, a quenching heat treatment is conducted and, thereby, the microstructure remains in a martensitic structure which is the state after quenching and the strength is high. As a result, the deformation resistance in bending increases and it is difficult to say that the bending is easy. Therefore, a bending formability problem remains.

[0013] In the technology described in Japanese Unexamined Patent Application Publication No. 4-41616, the surface hardness is specified to be 401 or less on a Brinell hardness basis in order to ensure the bending formability. However, since the amount of addition of the alloy elements is large, the tensile strength exceeds 780 MPa. Therefore, satisfactory bending formability is not achieved from the viewpoint of reduction in a load during forming.

[0014] Regarding the abrasion resistant steel described in each of Japanese Unexamined Patent Application Publication No. 62-142726, Japanese Unexamined Patent Application Publication No. 63-169359, Japanese Unexamined Patent Application Publication No. 1-142023, and Japanese Unexamined Patent Application Publication No. 4-41616, it is indispensable to conduct the heat treatment, and problems remain from the viewpoint of production times and production costs.

[0015] Accordingly, it is an object of the present invention to provide an abrasion resistant steel which can be produced by hot rolling without conducting a heat treatment and which is excellent in abrasion resistant property and bending formability, as well as a production method thereof.

Disclosure of Invention

[0016] In order to achieve the above-described object, the inventors of the present invention conducted intensive research on various factors having influences on the abrasion resistant property and the bending formability. As a result, it was found that a forming load in the bending was able to be reduced, i.e. the bending formability was able to be improved, while the abrasion resistant property was ensured, by including a chemical composition containing Ti and C, allowing a microstructure of base metal to include a complex structure of a ferrite and pearlite structure, which remained unchanged after rolling, as a base phase, and dispersing a second phase (hard phase: Ti based carbide) in a matrix.

[0017] The present invention has been made on the basis of the obtained findings and additional research. That is, the present invention relates to the followings.

1. An abrasion resistant steel excellent in formability, containing, on a percent by mass basis, 0.05% to 0.35% of C, 0.05% to 1.0% of Si, 0.1% to 2.0% of Mn, 0.1% to 1.2% of Ti, 0.1% or less of Al, 0.05% to 1.0% Mo, at least one element of 0.1% to 1.0% of Cu, 0.1% to 2.0% of Ni, 0.1% to 1.0% of Cr, 0.05% to 1.0% of W, and 0.0003% to 0.0030% of B, and optionally at least one element of 0.005% to 1.0% of Nb and 0.005% to 1.0% of V on a percent by mass basis, and/or not more than 0.015% P, and/or not more than 0.012% S; and/or 0.01% or less N, and/or wherein the remainder including Fe and incidental impurities, where DI* represented by Formula (1) is less than 60.

$$DI^* = 33.85 \times (0.1 \times C^*)^{0.5} \times (0.7 \times Si + 1) \times (3.33 \times Mn + 1) \times (0.35 \times Cu + 1) \times (0.36 \times Ni + 1) \times (2.16 \times Cr + 1) \times (3 \times Mo^* + 1) \times (1.5 \times W^* + 1) \quad (1)$$

where $C^* = C - 1/4 \times (Ti - 48/14N)$, $Mo^* = Mo \times (1 - 0.5 \times (Ti - 48/14N))$, $W^* = W \times (1 - 0.5 \times (Ti - 48/14N))$, and C, Si, Mn, Cu, Ni, Cr, Mo, W, Ti, and N represent contents (percent by mass), and wherein the steel sheet has TS 800MPa and YS < 600MPa.

2. The abrasion resistant steel according to the item 1, characterized in that a microstructure of base metal includes a ferrite and pearlite structure as a base phase having a volume fraction of 90% or more, and a Ti based carbide hard phase is dispersed in the base phase.

3. The abrasion resistant steel according to the item 3, characterized in that the dispersion density of the above-described hard phase is 400 particles/mm^2 or more.

4. A method for producing an abrasion resistant steel excellent in formability, the method characterized by including the steps of hot rolling a steel slab having the composition according to the item 1 or the item 2 and conducting cooling to 400°C or lower at a cooling rate of 2°C/s or less.

5. The method for producing an abrasion resistant steel excellent in formability, according to the item 4, the method characterized in that the hot rolling reduction rate at 920°C or lower is specified to be 30% or more and the rolling finishing temperature is specified to be 900°C or lower.

[0018] Here, it is preferable that the above-described hard phase is specified to be a Ti based carbide, e.g., TiC. Examples thereof can include TiC, (NbTi)C, (VTi)C, and a TiC which Mo and/or W is dissolved in.

[0019] According to the present invention, the abrasion resistant steel exhibiting the bending formability improved without impairing the abrasion resistant property can be obtained without conducting a heat treatment after hot rolling. Therefore, rational production, e.g., a reduction in heat treatment cost and a reduction in production time, can be conducted, so that remarkable industrial effects are exerted.

Brief Description of Drawings

[0020]

Fig. 1 is a diagram showing an effect of the amount of addition of Ti on the abrasion resistant property.
Fig. 2 is a diagram showing an effect of the amount of addition of Ti on the tensile properties (yield strength: YS, tensile strength: TS).
Fig. 3 is a diagram showing an effect of DI* on the abrasion resistant property.
Fig. 4 is a diagram showing an effect of the amount of DI* on the tensile properties (yield strength: YS, tensile strength: TS).

Best Modes for Carrying Out the Invention

[0021] The reasons for specifying the chemical composition and the microstructure of base metal of the abrasion resistant steel according to the present invention will be described. (Chemical composition) Hereafter, every expression in the unit % is on a percent by mass basis.

C: 0.05% to 0.35%

[0022] An element C is effective for increasing the hardness of the matrix in the microstructure of base metal so as to improve the abrasion resistant property, as well as for forming Ti carbide serving as a hard second phase (hereafter may be referred to as a hard phase) so as to improve the abrasion resistant property. In order to obtain such effects, it is necessary that the content is 0.05% or more.

[0023] On the other hand, if the content of C exceeds 0.35%, the carbide serving as the hard phase become coarse, and cracking occurs during bending while the carbide serves as a crack initiation site. Consequently, C is specified to be within the range of 0.05% to 0.35%. Preferably, C is 0.15% to 0.32%.

Ti: 0.1% to 1.2%

[0024] Elements Ti and C are important in the present invention, and Ti is an indispensable element which forms Ti carbide serving as a hard phase contributing to improvement of the abrasion resistant property. In order to obtain such effects, it is necessary that the content is 0.1% or more.

[0025] Fig. 1 shows an effect of the amount of addition of Ti on the abrasion resistant property. Fig. 2 shows an effect of the amount of addition of Ti on the tensile properties (yield strength: YS, tensile strength: TS). In Fig. 1, the vertical axis indicates the abrasion resistance ratio, where the amount of abrasion in a rubber wheel abrasion test is compared with the abrasion weight loss of a mild steel (SS400) .

[0026] If the amount of addition of Ti is 0.1% or more, characteristics in which the abrasion resistant property is higher than or equal to that of a common abrasion resistant steel are obtained and TS is reduced to 800 MPa or less. That is, the formability can be improved while the abrasion characteristics equal to the known abrasion resistant steel, which has been subjected to a quenching heat treatment, is maintained.

[0027] The test steel in the rubber wheel abrasion test was produced by rolling a steel slab containing 0.33%C-0.35%Si-0.82%Mn-0.05% to 1.2%Ti to 19 mmt and, thereafter, conducting air-cooling at a cooling rate of 0.5°C/s.

[0028] The resulting steel was subjected to tensile tests and abrasion tests. Regarding the tensile test, a JIS No. 5 test piece was taken on the basis of the stipulation of JIS Z2201, and the tensile test was conducted so as to determine the tensile properties (yield strength: YS, tensile strength: TS).

[0029] Regarding the abrasion test, the rubber wheel abrasion test was conducted on the basis of ASTM G65, and the test results were organized in terms of the abrasion resistance ratio that is the ratio of the amount of abrasion weight

loss of the mild steel (SS400) to the amount of abrasion weight loss of each test steel. The larger abrasion resistance ratio corresponds to better abrasion characteristics.

[0030] For the purpose of a comparison test, the same test as the above-described test was conducted regarding an abrasion resistant steel produced by a common heat treatment. The obtained results are shown as a known steel in Fig. 1 and Fig. 2. Here, the common abrasion resistant steel refers to a steel which is a material produced by hot rolling a steel having a composition of 0.15 mass%C-0.35 mass%Si-1.50 mass%Mn-0.13 mass%Cr-0.13 mass%Mo-0.01 mass%Ti-0.0010 mass%B, conducting reheating to 900°C and, thereafter, conducting a quenching heat treatment, and which has a Brinell hardness of about 400 HB.

[0031] On the other hand, if the Ti content exceeds 1.2%, the hard phase (Ti based carbide) becomes coarse, and cracking occurs during bending while the coarse hard phase serves as a crack initiation site. Consequently, Ti is limited within the range of 0.1% to 1.2%, and preferably 0.1% to 0.8%.

Si: 0.05% to 1.0%

[0032] An element Si is effective as a deoxidizing element. In order to obtain such an effect, it is necessary that the content is 0.05% or more. Furthermore, Si is an element which forms a solid solution in a steel so as to contribute to an increase in hardness because of solid solution strengthening. However, if the content exceeds 1.0%, problems occur in that, for example, the ductility and the toughness deteriorate and the inclusion content increases. Therefore, preferably, Si is limited within the range of 0.05% to 1.0%. More preferably, Si is 0.05% to 0.40%.

Mn: 0.1% to 2.0%

[0033] An element Mn contributes to an increase in hardness because of solid solution strengthening. In order to obtain such an effect, it is necessary that the content is 0.1% or more. On the other hand, if the content exceeds 2.0%, the weldability deteriorates. Therefore, preferably, Mn is limited within the range of 0.1% to 2.0%. More preferably, Mn is 0.1% to 1.60%.

Al: 0.1% or less

[0034] An element Al acts as a deoxidizing element. Such an effect is observed if the content is 0.0020% or more. However, a large content exceeding 0.1% allows the cleanness of the steel to deteriorate. Therefore, preferably, Al is limited to 0.1% or less.

[0035] At least one element of 0.1% to 1.0% of Cu, 0.1% to 2.0% of Ni, 0.1% to 1.0% of Cr, 0.05% to 1.0% of Mo, 0.05% to 1.0% of W, and 0.0003% to 0.0030% of B

Cu: 0.1% to 1.0%

[0036] An element Cu improve the hardenability because of solid solution. In order to obtain this effect, it is necessary that the content is 0.1% or more. On the other hand, if the content exceeds 1.0%, the hot formability deteriorates. Therefore, preferably, Cu is limited within the range of 0.1% to 1.0%. More preferably, Cu is 0.1% to 0.5%.

Ni: 0.1% to 2.0%

[0037] An element Ni improve the hardenability because of solid solution. Such an effect becomes remarkable if the content is 0.1% or more. On the other hand, if the content exceeds 2.0%, the material cost increases significantly. Therefore, preferably, Ni is limited within the range of 0.1% to 2.0%. More preferably, Ni is 0.1% to 1.0%.

Cr: 0.1% to 1.0%

[0038] An element Cr exerts an effect of improving the hardenability. In order to obtain such an effect, it is necessary that the content is 0.1% or more. However, if the content exceeds 1.0%, the weldability deteriorates. Therefore, preferably, Cr is limited within the range of 0.1% to 1.0%. More preferably, Cr is 0.1% to 0.8%. Further preferably, Cr is 0.4% to 0.7%.

Mo: 0.05% to 1.0%

[0039] An element Mo improves the hardenability. In order to obtain such an effect, it is necessary that the content is 0.05% or more. On the other hand, if the content exceeds 1.0%, the weldability deteriorates. Therefore, Mo is limited within the range of 0.05% to 1.0%. Preferably Mo is 0.05% to 0.40%.

W: 0.05% to 1.0%

[0040] An element W improves the hardenability. In order to obtain such an effect, it is necessary that the content is 0.05% or more. On the other hand, if the content exceeds 1.0%, the weldability deteriorates. Therefore, preferably, W is limited within the range of 0.05% to 1.0%. More preferably, W is 0.05% to 0.40%. Since Mo and W form solid solutions in TiC, an effect of increasing the amount of hard phase is also exerted.

B: 0.0003% to 0.0030%

[0041] An element B segregates at grain boundaries, strengthen grain boundaries, and contributes to improvement of the toughness effectively. In order to obtain such effects, it is necessary that the content is 0.0003% or more. On the other hand, if the content exceeds 0.0030%, the weldability deteriorates. Therefore, preferably, B is limited within the range of 0.0003% to 0.0030%. More preferably, B is 0.0003% to 0.0015%.

DI* < 60

[0042] In the present invention, DI* (hardenability index) is defined as $DI^* = 33.85 \times (0.1 \times C^*)^{0.5} \times (0.7 \times Si + 1) \times (3.33 \times Mn + 1) \times (0.35 \times Cu + 1) \times (0.36 \times Ni + 1) \times (2.16 \times Cr + 1) \times (3 \times Mo^* + 1) \times (1.5 \times W^* + 1)$, where $C^* = C - 1/4 \times (Ti - 48/14N)$, $Mo^* = Mo \times (1 - 0.5 \times (Ti - 48/14N))$, and $W^* = W \times (1 - 0.5 \times (Ti - 48/14N))$, and satisfies $DI^* < 60$. Here, C, Si, Mn, Cu, Ni, Cr, Mo, W, Ti, and N represent contents (percent by mass). Fig. 3 shows an effect of DI* on the abrasion resistant property. Fig. 4 shows an effect of DI* on the tensile properties (yield strength: YS, tensile strength: TS). In Fig. 3, the vertical axis indicates the abrasion resistance ratio, where the amount of abrasion in the rubber wheel abrasion test is compared with the amount of abrasion of the mild steel (SS400). The larger abrasion resistance ratio corresponds to better abrasion characteristics.

[0043] As is recognized from Fig. 3 and Fig. 4, in the case where DI* is less than 60, the amount of abrasion is at a level equal to that of a common abrasion resistant steel regardless of low strength, that is, TS is 800 MPa or less.

[0044] On the other hand, if DI* is 60 or more, excellent abrasion resistant property is exhibited, however, the tensile strength is 800 MPa or more and the formability is poor. The reason is estimated that in the case where DI* is 60 or more, a ferrite and bainite structure results.

[0045] The test steel in the rubber wheel abrasion test was produced by rolling a steel slab containing 0.34%C-0.22%Si-0.55%Mn-0.22%Ti on a percent by mass basis and at least one element of Cu, Ni, Cr, Mo, and W, where DI* is 40 to 120, to 8 mmt and, thereafter, conducting air-cooling (cooling rate: 1.2°C/s) .

[0046] The resulting steel was subjected to tensile tests and abrasion tests. Regarding the tensile test, a JIS No. 5 test piece was taken on the basis of the stipulation of JIS Z2201, and the tensile test was conducted so as to determine the tensile properties (yield strength: YS, tensile strength: TS).

[0047] The rubber wheel abrasion test was conducted on the basis of ASTM G65, and the test results were organized in terms of the abrasion resistance ratio that is the ratio of the amount of abrasion of the mild steel (SS400) to the amount of abrasion of each test steel.

[0048] The above-described components constitute the basic components and an excellent abrasion resistant property is obtained. In the present invention, a hard second phase is formed and Nb and V, which are elements contributing to the abrasion resistant property, can be included as selective elements in order to further improve the abrasion resistant property.

Nb: 0.005% to 1.0%

[0049] An element Nb is added in combination with Ti, forms a complex carbide ((NbTi)C) of Ti and Nb, and disperses as a hard second phase, so as to contribute to an improvement of the abrasion resistant property effectively. In order to obtain such an effect of improving the abrasion resistant property, it is necessary that the content is 0.005% or more. On the other hand, if the content exceeds 1.0%, the hard second phase (complex carbide of Ti and Nb) becomes coarse, and cracking occurs during bending while the hard second phase (complex carbide of Ti and Nb) serves as a crack initiation site. Consequently, in the case where Nb is added, preferably, Nb is limited within the range of 0.005% to 1.0%. More preferably, Nb is 0.1% to 0.5%.

V: 0.005% to 1.0%

[0050] In a manner similar to that in the case of Nb, an element V is added in combination with Ti, forms a complex carbide ((VTi)C) of Ti and V, and disperses as a hard second phase, so as to contribute to an improvement of the abrasion resistant property effectively. In order to obtain such an effect of improving the abrasion resistant property, it

is necessary that the content is 0.005% or more.

[0051] On the other hand, if the content exceeds 1.0%, the hard second phase (complex carbide of Ti and V) becomes coarse, and cracking occurs during bending while the hard second phase (complex carbide of Ti and V) serves as a crack initiation site. Consequently, in the case where V is added, preferably, V is limited within the range of 0.005% to 1.0%. More preferably, V is 0.1% to 0.5%.

[0052] In the case where Nb and V are added in combination, the same effect of improving the abrasion resistant property is exerted merely except that the hard second phase becomes (NbVTi)C. In the case where N is contained, a carbonitride may be formed in addition to a carbide, but the same effect is obtained.

[0053] However, in the case where the amount of addition of N exceeds 0.01%, the proportion of N in the carbonitride increases, the hardness of the hard second phase decreases, and deterioration of the abrasion resistant property is concerned. Therefore, it is preferable that the amount of addition of N is specified to be 0.01% or less.

(Microstructure of base metal)

[0054] Regarding the abrasion resistant steel according to the present invention, a microstructure of base metal is specified to be a microstructure in which a base phase is a ferrite and pearlite structure, and a hard phase (hard second phase) is dispersed in the base phase. The base phase means that the volume fraction thereof is 90% or more. Regarding the steel according to the present invention, two phases, i.e. ferrite and pearlite, constitute 90% or more of the whole.

[0055] Furthermore, it is desirable that the volume fraction of the ferrite phase is 70% or more, among them, and the ferrite phase has an average particle diameter of 20 μm in terms of an equivalent circle diameter. Preferably, the base phase has a Brinell hardness of 300 HB or less in consideration of the formability.

[0056] It is preferable that the hard phase is a Ti based carbide, e.g., TiC. Examples thereof can include TiC, (NbTi)C, (VTi)C, and TiC which Mo and/or W is dissolved in.

[0057] The size of the hard phase is not specifically limited. However, from the viewpoint of the abrasion resistant property, about 0.5 μm or more, and 50 μm or less is preferable. Furthermore, it is preferable that the dispersion density of the hard phase is 400 particles/mm^2 or more from the viewpoint of the abrasion resistant property.

[0058] Regarding the size of the hard phase, the area of each hard phase is measured, an equivalent circle diameter is calculated from the area, the resulting equivalent circle diameters are arithmetically averaged, and the average value is assumed to be the size (average particle diameter) of the hard phase in the steel.

(Production method)

[0059] Regarding the abrasion resistant steel according to the present invention, preferably, a molten steel having the above-described composition is melted by a known melting method and steel materials, e.g., a slab, having a predetermined dimension is produced by a continuous casting method or an ingot making-blooming method.

[0060] In order to adjust the size and the number of the hard phase at predetermined values, for example, in the case where the continuous casting method is used, preferably, the cooling is adjusted in such a way that the cooling rate of a cast slab having a thickness of 200 to 400 mm in a temperature range of 1,500°C to 1,200°C becomes 0.2°C/s to 10°C/s.

[0061] In the case where the ingot making method is used as well, there is a need to adjust the size of the ingot and the cooling condition in such a way that the size and the number of the hard phase become predetermined values, as a matter of course.

[0062] The steel material (cast slab or ingot) is hot rolled immediately without cooling or the above material is cooled, reheated to 950°C to 1,250°C, and hot rolled, so as to produce a steel having a predetermined sheet thickness. After the hot rolling, cooling is conducted at an average cooling rate of 2°C/s or less without a heat treatment.

[0063] If the cooling rate exceeds 2°C/s, the ferrite and pearlite structure is not obtained, the tensile strength becomes 800 MPa or more, the forming load in the steel bending increases, and the formability deteriorates. Therefore, the cooling rate is specified to be 2°C/s or less.

[0064] The hot rolling condition is not specifically limited, insofar as the steel having predetermined size and shape can be produced. However, in consideration of the toughness which is a performance necessary to the steel, it is necessary that the rolling reduction rate at a steel surface temperature of 920°C or lower is specified to be 30% or more and the rolling finishing temperature is specified to be 900°C or lower.

[0065] The abrasion resistant steel according to the present invention can be used for various purposes in which bending is required to the hot-rolled steel with no need to conduct a heat treatment after the hot rolling.

EXAMPLES

[0066] A molten steel having the composition shown in Table 1 was melted in a vacuum melting furnace so as to produce a small steel ingot (50 kg) (steel material). Thereafter, heating to 1,050°C to 1,250°C and hot rolling were

conducted so that a test steel having a sheet thickness of 6 to 100 mm was produced. Regarding each test steel, a microstructure observation, a tensile test, an abrasion test, a Charpy impact test, and a bend test were conducted.

(Microstructure observation)

[0067] A test piece for the microstructure observation was polished and etched with nital. Regarding the site at a position 1 mm under the surface layer, the microstructure was identified by using an optical microscope (magnification ratio: 400 times), and the ferrite grain diameter and the size and the number of the hard phase were measured. The microstructure constituting 90% or more of the observation field of view was assumed to be a base phase, and an average particle diameter determined by the above-described method was assumed to be the size of hard phase.

(Tensile test)

[0068] A JIS No. 5 test piece was taken on the basis of the stipulation of JIS Z2201, and the tensile test was conducted on the basis of the stipulation of JIS Z2241, so as to determine the tensile properties (yield strength: YS, tensile strength: TS). The present invention is specified to be within the range of a tensile strength (TS) of less than 800 MPa and a yield strength (YS) of less than 600 MPa.

(Abrasion test)

[0069] A test piece was t (sheet thickness) $\times$ 20 $\times$ 75 (mm) and the rubber wheel abrasion test was conducted by using abrasion sand on the basis of the stipulation of ASTM G65. After the test, the amount of abrasion of the test piece was measured.

[0070] The test results were evaluated on the basis of the abrasion resistance ratio = (amount of abrasion of mild steel)/(amount of abrasion of each test steel) with reference to the amount of abrasion (1.0) of the mild steel (SS400). The larger abrasion resistance ratio corresponds to better abrasion property. The range of the present invention is specified to be an abrasion resistance ratio of 4.0 or more.

(Charpy impact test)

[0071] A V notch impact test piece was taken from the position at 1/4 in the plate thickness direction toward an L direction on the basis of the stipulation of JIS Z2202. The Charpy impact test was conducted at a test temperature of 0°C on the basis of the stipulation of JIS Z2242, so as to determine Charpy absorbed energy. The number of test pieces was three, and an average value was determined.

(Bend test)

[0072] Test pieces were taken on the basis of the stipulation of JIS Z2204. The width was 50 mm and in the case where the plate thickness of the test steel was 45 mm or more, the thickness was reduced to 25 mm by cutting from one surface side. In the case where the plate thickness of the test steel was less than 45 mm, the plate thickness was not changed. The bend test was conducted on the basis of the stipulation of JIS Z2248. The bend test was conducted by a pressing bend method at a pressing bend radius r of 1.5t.

[0073] Table 2 shows the results of the microstructure observation, the tensile test, and the abrasion test. Invention examples (Steel Nos. 1 to 6 and Steel Nos. 8 and 9) are steels having a very excellent abrasion resistant property in spite of the tensile strength (TS) < 800 MPa and the yield strength (YS) < 600 MPa.

[0074] Furthermore, the Charpy absorbed energy was 27 J or more in the case where the rolling finishing temperature was 900°C or lower. On the other hand, Comparative examples are inferior in the abrasion resistant property to Invention examples, or inferior in the bending formability because YS and TS are high even if the abrasion resistant property is at an equal level.

Table 1

Steel symbol	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	W	V	Nb	Ti	B	Al	N	DI*	Remarks
A	0.12	0.33	1.22	0.015	0.003	-	-	0.81	0.12	-	-	-	0.28	0.0011	0.025	0.0025	54.9	Invention example
B	0.15	0.41	1.06	0.014	0.005	-	-	0.25	0.35	0.22	-	-	0.46	0.0013	0.035	0.0031	42.5	Invention example
C	0.25	0.27	1.12	0.012	0.008	0.45	0.35	-	0.24	0.33	-	-	0.67	-	0.051	0.0029	45.1	Invention example
D	0.30	0.43	1.31	0.008	0.011	-	-	-	0.33	-	-	-	0.74	0.0018	0.045	0.0045	42.0	Invention example
E	0.35	0.44	1.15	0.013	0.012	-	-	0.45	0.25	0.35	-	-	0.98	0.0006	0.038	0.0046	77.7	Invention example
F	0.25	0.29	0.88	0.011	0.004	-	-	0.28	0.12	-	0.05	-	0.77	-	0.051	0.0029	55.2	Invention example
G	0.25	0.23	0.83	0.015	0.003	-	-	0.33	0.15	-	-	0.31	0.63	0.0025	0.051	0.0029	58.1	Invention example
H	0.25	0.15	0.55	0.013	0.002	-	-	0.45	0.24	-	0.02	0.02	0.59	-	0.051	0.0029	56.8	Invention example
I	0.28	0.33	0.78	0.012	0.004	-	-	0.34	0.11	-	-	-	0.01*	0.0022	0.038	0.0033	57.9	Comparative example
J	0.24	0.29	1.18	0.013	0.005	-	-	0.57	0.22	-	-	-	0.9	0.0017	0.044	0.0034	115.2*	Comparative example
K	0.22	0.35	1.44	0.013	0.003	-	-	0.46	0.18	-	-	-	0.01*	0.0001	0.048	0.0043	111.2*	Comparative example
L	0.31	0.36	0.71					1.02	0.23		0.045		0.38	0.0008	0.045	0.0033	105.3*	Comparative example

Note 1 : asterisked numbers are out of the present invention

Note 2: $DI^*=33.85X(0.1XC^*)^{0.5}X(0.7XSi+1)X(3.33XMn+1)X(0.35XCu+1)X(0.36XNi+1)X(2.16XCr+1)X(3XMo^*+1)X(1.5XW^*+1)$

Table 2

Steel No.	Steel symbol	Sheet thickness (mm)	Rolling condition			Microstructure		
			Heating temperature (°C)	Finishing temperature (°C)	Cooling rate (°C/s)	Primary structure	Ferrite grain diameter (μ m)	Number of hard phase particles (particles/mm2)
1	A	6	1130	820	1.5	ferrite-pearlite	14.8	623
2	B	19	1130	810	0.5	ferrite-pearlite	16.3	732
3	C	25	1130	830	0.3	ferrite-pearlite	17.2	845
4	D	45	1130	840	0.1	ferrite-pearlite	15.3	903
5	E	60	1130	860	0.05	ferrite-pearlite	19.4	1125
6	F	100	1130	920	0.03	ferrite-pearlite	24.5	809
7	F	20	1130	920	45*	martensite*	-	888
8	G	19	1130	940	0.5	ferrite-pearlite	31.6	756
9	H	19	1130	910	0.5	ferrite-pearlite	29.5	735
10	1	19	1130	900	0.5	ferrite-pearlite	19.8	0*
11	J	19	1130	890	0.5	ferrite-bainite*	15.1	965
12	K	19	1130	880	0.5	ferrite-bainite*	14.9	0*
13	L	19	1130	880	0.5	ferrite-bainite*	11.2	675

Note 1 : asterisked numbers are out of the present invention
Note 2: abrasion resistance ratio (amount of abrasion of mild steel)/(amount of abrasion of each steel) (range of the present invention: abrasion resistance ratio 4.0 or more)

Table 3

Steel No.	Steel symbol	Sheet thickness (mm)	Bend test (radius 1.5t)	Tensile test		Abrasion resistance ratio	vE0 (J)	Remarks
				YS (MPa)	TS (MPa)			
1	A	6	○	559	761	4.6	49	Invention example
2	B	19	○	549	689	4.9	52	Invention example
3	C	25	○	538	669	5.2	56	Invention example
4	D	45	○	544	654	5.4	49	Invention example
5	E	60	○	521	603	4.3	51	Invention example
6	F	100	○	498	592	5.6	15	Invention example
7	F	20	×	1044	1339	6.3	48	Comparative example
8	G	19	○	533	672	5.2	16	Invention example
9	H	19	○	562	655	5.1	19	Invention example
10	I	19	○	523	651	1.6	210	Comparative example
11	J	19	×	712	889	4.8	14	Comparative example
12	K	19	×	803	905	2.4	85	Comparative example
13	L	19	×	699	838	5.9	16	Comparative example

Note 1 : abrasion resistance ratio (amount of abrasion of mild steel)/(amount of abrasion of each steel) (range of the present invention: abrasion resistance ratio 4.0 or more)
Note 2: vE0(J): Charpy impact absorbed energy (J) at a test temperature of 0°C

Claims

1. An abrasion resistant steel consisting of, on a percent by mass basis, 0.05% to 0.35% of C, 0.05% to 1.0% of Si, 0.1% to 2.0% of Mn, 0.1% to 1.2% of Ti, 0.1% or less of Al, 0,05% to 1.0% of Mo, at least one element of 0.1% to 1.0% of Cu, 0.1% to 2.0% of Ni, 0.1% to 1.0% of Cr, 0.05% to 1.0% of W, and 0.0003% to 0.0030% of B, and optionally at least one element of 0.005% to 1.0% of Nb and 0.005% to 1.0% of V on a percent by mass basis, and/or
not more than 0.015% P, and/or
not more than 0.012% S; and/or 0.01% or less N,
wherein the remainder being Fe and incidental impurities,
where DI* represented by Formula (1) is less than 60.

$$DI^* = 33.85 \times (0.1 \times C^*)^{0.5} \times (0.7 \times Si + 1) \times (3.33 \times Mn + 1) \times (0.35 \times Cu + 1) \times (0.36 \times Ni + 1) \times (2.16 \times Cr + 1) \times (3 \times Mo^* + 1) \times (1.5 \times W^* + 1) \quad (1)$$

where $C^* = C - 1/4 \times (Ti - (48/14)N)$, $Mo^* = Mo \times (1 - 0.5 \times (Ti - (48/14)N)$, $W^* = W \times (1 - 0.5 \times (Ti - (48/14)N)$, and C, Si, Mn, Cu, Ni, Cr, Mo, W, Ti, and N represent contents (percent by mass), and
wherein the steel sheet has TS < 800MPa and YS < 600MPa.

2. The abrasion resistant steel according to Claim 1, wherein a microstructure of base metal comprises a ferrite and pearlite phase as a base phase having a volume fraction of 90% or more, and a Ti based carbide hard phase is dispersed in the base phase.

3. The abrasion resistant steel according to Claim 2, wherein the dispersion density of the hard phase is 400 particles/mm^2 or more.

4. A method for producing an abrasion resistant steel, the method comprising the steps of hot rolling a steel slab having the composition according to Claim 1 and conducting cooling to 400°C or lower at a cooling rate of 2°C/s or less after hot rolling.

5. The method for producing an abrasion resistant steel excellent in formability, according to Claim 4, wherein the hot rolling reduction rate at 920°C or lower is specified to be 30% or more and the rolling finishing temperature is specified to be 900°C or lower.

Patentansprüche

1. Abriebfester Stahl, bestehend aus, basierend auf Massenprozent, 0,05 % bis 0,35 % C, 0,05 % bis 1,0 % Si, 0,1 % bis 2,0 % Mn, 0,1 % bis 1,2 % Ti, 0,1 % oder weniger Al, 0,05 % bis 1,0 % Mo, mindestens einem Element aus 0,1 % bis 1,0 % Cu, 0,1 % bis 2,0 % Ni, 0,1 % bis 1,0 % Cr, 0,05 % bis 1,0 % W und 0,0003 % bis 0,0030 % B, und optional
mindestens einem Element aus 0,005 % bis 1,0 % Nb und 0,005 % bis 1,0 % V auf Massenprozentbasis, und/oder
nicht mehr als 0,015 % P, und/oder
nicht mehr als 0,012 % S; und/oder 0,01 % oder weniger N,
wobei der Rest Fe und zufällige Verunreinigungen sind;
wobei DI*, repräsentiert durch die Formel (1), weniger als 60 ist.

$$DI^* = 33{,}85 \times (0{,}1 \times C^*)^{0{,}5} \times (0{,}7 \times Si + 1) \times (3{,}33 \times Mn + 1) \times (0{,}35 \times Cu + 1) \times (0{,}36 \times Ni + 1) \times (2{,}16 \times Cr + 1) \times (3 \times Mo^* + 1) \times (1{,}5 \times W^* + 1) \quad (1)$$

wobei $C^* = C - 1/4 \times (Ti - (48/14)N)$, $Mo^* = Mo \times (1 - 0{,}5 \times (Ti - (48/14)N)$, $W^* = W \times (1 - 0{,}5 \times (Ti - (48/14)N)$, und C, Si, Mn, Cu, Ni, Cr, Mo, W, Ti und N Inhalte repräsentieren (Massenprozent), und
wobei das Stahlblech eine Zugfestigkeit < 800 MPa und eine Streckgrenze < 600 MPa aufweist.

2. Abriebfester Stahl nach Anspruch 1, wobei eine Mikrostruktur eines Basismetalls eine Ferrit- und eine Perlitphase als eine Basisphase mit einem Volumenanteil von 90 % oder mehr aufweist, und eine Ti-basierte Carbid-Hartphase in der Basisphase verteilt ist.

3. Abriebfester Stahl nach Anspruch 2, wobei die Verteilungsdichte der Hartphase 400 Partikel/mm^2 oder mehr beträgt.

4. Herstellungsverfahren für einen abriebfesten Stahl, wobei das Verfahren die Schritte zum Warmwalzen einer Stahlbramme mit der Zusammensetzung nach Anspruch 1 und das Durchführen von Abkühlen auf 400 °C oder weniger bei einer Abkühlungsgeschwindigkeit von 2 °C/s oder weniger nach dem Warmwalzen umfasst.

5. Herstellungsverfahren für einen abriebfesten Stahl mit hervorragender Umformbarkeit nach Anspruch 4, wobei die Warmwalz-Reduzierungsrate bei 920 °C oder weniger auf 30 % oder mehr spezifiziert ist und die Fertigwalztem-

peratur auf 900 °C oder weniger spezifiziert ist.

Revendications

1. Acier résistant à l'abrasion constitué, sur une base de pourcentage en masse, de 0,05 % à 0,35 % de C, de 0,05 % à 1,0 % de Si, de 0,1 % à 2,0 % de Mn, de 0,1 % à 1,2 % de Ti, de 0,1 % ou moins d'Al, de 0,05 % à 1,0 % de Mo, d'au moins un élément parmi 0,1 % à 1,0 % de Cu, 0,1 % à 2,0 % de Ni, 0,1 % à 1,0 % de Cr, 0,05 % à 1,0 % de W et 0,0003 % à 0,0030 % de B, et éventuellement
d'au moins un élément parmi 0,005 % à 1,0 % de Nd et 0,005 % à 1,0 % de V sur une base de pourcentage en masse, et/ou
pas plus de 0,015 % de P, et/ou
pas plus de 0,012 % de S ; et/ou 0,01 % ou moins de N,
le reste étant du Fe et des impuretés inévitables,
où DI* représenté par la formule (1) est inférieur à 60.

$$DI^* = 33{,}85 \times (0{,}1 \times C^*)^{0,5} \times (0{,}7 \times Si + 1) \times (3{,}33 \times Mn + 1) \times (0{,}35 \times Cu + 1) \times (0{,}36 \times Ni + 1) \times (2{,}16 \times Cr + 1) \times (3 \times Mo^* + 1) \times (1{,}5 \times W^* + 1) \quad (1)$$

où $C^* = C - 1/4 \times (Ti - (48/14)N)$, $Mo^* = Mo \times (1 - 0{,}5 \times (Ti - (48/14)N)$, $W^* = W \times (1 - 0{,}5 \times (Ti - (48/14)N)$, et C, Si, Mn, Cu, Ni, Cr, Mo, W, Ti et N représentent des teneurs (pourcentage en masse), et
où la tôle d'acier a une TS < 800 MPa et une YS < 600 MPa.

2. Acier résistant à l'abrasion selon la revendication 1, dans lequel une microstructure du métal de base comprend une phase de ferrite et de perlite en tant que phase de base ayant une fraction volumique de 90 % ou plus, et une phase dure de carbure à base de Ti est dispersée dans la phase de base.

3. Acier résistant à l'abrasion selon la revendication 2, dans lequel la densité de dispersion de la phase dure est de 400 particules/mm^2 ou plus.

4. Procédé de production d'un acier résistant à l'abrasion, le procédé comprenant les étapes de laminage à chaud d'une brame d'acier ayant la composition selon la revendication 1 et de réalisation d'un refroidissement jusqu'à 400 °C ou moins à une vitesse de refroidissement de 2 °C/s ou moins après laminage à chaud.

5. Procédé de production d'un acier résistant à l'abrasion extrêmement facile à mettre en oeuvre, selon la revendication 4, dans lequel le taux de réduction par laminage à chaud à 920 °C ou moins est spécifié comme étant égal ou supérieur à 30 % et la température de finissage de laminage est spécifiée comme étant égale ou inférieure à 900 °C.

FIG.1

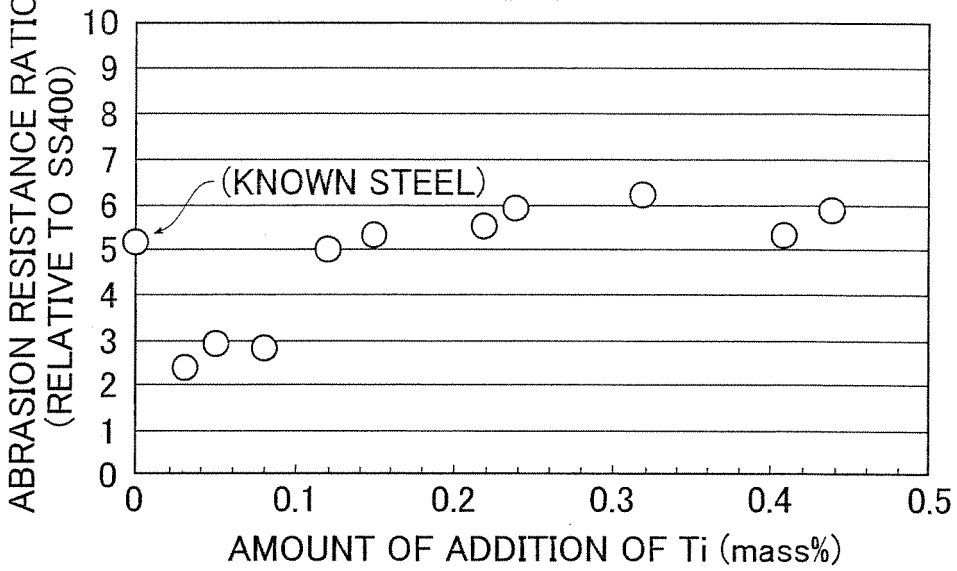

ABRASION RESISTANCE RATIO
(RELATIVE TO SS400)
10
9
8
7
6
5
4
3
2
1
0
(KNOWN STEEL)
0
0.1
0.2
0.3
0.4
0.5
AMOUNT OF ADDITION OF Ti (mass%)

FIG.2

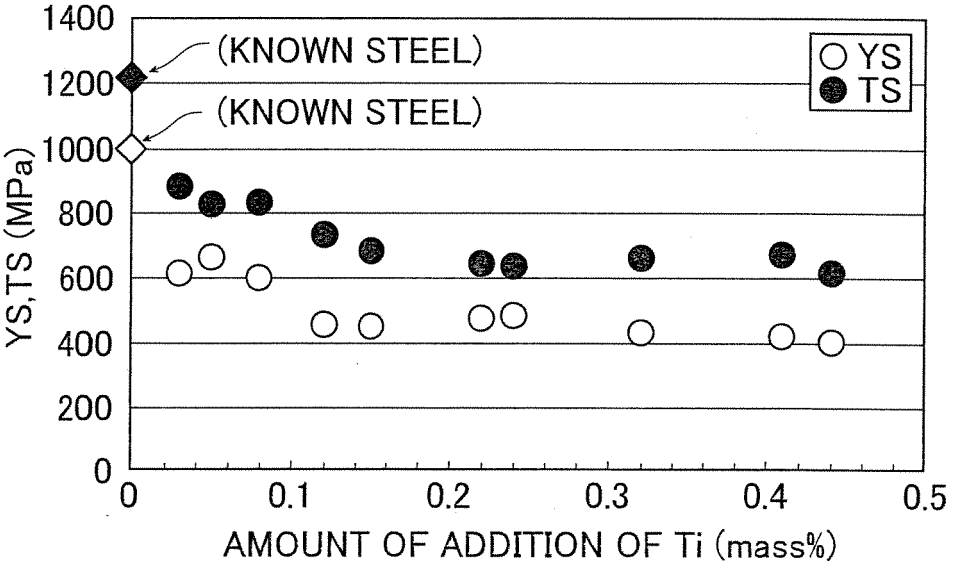

YS,TS (MPa)
1400
1200
1000
800
600
400
200
0
(KNOWN STEEL)
(KNOWN STEEL)
YS
TS
0
0.1
0.2
0.3
0.4
0.5
AMOUNT OF ADDITION OF Ti (mass%)

FIG.3

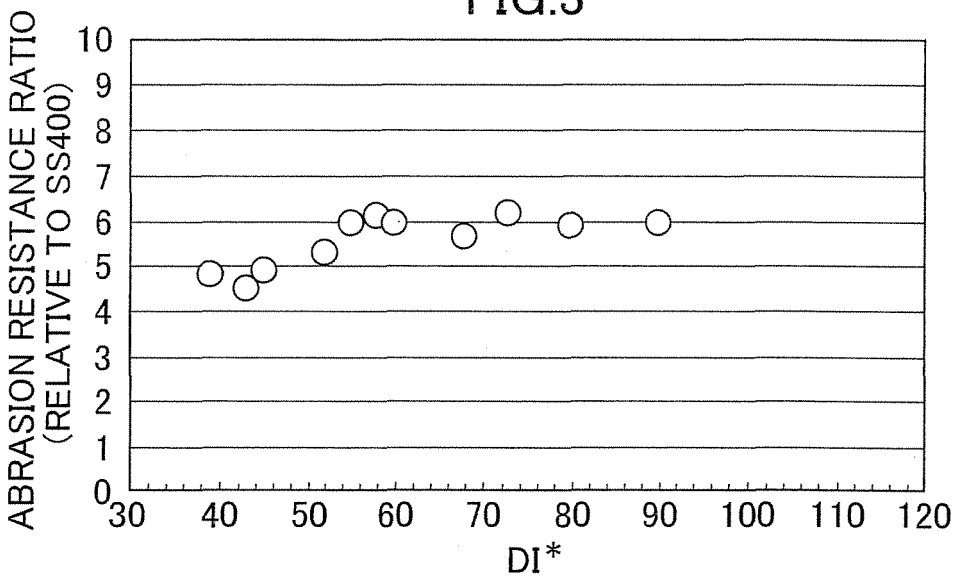
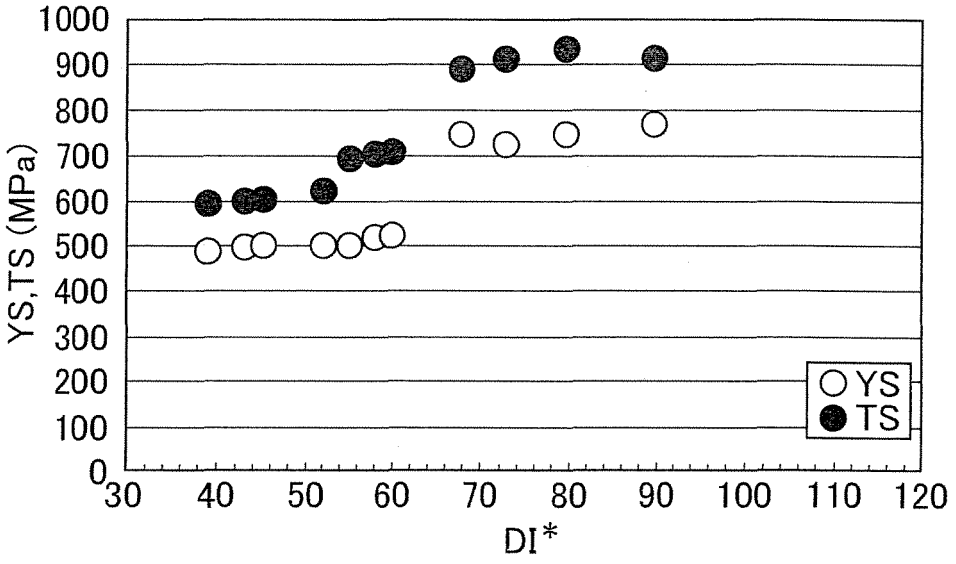

ABRASION RESISTANCE RATIO
(RELATIVE TO SS400)
10
9
8
7
6
5
4
3
2
1
0
30
40
50
60
70
80
90
100
110
120
DI*

FIG.4


YS,TS (MPa)
1000
900
800
700
600
500
400
300
200
100
0
30
40
50
60
70
80
90
100
110
120
DI*
YS
TS

REFERENCES CITED IN THE DESCRIPTION

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