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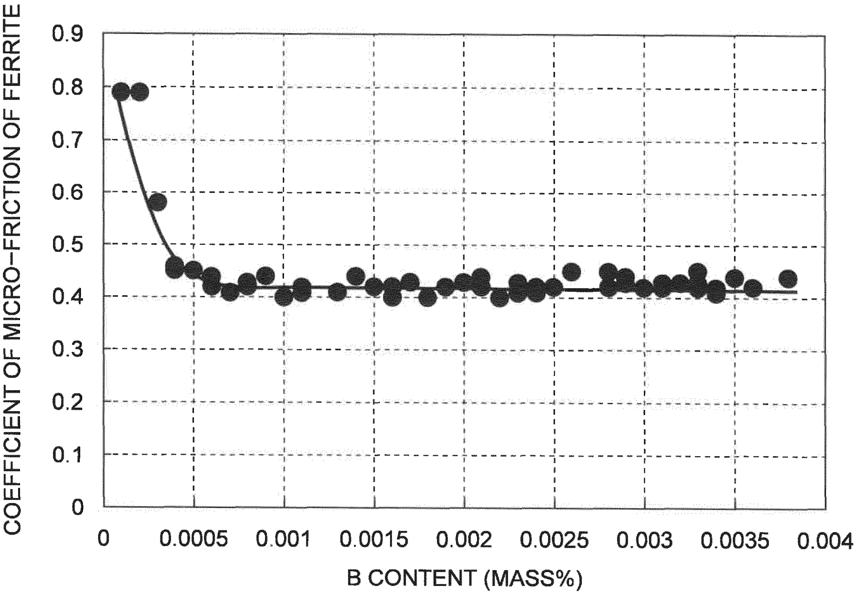
(54) HIGH CARBON STEEL PLATE AND MANUFACTURING METHOD THEREFOR

(57) A high-carbon steel sheet includes: a chemical composition represented by, in mass%, C: 0.30% to 0.70%, B: 0.0004% to 0.0035%, and others; and a structure represented by a spheroidized ratio of cementite: 80% or more; and an average diameter of cementite: 0.3 μm to 2.2 μm, wherein a coefficient of micro-friction of ferrite on a surface of the steel sheet is less than 0.5.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a high-carbon steel sheet with improved formability and a method of manufacturing the same.

BACKGROUND ART

[0002] A high-carbon steel sheet is used for various steel products, which are a driving system component for automobile such as a chain, a gear and a clutch, a saw, a knife, and others. When the steel products are manufactured, forming and heat treatments of a high-carbon steel sheet are performed. As the forming, punching, tensile forming, compressing, shearing, and so on are performed, and as the heat treatment, quenching, tempering, carburizing, nitriding, soft-nitriding, and so on are performed. A strength of a high-carbon steel sheet is higher than that of a mild steel sheet, and therefore a metal mold used for forming of a high-carbon steel sheet is more easily worn than a metal mold used for forming of a mild steel sheet. Further, a high-carbon steel sheet cracks more easily than a mild steel sheet during forming.

[0003] For suppressing the wearing of a metal mold, improving lubricity on a surface of a high-carbon steel sheet is effective, and for suppressing the cracking during forming, softening of a high-carbon steel sheet is effective. Thus, some techniques have been proposed aiming at an improvement in lubricity and softening (Patent Literatures 1 to 5).

[0004] However, these prior techniques cause a significant increase in cost, and therefore are not preferred.

[0005] Although a carbon steel sheet aiming at an improvement in punchability has been described in Patent Literature 6 and a high-carbon steel sheet aiming at an improvement in formability has been described in Patent Literature 7, it is not possible for them to obtain sufficient formability.

CITATION LIST

PATENT LITERATURE

[0006]

Patent Literature 1: Japanese Laid-open Patent Publication No. 2010-174252

Patent Literature 2: Japanese Laid-open Patent Publication No. 2009-215612.

Patent Literature 3: Japanese Laid-open Patent Publication No. 2011-168842

Patent Literature 4: Japanese Laid-open Patent Publication No. 2010-255066

Patent Literature 5: Japanese Laid-open Patent Publication No. 2000-34542

Patent Literature 6: Japanese Laid-open Patent Publication No. 2000-265240

Patent Literature 7: Japanese Laid-open Patent Publication No. 10-147816

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0007] An object of the present invention is to provide a high-carbon steel sheet capable of obtaining excellent formability while avoiding a significant increase in cost, and a method of manufacturing the same.

SOLUTION TO PROBLEM

[0008] The present inventors conducted earnest studies repeatedly to solve the above-described problem, and consequently found out that it is important that a high-carbon steel sheet contains a specific amount of B, that a coefficient of micro-friction of ferrite on a surface is a specific one, and that form of cementite is a specific one. Further, it was also found out that, in order to manufacture such a high-carbon steel sheet, it is important to perform hot-rolling and annealing under specific conditions while assuming hot-rolling and annealing as what is called a consecutive process. Then, the inventors of the present application devised the following various aspects of the invention based on these findings.

(1) A high-carbon steel sheet, including:

a chemical composition represented by, in mass%:

C: 0.30% to 0.70%,
Si: 0.07% to 1.00%,
Mn: 0.20% to 3.00%,
Ti: 0.010% to 0.500%,
Cr: 0.01% to 1.50%,
B: 0.0004% to 0.0035%,
P: 0.025% or less,
Al: 0.100% or less,
S: 0.0100% or less,
N: 0.010% or less,
Cu: 0.500% or less,
Nb: 0.000% to 0.500%
Mo: 0.000% to 0.500%,
V: 0.000% to 0.500%,
W: 0.000% to 0.500%,
Ta: 0.000% to 0.500%,
Ni: 0.000% to 0.500%,
Mg: 0.000% to 0.500%,
Ca: 0.000% to 0.500%,
Y: 0.000% to 0.500%,
Zr: 0.000% to 0.500%,
La: 0.000% to 0.500%,
Ce: 0.000% to 0.500%, and
balance: Fe and impurities; and

a structure represented by:

a spheroidized ratio of cementite: 80% or more; and
an average diameter of cementite: 0.3 μm to 2.2 μm, wherein
a coefficient of micro-friction of ferrite on a surface of the steel sheet is less than 0.5.

(2) The high-carbon steel sheet according to (1), wherein in the chemical composition,

Nb: 0.001% to 0.500%,
Mo: 0.001% to 0.500%,
V: 0.001% to 0.500%,
W: 0.001% to 0.500%,
Ta: 0.001% to 0.500%,
Ni: 0.001% to 0.500%,
Mg: 0.001% to 0.500%,
Ca: 0.001% to 0.500%,
Y: 0.001% to 0.500%,
Zr: 0.001% to 0.500%,
La: 0.001% to 0.500%, or
Ce: 0.001% to 0.500%, or

any combination thereof is satisfied.

(3) A method of manufacturing a high-carbon steel sheet, including:

hot-rolling of a slab so as to obtain a hot-rolled steel sheet;

pickling of the hot-rolled steel sheet; and
annealing of the hot-rolled steel sheet after the pickling,
the slab including a chemical composition represented by, in mass%:

C: 0.30% to 0.70%,
Si: 0.07% to 1.00%,
Mn: 0.20% to 3.00%,
Ti: 0.010% to 0.500%,
Cr: 0.01% to 1.50%,
B: 0.0004% to 0.0035%,
P: 0.025% or less,
A1: 0.100% or less,
S: 0.0100% or less,
N: 0.010% or less,
Cu: 0.500% or less,
Nb: 0.000% to 0.500%,
Mo: 0.000% to 0.500%,
V: 0.000% to 0.500%,
W: 0.000% to 0.500%,
Ta: 0.000% to 0.500%,
Ni: 0.000% to 0.500%,
Mg: 0.000% to 0.500%,
Ca: 0.000% to 0.500%,
Y: 0.000% to 0.500%,
Zr: 0.000% to 0.500%,
La: 0.000% to 0.500%,
Ce: 0.000% to 0.500%, and
balance: Fe and impurities, wherein

in the hot-rolling,
the slab is heated at a temperature of 1000°C or more and less than 1150°C,
a finish rolling temperature is 830°C or more and 950°C or less, and
a coiling temperature is 450°C or more and 700°C or less, and
the annealing comprises:

retaining the hot-rolled steel sheet at a temperature of 730°C or more and 770°C or less for 3 hours or more and 60 hours or less; and
then cooling the hot-rolled steel sheet down to 650°C at a cooling rate of 1°C/hr or more and 60°C/hr or less.

(4) The method of manufacturing the high-carbon steel sheet according to (3), wherein
in the chemical composition,

Nb: 0.001% to 0.500%,
Mo: 0.001% to 0.500%,
V: 0.001% to 0.500%,
W: 0.001% to 0.500%,
Ta: 0.001% to 0.500%,
Ni: 0.001% to 0.500%,
Mg: 0.001% to 0.500%,
Ca: 0.001% to 0.500%,
Y: 0.001% to 0.500%,
Zr: 0.001% to 0.500%,
La: 0.001% to 0.500%, or
Ce: 0.001% to 0.500%, or

any combination thereof is satisfied.

ADVANTAGEOUS EFFECTS OF INVENTION

[0009] According to the present invention, a B content, a coefficient of micro-friction of ferrite on a surface and others are appropriate, thereby making it possible to obtain excellent formability while avoiding a significant increase in cost.

BRIEF DESCRIPTION OF DRAWINGS

[0010]

[Fig. 1.] Fig. 1. is a chart. illustrating a relationship between a coefficient of micro-friction of ferrite and a B content;
[Fig. 2] Fig. 2 is a chart illustrating a relationship between a coefficient of micro-friction of ferrite and a number of pressing until a flaw occurs;
[Fig. 3A] Fig. 3A is a micrograph showing a surface of a high-carbon steel sheet before measuring a coefficient of micro-friction;
[Fig. 3B] Fig. 3B is a micrograph showing the surface of the high-carbon steel sheet after measuring the coefficient of micro-friction;
[Fig. 4] Fig. 4 is a schematic diagram illustrating changes in temperature from hot-rolling to cooling;
[Fig. 5A] Fig. 5A is a schematic diagram illustrating a structure at time t_A;
[Fig. 5B] Fig. 5B is a schematic diagram illustrating a structure at time t_B;
[Fig. 5C] Fig. 5C is a schematic diagram illustrating a structure at time t_c;
[Fig. 5D] Fig. 5D is a schematic diagram illustrating a structure at time t_D;
[Fig. 5E] Fig. 5E is a schematic diagram illustrating a structure at time t_E;
[Fig. 6A] Fig. 6A is a schematic diagram illustrating a structure when a slab heating temperature is high than 1150°C;
[Fig. 6B] Fig. 6B is a schematic diagram illustrating a structure when the slab heating temperature is lower than 1000°C;
[Fig. 6C] Fig. 6C is a schematic diagram illustrating a structure when an annealing retention temperature is lower than 730°C;
[Fig. 6D] Fig. 6D is a schematic diagram illustrating a structure when the annealing retention temperature is higher than 770°C or an annealing retention is longer than 60 hours;
[Fig. 6E] Fig. 6E is a schematic diagram illustrating a structure when the annealing retention is shorter than 3 hours;
[Fig. 6F] Fig. 6F is a schematic diagram illustrating a structure when a cooling rate is less than 1°C/hr;
[Fig. 6G] Fig. 6G is a schematic diagram illustrating a structure when the cooling rate is greater than 60°C/hr; and
[Fig. 7] Fig. 7 is a chart illustrating a relationship between a coefficient of micro-friction of ferrite and a B content for a part of inventive examples in a first experiment or a third experiment.

DESCRIPTION OF EMBODIMENTS

[0011] Hereinafter, there will be explained an embodiment of the present invention.

[0012] First, chemical compositions of a high-carbon steel sheet according to the embodiment of the present invention and a slab (steel ingot) used for manufacturing the same will be explained. Although details will be described later, the high-carbon steel sheet according to the embodiment of the present invention is manufactured by going through hot-rolling of the slab, annealing, and the like. Accordingly, the chemical compositions of the high-carbon steel sheet and the slab are appropriate for the above-stated processes in addition to properties of the high-carbon steel sheet. In the following description, "%" being a unit of content of each element contained in the high-carbon steel sheet and the slab used for manufacturing the same means "masso" unless otherwise mentioned. The high-carbon steel sheet according to the embodiment and the slab used for manufacturing the same include a chemical composition represented by C: 0.30% to 0.70%, Si: 0.07% to 1.00%, Mn: 0.20% to 3.00%, Ti: 0.010% to 0.500%, Cr: 0.01% to 1.50%, B: 0.0004% to 0.0035°, P: 0.025% or less, Al : 0.100% or less, S: 0.100% or less, N: 0.010% or less, Cu: 0.500% or less, Nb: 0.000% to 0.500%, Mo: 0.000% to 0.500%, V: 0.000% to 0.500%, W: 0.000% to 0.500%, Ta: 0.000% to 0.500%, Ni: 0.000% to 0.500%, Mg: 0.000% to 0.500%, Ca: 0.000% to 0.500%, Y: 0.000% to 0.500%, Zr: 0.000% to 0.500%, La: 0.000% to 0.500%, Ce: 0.000% to 0.500%, and balance: Fe and impurities. As the impurities, ones contained in raw materials such as ore and scrap, and ones contained during a manufacturing process are exemplified. For example, when scrap is used as a raw material, Sn, Sb or As or any combination thereof may mix in by 0.003% or more. If the content is 0.03% or less, none of them hinder the effect of the embodiment, and thus may be tolerated as impurities. Further, O may be tolerated as an impurity up to 0.0025%. O forms oxide, and when oxides aggregate and become coarse, sufficient formability is not obtained. Therefore, the O content is the lower the better. However, it is technically difficult to decrease the O content to less than 0.0001%.

(C: 0.30% to 0.70%)

[0013] C bonds to Fe to form cementite having a small friction coefficient, and thus is an important element when securing macro-lubricity of the high-carbon steel sheet. When the C content is less than 0.30%, the amount of cementite is insufficient, resulting in that sufficient lubricity cannot be obtained and adhesion to a metal mold occurs during forming. Thus, the C content is 0.30% or more, and preferably 0.35% or more. When the C content is greater than 0.70%, the amount of cementite is excessive, resulting in that a crack originating from the cementite occurs easily during forming. Thus, the C content is 0.70% or less, and preferably 0.65% or less.

(Si: 0.07% to 1.00%)

[0014] Si operates as a deoxidizer, and is effective for suppressing excessive coarsening of cementite during annealing. When the Si content is less than 0.07%, the effect by the above-described operation cannot be obtained sufficiently. Thus, the Si content is 0.07% or more, and preferably 0.10% or more. When the Si content is greater than 1.00%, the ductility of ferrite is low and a crack originating from transgranular fracture of ferrite occurs easily during forming. Thus, the Si content is 1.00% or less, and preferably 0.80% or less.

(Mn: 0.20% to 3.00%)

[0015] Mn is important for controlling pearlite transformation. When the Mn content is less than 0.20%, the effect by the above-described operation cannot be obtained sufficiently. That is, when the Mn content is less than 0.20%, pearlite transformation occurs in cooling after dual-phase annealing and a spheroidized ratio of cementite becomes insufficient. Thus, the Mn content is 0.20% or more, and preferably 0.25% or more. When the Mn content is greater than 3.00%, the ductility of ferrite is low and a crack originating from transgranular fracture of ferrite occurs easily during forming. Thus, the Mn content is 3.00% or less, and preferably 2.00% or less.

(Ti: 0.010% to 0.500%)

[0016] Ti forms a nitride in molten steel, and effective for preventing formation of BN. When the Ti content is less than 0.010%, the effect by the above-described operation cannot be obtained sufficiently. Thus, the Ti content is 0.010% or more, and preferably 0.040% or more. When the Ti content is greater than 0.500%, a crack originating from a coarse oxide of Ti occurs easily during forming. This is because during continuous casting, coarse oxides of Ti are formed to get involved inside the slab. Thus, the Ti content is 0.500% or less, and preferably 0.450% or less.

(Cr: 0.01% to 1.50%)

[0017] Cr has a high affinity with N, effective for suppressing formation of BN, and effective also for controlling pearlite transformation. When the Cr content is less than 0.01%, the effect by the above-described operation cannot be obtained sufficiently. Thus, the Cr content is 0.01% or more, and preferably 0.05% or more. When the Cr content is greater than 1.50%, spheroidizing of cementite during annealing is hindered and coarsening of cementite is suppressed drastically. Thus, the Cr content is 1.50% or less, and preferably 0.90% or less.

(B: 0.0004% to 0.0035%)

[0018] B lowers the coefficient of micro-friction of ferrite on the surface of the high-carbon steel sheet. B segregates to and concentrates at an interface between ferrite and cementite during later-described annealing and suppresses peeling at the interface during forming, and B is also effective for preventing a crack. When the B content is less than 0.0004%, the effect by the above-described operation cannot be obtained sufficiently. Thus, the B content is 0.0004% or more, and preferably 0.0008% or more. When the B content is greater than 0.0035%, a crack originating from boride such as carbide of Fe and B occurs easily during forming. Thus, the B content is 0.0035% or less, and preferably 0.0030% or less.

[0019] Fig. 1 is a chart illustrating a relationship between a coefficient of micro-friction of ferrite and a B content. As illustrated in Fig. 1, when the B content is 0.0004% or more, the coefficient of micro-friction of ferrite is significantly low as compared to the case when it is less than 0.0004%. It may be inferred that the reason why wearing of a metal mold can be suppressed as a coefficient of micro-friction of ferrite is lower is because a hard film of B is formed on a surface of a high-carbon steel sheet, as will be described later. Further, it may be inferred that the operation that B segregated to and concentrated at an interface between ferrite and cementite improves strength of the interface, suppresses cracking of a high-carbon steel sheet, and suppresses wearing of a metal mold caused by cracking is also a reason for the above.

(P: 0.025% or less)

[0020] P is not an essential element and is contained as an impurity in the steel sheet, for example. P strongly segregates to the interface between ferrite and cementite, and thereby the segregation of B to the interface is hindered and peeling at the interface is caused. Therefore, the P content is the smaller the better. When the P content is greater than 0.025%, adverse effects are particularly prominent. Thus, the P content is 0.025% or less. Decreasing the P content takes refining cost, and it requires a considerable refining cost to decrease the P content to less than 0.0001%. Thus, the P content may be 0.0001% or more.

(Al: 0.100% or less)

[0021] Al operates as a deoxidizer in steelmaking and is effective for fixing N, but is not an essential element of the high-carbon steel sheet and is contained as an impurity in the steel sheet, for example. When the Al content is greater than 0.100%, the ductility of ferrite is low and a crack originating from transgranular fracture of ferrite occurs easily during forming, and strength is excessive to cause an increase in forming load. Thus, the Al content is set to 0.100% or less. When the Al content of the high-carbon steel sheet is less than 0.001%, fixation of N sometimes may be insufficient. Thus, the Al content may be 0.001% or more.

(S: 0.0100% or less)

[0022] S is not an essential element and is contained as an impurity in the steel sheet, for example. S forms coarse non-metal inclusions such as MnS to impair formability. Therefore, the S content is the smaller the better. When the S content is greater than 0.0100%, adverse effects are particularly prominent. Thus, the S content is 0.100% or less. Decreasing the S content takes refining cost, and it requires a considerable refining cost to decrease the S content to less than 0.0001%. Thus, the S content may be 0.0001% or more.

(N: 0.010% or less)

[0023] N is not an essential element and is contained as an impurity in the steel sheet, for example. N lowers an amount of solid-solution B due to formation of BN so as to cause adhesion to the metal mold, cracking during forming, and the like. Therefore, the N content is the smaller the better. When the N content is greater than 0.010%, adverse effects are particularly prominent. Thus, the N content is set to 0.010% or less. Decreasing the N content takes refining cost, and it requires a considerable refining cost to decrease the N content to less than 0.001%. Thus, the N content may be 0.001% or more.

(Cu: 0.000% to 0.500%)

[0024] Cu is not an essential element and is mixed from scrap or the like to be contained as an impurity in the steel sheet, for example. Cu causes an increase in strength and brittleness in hot working. Therefore, the Cu content is the smaller the better. When the Cu content is greater than 0.500%, adverse effects are particularly prominent. Thus, the Cu content is 0.500% or less. Decreasing the Cu content takes refining cost, and it requires a considerable refining cost to decrease the Cu content to less than 0.001%. Thus, the Cu content may be 0.001% or more.

[0025] Nb, Mo, V, W, Ta, Ni, Mg, Ca, Y, Zr, La, and Ce are not essential elements, and are optional elements that may be appropriately contained in the high-carbon steel sheet and the slab up to a specific amount.

(Nb: 0.000% to 0.500%)

[0026] Nb forms a nitride and is effective for suppressing formation of BN. Thus, Nb may be contained. However, when the Nb content is greater than 0.500%, the ductility of ferrite is low to make it impossible to obtain sufficient formability. Thus, the Nb content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Nb content is preferably 0.001% or more.

(Mo: 0.000% to 0.500%)

[0027] Mo is effective for improving hardenability. Thus, Mo may be contained. However, when the Mo content is greater than 0.500%, the ductility of ferrite is low to make it impossible to obtain sufficient formability. Thus, the Mo content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Mo content is preferably 0.001% or more.

(V: 0.000% to 0.500%)

[0028] V forms a nitride and is effective for suppressing formation of BN similarly to Nb. Thus, V may be contained. However, when the V content is greater than 0.500%, the ductility of ferrite is low to make it impossible to obtain sufficient formability. Thus, the V content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the V content is preferably 0.001% or more.

(W: 0.000% to 0.500%)

[0029] W is effective for improving hardenability similarly to Mo. Thus, W may be contained. However, when the W content is greater than 0.500%, the ductility of ferrite is low to make it impossible to obtain sufficient formability. Thus, the W content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the W content is preferably 0.001% or more.

(Ta: 0.000% to 0.500%)

[0030] Ta forms a nitride and is effective for suppressing formation of BN similarly to Nb and V. Thus, Ta may be contained. However, when the Ta content is greater than 0.500%, the ductility of ferrite is low to make it impossible to obtain sufficient formability. Thus, the Ta content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Ta content is preferably 0.001% or more.

(Ni: 0.000% to 0.500%)

[0031] Ni is effective for improving toughness and improving hardenability. Thus, Ni may be contained. However, when the Ni content is greater than 0.500%, the coefficient of micro-friction of ferrite is high to cause adhesion to the metal mold easily. Thus, the Ni content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Ni content is preferably 0.001% or more.

(Mg: 0.000% to 0.500%)

[0032] Mg is effective for controlling the form of sulfide. Thus, Mg may be contained. However, Mg forms oxide easily, and when the Mg content is greater than 0.500%, sufficient formability cannot be obtained due to a crack originating from the oxide. Thus, the Mg content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Mg content is preferably 0.001% or more.

(Ca: 0.000% to 0.500%)

[0033] Ca is effective for controlling the form of sulfide similarly to Mg. Thus, Ca may be contained. However, Ca forms oxide easily, and when the Ca content is greater than 0.500%, sufficient formability cannot be obtained due to a crack originating from the oxide. Thus, the Ca content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Ca content is preferably 0.001% or more.

(Y: 0.000% to 0.500%)

[0034] Y is effective for controlling the form of sulfide similarly to Mg and Ca. Thus, Y may be contained. However, Y forms oxide easily, and when the Y content is greater than 0.500%, sufficient formability cannot be obtained due to a crack originating from the oxide. Thus, the Y content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Y content is preferably 0.001% or more.

(Zr: 0.000% to 0.500%)

[0035] Zr is effective for controlling the form of sulfide similarly to Mg, Ca, and Y. Thus, Zr may be contained. However, Zn forms oxide easily, and when the Zr content is greater than 0.500%, sufficient formability cannot be obtained due to a crack originating from the oxide. Thus, the Zr content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Zr content is preferably 0.001% or more.

(La: 0.000% to 0.500%)

[0036] La is effective for controlling the form of sulfide similarly to Mg, Ca, Y, and Zr. Thus, La may be contained. However, La forms oxide easily, and when the La content is greater than 0.500%, sufficient formability cannot be obtained due to a crack originating from the oxide,. Thus, the La content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the La content is preferably 0.001% or more.

(Ce: 0.000% to 0.500%)

[0037] Ce is effective for controlling the form of sulfide similarly to Mg, Ca, Y, Zr, and La. Thus, Ce may be contained. However, Ce forms oxide easily, and when the Ce content is greater than 0.500%, sufficient formability cannot be obtained due to a crack originating from the oxide,. Thus, the Ce content is 0.500% or less. In order to securely obtain the effect by the above-described operation, the Ce content is preferably 0.001% or more.

[0038] Thus, Nb, Mo, V, W, Ta, Ni, Mg, Ca, Y, Zr, La and Ce are optional elements, and it is preferred that "Nb: 0.001% to 0.500%," "Mo: 0.001% to 0.500%," "V: 0.001% to 0.500%," "W: 0.001% to 0.500%," "Ta: 0.001% to 0.500%," "Ni: 0.001% to 0.500%," "Mg: 0.001% to 0.500%," "Ca: 0.001% to 0.500%," "Y: 0.001% to 0.500%," "Zr: 0.001% to 0.500%," "La: 0.001% to 0.500%," or "Ce: 0.001% to 0.500%," or any combination thereof be satisfied.

[0039] Next, the coefficient of micro-friction of ferrite on the surface of the high-carbon steel sheet according to the embodiment is explained. The coefficient of micro-friction of ferrite on the surface of the high-carbon steel sheet according to the embodiment is less than 0.5.

(Coefficient of micro-friction of ferrite on the surface: less than 0.5)

[0040] The coefficient of micro-friction of ferrite on the surface closely relates to adhesion of the high-carbon steel sheet to the metal mold during forming. When the coefficient of micro-friction of ferrite is 0.5 or more, micro-adhesion occurs between the high-carbon steel sheet and the metal mold during forming using the metal mold. As a result, when forming such as punching is performed with several thousands to several tens of thousands of shots by using the metal mold, adhesive matters are accumulated on the metal mold during the forming, and a flaw occurs on either the metal mold or the high-carbon steel sheet or on the both and formability deteriorates. Thus, the coefficient of micro-friction of ferrite is less than 0.5. From the viewpoint of formability, the coefficient of micro-friction is the lower the better. The coefficient of micro-friction often tends to be 0.35 or more, though it depends on a method of manufacturing the high-carbon steel sheet and others.

[0041] Fig. 2 is a chart illustrating a relationship between a coefficient of micro-friction of ferrite and a number of pressing (shots) until a flaw occurs on a metal mold or a high-carbon steel sheet in punch forming of high-carbon steel sheets. As illustrated in Fig. 2, when the coefficient of micro-friction is less than 0.5, the number of pressing until a flaw occurs is significantly high as compared to the case when it is 0.5 or more.

[0042] A coefficient of micro-friction may be measured using a nanoindenter. That is, a kinetic friction force F to occur when a diamond indenter loads a normal load P of 10 μN onto a surface of a high-carbon steel sheet and is moved horizontally is obtained. A moving speed then is 1 μm/second, for example. A coefficient of micro-friction μ (kinetic friction coefficient) is calculated by Expression (1) below. "TI-900 TriboIndenter" made by Omicron, Inc. may be used as a nanoindenter, for example.

$$F = \mu P \ldots \text{Expression}(1)$$

[0043] Fig. 3A is a micrograph showing a surface of a high-carbon steel sheet before measuring a coefficient of micro-friction, and Fig. 3B is a micrograph showing the surface of the high-carbon steel sheet after measuring the coefficient of micro-friction. Fig. 3A and Fig. 3B each show an example of a 10 μm × 10 μm visual I-ie7_d. As shown in Fig. 3A and Fig. 3B, ferrite 31 and cementite 32 exist in the visual field example. Further, as shown in Fig. 3B, measurement flaws 33 caused by horizontal movement of the diamond indenter exist after the measurement. The coefficient of micro-friction of cementite was 0.4 or less.

[0044] Next, a structure of the high-carbon steel sheet according to the embodiment is explained. The high-carbon steel sheet according to the embodiment includes a structure represented by a spheroidized ratio of cementite: 80% or more and an average diameter of cementite: 0.3 μm to 2.2 μm.

(Spheroidized ratio of cementite: 80% or more)

[0045] Stress concentration sometimes originates from cementite during forming, and stress is likely to concentrate locally in acicular cementite particularly. When the spheroidized ratio of cementite is less than 80%, acicular cementite, in which stress is likely to concentrate, is contained in large amounts, and thus stress concentration occurs easily and peeling occurs at an interface between ferrite and cementite, resulting in that sufficient formability cannot be obtained. Thus, the spheroidized ratio of cementite is 80% or more, and preferably 85% or more. From the viewpoint of formability, the spheroidized ratio of cementite is preferred to be as higher as possible, and may be 100%. However, when the spheroidized ratio of cementite is attempted to become 100%, productivity could decrease, and the spheroidized ratio of cementite is preferably 80% or more and less than 100% from the viewpoint of productivity.

(Average diameter of cementite: 0.3 μm to 2.2 μm)

[0046] The average diameter of cementite closely relates to the degree of the stress concentration to cementite. When the average diameter of cementite is less than 0.3 μm, an Orowan loop is formed by dislocation occurred during forming with respect to cementite, and thereby a dislocation density in the vicinity of cementite increases and voids occur. Thus, the average diameter of cementite is 0.3 μm or more, and preferably 0.5 μm or more. When the average diameter of cementite is greater than 2.2 μm, dislocations occurred during forming are accumulated in large amounts, local stress concentration is generated and a crack occurs. Thus, the average diameter of cementite is 2.2 μm or less, and preferably 2.0 μm or less.

[0047] The spheroidized ratio and the average diameter of cementite may be measured by structure observation using a scanning electron microscope. In preparing of a sample for structure observation, an observation surface is mirror finished by wet polishing with an emery paper and polishing with diamond abrasive grains having a size of 1 μm, then the observation surface is etched with an etching solution of 3 vol% of nitric acid and 97 vol% % of alcohol. An observation magnification is between. 3000 times to 10000 times, for example, 10000 times, 16 visual fields where 500 or more grains of cementite exist on the observation surface are selected, and structure images of them are taken. Then, an area of each cementite in the structure image is measured by using image processing software. "Win ROOF" made by MITANI Corporation may be used as an image processing software, for example. Any cementite grain having an area of 0.01 μm^2 or less is excluded from the target of revaluation in order to suppress an influence of measurement error by noise in the measuring. Then, the average area of cementite as an evaluation target is obtained, and the diameter of a circle with which this average area can be obtained is obtained, thereby taking this diameter as the average diameter of cementite. The average area of cementite is a value obtained by dividing the total area of cementite as the evaluation target by the number of grains of cementite in question. Further, any cementite having a ratio of major axis length to minor axis length of 3 or more is assumed as an acicular cementite, any cementite having the ratio of less than 3 is assumed as a spherical cementite grain, and a value obtained by dividing the number of spherical cementite by the number of all cementite is taken as the spheroidized ratio of cementite.

[0048] Next, a method of manufacturing the high-carbon steel sheet according to the embodiment is explained. The manufacturing method includes hot-rolling of a slab including the above chemical composition so as to obtain a hot-rolled steel sheet, pickling of the hot-rolled steel sheet, and thereafter annealing of the hot-rolled steel sheet. In the hot-rolling, the slab is heated at a temperature of 1000°C or more and less than 1150°C, a finish rolling temperature is 830°C or more and 950°C or less, and a coiling temperature is 450°C or more and 700°C or less. In the annealing, the hot-rolled steel sheet is retained at a temperature of 730°C or more and 770°C or less for 3 hours or more and 60 hours or less, and then, the hot-rolled steel sheet is cooled down to 650°C at a cooling rate of 1°C/h or more and 60°C/hr or less. An atmosphere of the annealing may be one containing hydrogen by 75 viol% or more at a temperature higher than 400°C, for example, but is not limited to that.

[0049] Here, an outline of changes in the steel sheet from the hot-rolling to the cooling is explained. Fig. 4 is a schematic diagram illustrating changes in temperature. Fig. 5A to Fig. 5E are schematic diagrams illustrating changes in structure.

[0050] In an example illustrated in Fig. 4, hot-rolling S1 includes slab heating S11, finish rolling S12, and coiling S13, and annealing S3 includes high-temperature retention S31 and cooling S32. Pickling S2 is performed between the hot-rolling S1 and the annealing S3, and after cooling S4 is performed the annealing S3.

[0051] At a time t_A after completion of the slab heating S11, B atoms 13 segregate to an interface between austenite 12 and austenite 12, as illustrated in Fig. 5A. At a time t_B after completion of the high-temperature retention S31, the structure of the steel sheet contains ferrite 11 and the austenite 12, as illustrated in Fig. 5B. Further, the B atoms 13 segregate to an interface between the ferrite 11 and the austenite 12. Some of the B atoms 13 are present also on a surface 15 of the steel sheet, and the B atoms 13 present on the surface of the steel sheet are bonded to each other by covalent bonding 14. Although not illustrated in Fig. 5B, cementite is also contained in the structure of the steel sheet and some of the B atoms 13 segregate also to an interface between the ferrite 11 and the cementite. At a time t_C in a middle of the cooling S32, the ratio of the ferrite 11 increases and the ratio of the austenite 12 decreases as compared to the structure illustrated in Fig. 5B, as illustrated in Fig. 5C, and the interface between these two phases moves due to the increasing and decreasing or the ratios. Also, the B atoms 13 present on the surface of the steel sheet increase with the movement of the interface. Further, at a time t_D when the cooling S32 has advanced, the ratio of the ferrite 11 increases, the ratio of the austenite 12 decreases, and the B atoms 13 present on the surface of the steel sheet increase as compared to the structure illustrated in Fig. 5C, as illustrated in Fig. 5D. Then, at a time t_E when the temperature of the steel sheet has reached 650°C, the austenite 12 disappears and the surface 15 of the steel sheet is covered with many of the B atoms 13, as illustrated in Fig. 5E. Since the B atoms 13 are bonded to each other by the covalent bonding 14, they are crystallized. The structure illustrated in Fig. 5E does not change also during the cooling S4, and is maintained even when the temperature of the steel sheet has reached room temperature, for example, a temperature of less than 600°C.

[0052] According to the manufacturing method, the surface 15 of the steel sheet is covered with many of the B atoms 13 bonded to each other by the covalent bonding 14, and thereby the coefficient of micro-friction of ferrite on the surface 15 can be less than 0.5.

(Slab heating temperature: 1000°C or more and less than 1150°C)

[0053] When the slab heating temperature is higher than 1150°C, oxygen easily diffuses into the inside of the slab from the surface of the slab to bond to B in the slab. That is, as illustrated in Fig. 6A, the B atoms 13 are consumed due to bonding to O atoms 16. Therefore, even though a process thereafter is performed appropriately, it is not possible to obtain a good surface covered with crystals of B, resulting in that the coefficient of micro-friction of ferrite on the surface cannot be less than 0.5. Thus, the slab heating temperature is 1150°C or less, and preferably 1140°C or less. When the slab heating temperature is lower than 1000°C, micro-segregation and/or macro-segregation formed during casting cannot be eliminated, and as illustrated in Fig. 6B, solidification segregations of the B atoms 13 remain. The solidification segregations of the B atoms 13 cannot be eliminated even though a process thereafter is performed appropriately, and therefore, it is not possible to obtain a good surface covered with crystals of B, resulting in that the coefficient of micro-friction of ferrite on the surface cannot be less than 0.5. Further, when the slab heating temperature is lower than 1000°C, regions where Cr atoms and/or Mn atoms segregate and concentrate also remain in the high-carbon steel sheet. Therefore, even though a process thereafter is performed appropriately, cracks occur from the regions during forming, thus making it impossible to obtain good formability. Thus, the slab heating temperature is 1000°C or more, and preferably 1030°C or more.

(Finish rolling temperature: 830°C or more and 950°C or less)

[0054] When the finish rolling temperature is higher than 950°C, coarse scales are generated until completion of coiling on a run out table (ROT), for example. The coarse scales can be removed by pickling, but traces of large irregularities are left, resulting in that adhesion to the metal mold sometimes occurs during forming due to the traces. Further, when coarse scales are generated, irregular flaw is caused on the surface of the steel sheet in the coiling, resulting in that due to the flaw, adhesion to the metal mold sometimes occurs during forming. Thus, the finish rolling temperature is 950°C or less, and preferably 940°C or less. When the finish rolling temperature is lower than 830°C, adhesiveness of scales generated until completion of coiling to the steel sheet is extremely high, thus making it difficult to remove the scales by pickling. The scales may be removed by performing strong pickling, but the strong pickling makes the surface of the steel sheet rough, resulting in that adhesion to the metal mold sometimes occurs during forming. Further, when the finish rolling temperature is lower than 830°C, recrystallization of austenite is not completed by the coiling, so that anisotropy of the hot-rolled steel sheet increases. The anisotropy of the hot-rolled steel sheet is carried over even after annealing, and thus sufficient formability cannot be obtained. Thus, the finish rolling temperature is 830°C or more, and preferably 840°C or more.

(Coiling temperature: 450°C or more and 700°C or less)

[0055] When the coiling temperature is higher than 700°C, coarse lamellar pearlite is formed in the hot-rolled steel sheet to hinder spheroidizing of cementite during annealing, resulting in that the spheroidized ratio of 80% or more cannot be obtained. Thus, the coiling temperature is 700°C or less. Further, when the coiling temperature is higher than 570°C, coarse scales are generated until completion of coiling. Therefore, adhesion to the metal mold sometimes occurs during forming for a reason similar to the case where the finish rolling temperature is higher than 950°C. Thus, the coiling temperature is preferably 570°C or less, and further preferably 550°C or less. When the coiling temperature is lower than 450°C, adhesiveness of scales generated until completion of coiling to the steel sheet is extremely high, thus making it difficult to remove the scales by pickling. The scales may be removed by performing strong pickling, but the strong pickling makes the surface of the steel sheet rough, resulting in that adhesion to the metal mold sometimes occurs during forming. Further, when the coiling temperature is lower than 450°C, the hot-rolled steel sheet becomes brittle and the hot-rolled steel sheet may crack when a coil is uncoiled in pickling, resulting in that a sufficient yield cannot be obtained. Thus, the coiling temperature is 450°C or more, and preferably 460°C or more.

[0056] A rough-rolled bar may be heated near an inlet of a finishing mill in order to ensure qualities in a longitudinal direction and a width direction of a hot-rolled coil obtained by coiling(to reduce variation of quality or the like). An apparatus to be used for the heating and a method of the heating are not limited in particular, but heating by high-frequency induction heating is desirably performed. A preferred temperature range of the heated rough-rolled bar is between 850°C and 1100°C. Temperatures less than 850°C are close to a transformation temperature from austenite to ferrite, and therefore, when the temperature of the heated rough bar is lower than 850°C, heat generation and heat absorption due to transformation and reverse transformation sometimes occur, resulting in that temperature controlling is unstable and it is difficult to uniformize a temperatures in the longitudinal direction and the width direction of the hot-rolled coil. Therefore, if the rough-rolled bar is heated, the heating temperature is preferably 850°C or more. Increasing the temperature of the rough-rolled bar to temperature higher than 1100°C takes excessive time, and the productivity decreases. Therefore, if rough-rolled bar is heated, the heating temperature is preferably 1100°C or less.

(Annealing retention temperature: 730°C or more and 770°C or less)

[0057] When the annealing retention temperature is lower than 730°C, the austenite 12 is not formed sufficiently, and as illustrated in Fig. 6C, although a large number of interfaces between the ferrite 11 and the ferrite, 11 exist, sites where the B atom 13 segregates are insufficient. Therefore, even though a process thereafter is performed appropriately, a good surface covered with crystals of B cannot be obtained, resulting in that the coefficient of micro-friction of ferrite on the surface cannot be less than 0.5. Further, when the annealing retention temperature is lower than 730°C, segregation of the B atom 13 to the interface between the ferrite 11 and cementite does not occur easily, and therefore, segregating the B atoms 13 sufficiently takes an extremely long time, which is about 100 hours, and the productivity decreases. Thus, the annealing retention temperature is 730°C or more, and preferably 735°C or more. When the annealing retention temperature is higher than 770°C, as illustrated in Fig. 6D, the B atoms 13 concentrate and coarse crystals of B are formed in the vicinity of the triple point of the ferrite 11, the austenite 12, and the surface of the steel sheet. When coarse crystals of B are formed, even though a process thereafter is performed appropriately, the thickness of a film of the crystals of B varies greatly, resulting in that the coefficient of micro-friction of ferrite on the surface cannot be less than 0.5. Further, when the annealing retention temperature is higher than 770°C, thermal expansion of the hot-rolled steel sheet coiled in a coil shape is large, and the hot-rolled steel sheet itself sometimes rubs together during annealing to cause abrasions on the surface. The appearance of the surface is impaired and the yield is decreased by the abrasions. Thus, the annealing retention temperature is 770°C or less, and preferably 765°C or less.

(Annealing retention time: 3 hours or more and 60hours or less)

[0058] When the annealing retention time is less than 3 hours, as illustrated in Fig. 6E, the B atoms 13 do not sufficiently segregate to the interface between the ferrite 11 and the austenite 12, and therefore, even though a process thereafter is performed appropriately, a good surface covered with crystals of B cannot be obtained, resulting in that the coefficient of micro-friction of ferrite on the surface cannot be less than 0.5. Further, when the annealing retention time is less than 3 hours, cementite does not become coarse sufficiently, resulting in that the average diameter of cementite cannot be 0.3 μm or more. Thus, the annealing retention time is 3 hours or more, and preferably 5 hours or more. When the annealing retention time is greater than 60 hours, the coefficient of micro-friction of ferrite on the surface cannot be less than 0.5 for a reason similar to the case where the annealing retention temperature is higher than 770°C. Further, when the annealing retention time is greater than 60 hours, cementite becomes coarse excessively, resulting in that the average diameter of cementite cannot be 2.2 μm or less. Thus, the annealing retention time is 60 hours or less, and preferably 40 hours or less.

(cooling rate down to 650°C: 1°C/hr or more and 60°C /hr or less)

[0059] When the cooling rate down to 650°C is less than 1°C/hr, as illustrated in Fig. 6F, crystals of B are formed excessively during cooling and the crystals of B form a projection on the surface of the high-carbon steel sheet. Once a projection is formed, the thickness of the film of the crystals of B varies greatly, resulting in that adhesion to the metal mold occurs during forming and a flaw occurs on the metal mold. Further, when the cooling rate down to 650°C is less than 1°C/hr, sufficient productivity cannot be obtained. Thus, the cooling rate down to 650°C is 1°C/hr or more, and preferably 2°C/hr or more. When the cooling rate down to 650°C is greater than 60°C/hr, a decrease rate of the austenite 12 is excessive, and as illustrated in Fig. 6G, the sufficient covalent bonding 14 cannot be caused between the B atoms 13, resulting in that the coefficient of micro-friction of ferrite on the surface cannot be less than 0.5. Further, when the cooling rate down to 650°C is greater than 60°C/hr, pearlite is formed from the austenite 12 during cooling to hinder spheroidizing of cementite, resulting in that the spheroidized ratio of 80% or more cannot be obtained. Thus, the cooling rate down to 650°C is 60°C/hr or less, and 50°C/or less.

[0060] According to the embodiment, excellent lubricity can be obtained, and therefore it is possible to suppress adhesion of the high-carbon steel sheet to the metal mold and suppress wearing of the metal mold. Further, according to the embodiment, it is also possible to suppress cracking during forming.

[0061] It should be noted that all of the above-described embodiments merely illustrate concrete examples of implementing the present invention, and the technical scope of the present invention is not to be construed in a restrictive manner by these embodiments. That is, the present invention may be implemented in various forms without departing from the technical spirit or main features thereof.

EXAMPLE

[0062] Next, examples of the present invention will be described. Conditions in the examples are condition examples employed for confirming feasibility and effect of the present invention, and the present invention is not limited to these condition examples. The present invention can employ various conditions as long as the object of the present invention is achieved without departing from the spirit of the invention.

(First experiment)

[0063] In a first experiment, hot-rolling of a slab (Steel type A to Y, BK) including a chemical composition listed in Table 1 was performed, thereby obtaining a hot-rolled steel sheet having a thickness of 4 mm. In the hot-rolling, the slab heating temperature was 1130°C, the time thereof was 1 hour, the finish rolling temperature was 850°C, and the coiling temperature was 520°C. Then, cooling was performed down to a temperature of less than 60°C, and pickling using sulfuric acid was performed. Thereafter, annealing of the hot-rolled steel sheet was performed to then obtain a hot-rolled annealed steel sheet. In the annealing, the hot-rolled steel sheet was retained for 15 hours at 750°C, and then was cooled down to 650°C at a cooling rate of 30°C/hr. Subsequently, cooling was performed down to a temperature of less than 60°C. In this manner, various high-carbon steel sheets were manufactured. Blank fields in Table 1 indicate that the content of the element is less than a detection limit, and the balance is Fe and impurities. For example, the Cr content of Steel type BK may be regarded as 0.00%. An underline in Table 1 indicates that the numeric value is out of the range of the present invention.

[Table 1]

STEEL TYPE	CHEMICAL COMPONENT (MASS%)																							Ac1 (°C)	Ac3 (°C)	REMARKS
	C	Si	Mn	P	S	Al	N	Ti	Cr	B	Nb	Mo	V	Cu	W	Ta	Ni	Mg	Ca	Y	Zr	La	Ce			
A	0.32	0.78	1.21	0.023	0.0062	0.088	0.003	0.203	0.11	0.0022														732	850	INVENTIVE EXAMPLE
B	0.38	0.41	0.61	0.014	0.0064	0.035	0.002	0.332	0.39	0.0029														737	810	INVENTIVE EXAMPLE
C	0.41	0.32	1.40	0.013	0.0051	0.085	0.004	0.157	0.77	0.0018														731	811	INVENTIVE EXAMPLE
D	0.47	0.08	0.27	0.015	0.0085	0.072	0.006	0.282	1.22	0.0015														743	781	INVENTIVE EXAMPLE
E	0.53	0.19	1.67	0.010	0.0039	0.060	0.003	0.348	0.54	0.0011														714	758	INVENTIVE EXAMPLE
F	0.61	0.74	1.86	0.017	0.0097	0.048	0.006	0.046	1.32	0.0023														748	788	INVENTIVE EXAMPLE
G	0.64	0.97	0.99	0.002	0.0056	0.082	0.003	0.499	0.05	0.0005														735	766	INVENTIVE EXAMPLE
H	0.64	0.47	2.92	0.021	0.0003	0.011	0.008	0.163	0.47	0.0009														715	758	INVENTIVE EXAMPLE
I	0.67	0.60	1.48	0.024	0.0041	0.053	0.006	0.421	0.88	0.0008														740	755	INVENTIVE EXAMPLE
J	0.29	0.16	2.46	0.005	0.0006	0.027	0.002	0.042	0.88	0.0011														709	818	COMPARATIVE EXAMPLE
K	0.31	0.17	2.34	0.006	0.0056	0.049	0.011	0.061	0.67	0.0016														711	819	COMPARATIVE EXAMPLE
L	0.32	0.55	1.15	0.002	0.0017	0.110	0.005	0.194	0.29	0.0019														731	840	COMPARATIVE EXAMPLE
M	0.32	0.27	0.42	0.022	0.0094	0.006	0.005	0.057	1.46	0.0036														747	828	COMPARATIVE EXAMPLE
N	0.36	0.60	0.18	0.015	0.0045	0.008	0.009	0.138	0.57	0.0011														750	838	COMPARATIVE EXAMPLE
O	0.39	0.61	2.70	0.026	0.0003	0.024	0.002	0.056	1.20	0.0033														728	814	COMPARATIVE EXAMPLE
P	0.40	1.05	1.97	0.001	0.0095	0.070	0.006	0.445	0.36	0.0024														740	823	COMPARATIVE EXAMPLE
Q	0.40	0.67	0.58	0.006	0.0012	0.033	0.002	0.381	0.21	0.0001														740	814	COMPARATIVE EXAMPLE
R	0.41	0.21	1.74	0.006	0.0092	0.098	0.002	0.435	1.00	0.0002														725	782	COMPARATIVE EXAMPLE
S	0.49	0.06	0.53	0.018	0.0053	0.086	0.002	0.321	0.91	0.0014														730	764	COMPARATIVE EXAMPLE
T	0.53	0.35	1.72	0.003	0.0122	0.055	0.008	0.201	0.42	0.0034														722	778	COMPARATIVE EXAMPLE
U	0.65	0.78	3.10	0.005	0.0052	0.011	0.004	0.332	0.02	0.0013														709	756	COMPARATIVE EXAMPLE
V	0.70	0.58	0.60	0.019	0.0048	0.046	0.002	0.136	1.55	0.0029														758	775	COMPARATIVE EXAMPLE
W	0.78	0.91	2.01	0.005	0.0046	0.076	0.009	0.487	1.37	0.0028														747	751	COMPARATIVE EXAMPLE
X	0.42	0.24	0.58	0.011	0.0062	0.024	0.005	0.006	0.88	0.0022														738	808	COMPARATIVE EXAMPLE
Y	0.47	0.99	0.51	0.019	0.0093	0.091	0.009	0.519	1.06	0.0030														760	804	COMPARATIVE EXAMPLE
BK	0.37	0.38	1.24	0.018	0.0088	0.063	0.007	0.121		0.0022														721	816	COMPARATIVE EXAMPLE

[0064] Then, the coefficient of micro-friction of ferrite, and the spheroidized ratio and the average diameter of cementite, of each of the high-carbon steel sheets were measured. A friction coefficient of cementite was also measured in measuring the coefficient of micro-friction of ferrite. Results of them are listed in Table 2. An underline in Table 2 indicates that the item is out of the range of the present invention.

[0065] Further, evaluation of adhesion suppressive performance and evaluation of crack sensitivity of each of the high-carbon steel sheets were performed as formability evaluation. In the evaluation of adhesion suppressive performance, a draw bead test was performed. That is, an indentation bead with a tip having a 20 mm radius R was pressed against the high-carbon steel sheet with a load of 10 kN and was pulled out. Then, presence or absence of adhesive matter on the tip of the indentation bead was observed, and one with presence of adhesive matter was evaluated as × and one with no presence was evaluated as ○. The presence of adhesive matter in this test indicates that in press forming with several thousands to several tens of thousands of shots, an adhesive matter occurs early on the metal mold to deteriorate formability. In the evaluation of crack sensitivity, a compression test was performed. That is, a cylindrical test piece having a 10 mm diameter and a 4 mm height was cut out from the high-carbon steel sheet so that a height direction of the test piece was parallel to a sheet thickness direction, and the test piece was compressed to 1 mm in height. Then, an appearance observation and a sectional structure observation were performed, and then one in which cracking appeared in the appearance during compression or after compression and one in which a crack of 1 mm or more was present in the sectional structure observation were evaluated as ×, and one other than the above was evaluated as ○. Results of them are also listed in Table 2.

[Table 2]

SAMPLE No.	STEEL TYPE	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
1	A	0.40	0.24	80.4	0.76	○	○	INVENTIVE EXAMPLE
2	B	0.43	0.25	80.4	1.13	○	○	INVENTIVE EXAMPLE
3	C	0.40	0.31	86.5	0.62	○	○	INVENTIVE EXAMPLE
4	D	0.42	0.23	83.8	0.86	○	○	INVENTIVE EXAMPLE
5	E	0.42	0.32	95.5	0.69	○	○	INVENTIVE EXAMPLE
6	F	0.41	0.33	90.0	0.42	○	○	INVENTIVE EXAMPLE
7	G	0.49	0.23	85.4	0.96	○	○	INVENTIVE EXAMPLE
8	H	0.44	0.28	98.7	0.52	○	○	INVENTIVE EXAMPLE
9	I	0.42	0.33	94.8	0.56	○	○	INVENTIVE EXAMPLE
10	J	0.42	0.32	92.6	0.56	×	○	COMPARATIVE EXAMPLE
11	K	0.72	0.25	91.4	0.59	×	×	COMPARATIVE EXAMPLE
12	L	0.42	0.23	81.7	0.85	○	×	COMPARATIVE EXAMPLE
13	M	0.42	0.29	85.9	0.73	○	×	COMPARATIVE EXAMPLE

(continued)

SAMPLE No.	STEEL TYPE	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
14	N	0.41	0.30	75.6	1.04	○	×	COMPARATIVE EXAMPLE
15	O	0.42	0.31	90.9	0.36	○	×	COMPARATIVE EXAMPLE
16	P	0.41	0.23	82.4	0.54	○	×	COMPARATIVE EXAMPLE
17	Q	0.79	0.24	87.7	1.05	×	×	COMPARATIVE EXAMPLE
18	R	0.79	0.33	92.5	0.55	×	×	COMPARATIVE EXAMPLE
19	S	0.44	0.27	85.2	2.56	○	×	COMPARATIVE EXAMPLE
20	T	0.41	0.31	91.2	0.71	○	×	COMPARATIVE EXAMPLE
21	U	0.41	0.28	98.0	0.52	○	×	COMPARATIVE EXAMPLE
22	V	0.44	0.31	65.8	0.26	○	×	COMPARATIVE EXAMPLE
23	W	0.45	0.25	98.9	0.30	○	×	COMPARATIVE EXAMPLE
24	X	0.62	0.28	85.3	0.75	×	×	COMPARATIVE EXAMPLE
25	Y	0.42	0.27	82.2	0.59	○	×	COMPARATIVE. EXAMPLE
26	BK	0.69	0.29	80.6	0.92	×	○	COMPARATIVE EXAMPLE

[0066] As listed in Table 2, Sample No. 1 to Sample No. 9 were each within the range of the present invention, thus being able to obtain good adhesion suppressive performance and crack sensitivity.

[0067] On the other hand, in Sample No. 10, the C content of Steel type J was too low, and thus the amount of cementite was insufficient, sufficient lubricity was not able to be obtained, and adhesion to the metal mold occurred during forming. In Sample No. 11, the N content of Steel type K was too high, and thus BN precipitated, the amount of solid-solution B was insufficient, the coefficient of micro-friction of ferrite was low, and adhesion and cracking during the compression test occurred. In Sample No. 12, the Al content of Steel type L was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 13, the B content of Steel type M was too high, and thus boride was formed and a crack originating from the boride is occurred during the compression test. In Sample No. 14, the Mn content of Steel type N was too low, and thus pearlite transformation occurred during cooling in the annealing, the spheroidized ratio of cementite was low, and a crack originating from acicular cementite occurred during the compression test. In Sample No. 15, the P content of Steel type ○ was too high, and thus segregation of B to the interface between ferrite and cementite was hindered and cracking occurred during the compression test. In Sample No. 16, the Si content of Steel type P was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 17 and Sample No. 18, each B content of Steel type Q and Steel type R was too low, and thus the coefficient of micro-friction of ferrite was low and adhesion and cracking during the compression test occurred. In Sample No. 19, the Si content of Steel type S was too low, and thus cementite became coarse excessively during annealing and a crack originating from the coarse cementite occurred during the compression test. In Sample No. 20, the S content of Steel type T was too high, and thus coarse sulfides being non-metal inclusions were formed and a crack originating from the coarse sulfide occurred during the compression test. In Sample No. 21, the Mn content of Steel type U was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 22, the Cr content of Steel type V was too high, and thus spheroidizing of cementite during annealing was hindered, coarsening of cementite was suppressed, and a crack originating from micro acicular cementite occurred during the compression test. In Sample No. 23, the C content of Steel type W was too high, and thus the amount of cementite was excessive and a crack originating from the cementite occurred during the compression test. In Sample No. 24, the Ti content of Steel type X was too low, and thus BN precipitated, the amount of solid-solution B was insufficient, the coefficient of micro-friction of ferrite was low, and adhesion and cracking during the compression test occurred. In Sample No. 25, the Ti content of Steel type Y was too high, and thus coarse oxides of Ti were formed and a crack originating from the coarse oxide of Ti occurred during the compression test. In Sample No. 26, the Cr content of Steel type BK was too low, and thus BN precipitated, the amount of solid-solution B was insufficient, the coefficient of micro-friction of ferrite was low, and adhesion to the metal mold occurred during forming.

(Second experiment)

[0068] In a second experiment, hot-rolling of a slab (Steel type Z to BJ) including a chemical composition listed in Table 3 was performed, thereby obtaining a hot-rolled steel sheet having a thickness of 4 mm. In the hot-rolling, the slab heating temperature was 1130°C, the time thereof was 1 hour, the finish rolling temperature was 850°C, and the coiling temperature was 520°C. Then, cooling was performed down to a temperature of less than 60°C, and pickling using sulfuric acid was performed. Thereafter, annealing of the hot-rolled steel sheet was performed to then obtain a hot-rolled annealed steel sheet. In the annealing, the hot-rolled steel sheet was retained for 15 hours at 750°C, and then was cooled down to 650°C at a cooling rate of 30°C /hr. Subsequently, cooling was performed down to a temperature of less than 60°C. In this manner, various high-carbon steel sheets were manufactured. Blank fields in Table 3 indicate that the content of the element is less than a detection limit, and the balance is Fe and impurities. An underline in Table 3 indicates that the numeric value is out of the range of the present invention.

[Table 3]

STEEL TYPE	CHEMICAL COMPONENT (MASS%)																							Ac1 (°C)	Ac3 (°C)	REMARKS
	C	Si	Mn	P	S	Al	N	Ti	Cr	B	Nb	Mo	V	Cu	W	Ta	Ni	Mg	Ca	Y	Zr	La	Ce			
Z	0.34	0.52	2.38	0.015	0.0005	0.006	0.007	0.220	1.09	0.0017		0.004												726	811	INVENTIVE EXAMPLE
AA	0.35	0.81	2.20	0.013	0.0010	0.080	0.004	0.301	0.83	0.0020	0.192		0.003		0.032		0.047							737	832	INVENTIVE EXAMPLE
AB	0.37	0.22	0.31	0.022	0.0017	0.024	0.007	0.078	0.99	0.0011		0.100	0.326		0.163	0.101				0.005	0.002	0.004		741	817	INVENTIVE EXAMPLE
AC	0.39	0.11	0.42	0.022	0.0059	0.076	0.005	0.192	0.18	0.0026			0.355		0.395	0.056	0.330	0.114	0.371			0.242	0.311	722	798	INVENTIVE EXAMPLE
AD	0.44	0.57	1.45	0.019	0.0024	0.030	0.002	0.189	0.72	0.0013	0.108	0.266		0.114			0.225		0.263	0.467	0.272	0.481		733	805	INVENTIVE EXAMPLE
AE	0.47	0.37	0.49	0.018	0.0027	0.008	0.001	0.119	0.46	0.0008	0.313		0.044		0.087			0.441	0.129	0.122	0.339		0.003	734	795	INVENTIVE EXAMPLE
AF	0.50	0.26	0.90	0.005	0.0048	0.041	0.003	0.035	0.29	0.0031	0.037					0.002	0.002							727	797	INVENTIVE EXAMPLE
AG	0.52	0.65	2.05	0.007	0.0077	0.016	0.001	0.471	1.48	0.0017	0.040	0.258	0.271		0.183							0.002		741	773	INVENTIVE EXAMPLE
AH	0.57	0.13	0.51	0.002	0.0062	0.066	0.003	0.169	0.02	0.0025	0.350		0.130	0.383	0.287			0.327	0.007			0.329	0.278	723	772	INVENTIVE EXAMPLE
AI	0.57	0.89	2.67	0.001	0.0041	0.020	0.009	0.019	0.91	0.0016	0.080	0.485				0.005	0.491				0.490		0.443	729	798	INVENTIVE EXAMPLE
AJ	0.62	0.43	0.78	0.009	0.0078	0.097	0.003	0.365	0.63	0.0033		0.156		0.235	0.002	0.197								733	757	INVENTIVE EXAMPLE
AK	0.66	0.69	2.38	0.006	0.0054	0.093	0.007	0.255	0.20	0.0010	0.377	0.049			0.430		0.023	0.005		0.268	0.011	0.006	0.199	723	766	INVENTIVE EXAMPLE
AL	0.66	0.63	1.86	0.003	0.0071	0.079	0.001	0.011	1.38	0.0007	0.004		0.019	0.003		0.459								744	781	INVENTIVE EXAMPLE
AM	0.22	0.27	2.88	0.023	0.0081	0.018	0.006	0.021	0.83	0.0031	0.081		0.232		0.454	0.086	0.180	0.281		0.128			0.027	714	851	COMPARATIVE EXAMPLE
AN	0.34	0.87	2.26	0.006	0.0055	0.064	0.001	0.418	1.27	0.0004	0.082			0.506		0.126								740	819	COMPARATIVE EXAMPLE
AO	0.34	0.59	0.99	0.023	0.0021	0.080	0.005	0.296	0.54	0.0033			0.316		0.191		0.447	0.185	0.510					732	825	COMPARATIVE EXAMPLE
AP	0.35	0.27	0.97	0.004	0.0051	0.091	0.007	0.311	0.91	0.0006		0.538				0.236								730	811	COMPARATIVE EXAMPLE
AQ	0.36	0.99	2.37	0.022	0.0092	0.026	0.006	0.030	0.30	0.0003			0.183	0.471			0.126		0.099		0.107			730	846	COMPARATIVE EXAMPLE
AR	0.37	0.78	2.77	0.023	0.0029	0.064	0.002	0.062	0.35	0.0024	0.511		0.473				0.291							719	836	COMPARATIVE EXAMPLE
AS	0.38	0.63	0.17	0.022	0.0001	0.091	0.002	0.352	0.27	0.0016	0.196	0.038		0.044		0.005		0.011		0.255			0.013	741	817	COMPARATIVE EXAMPLE
AT	0.41	0.71	0.43	0.001	0.0045	0.062	0.004	0.231	0.08	0.0029	0.264		0.160	0.278	0.398	0.425			0.448	0.290	0.029		0.516	738	820	COMPARATIVE EXAMPLE
AU	0.42	0.77	1.28	0.016	0.0021	0.027	0.003	0.031	1.18	0.0038	0.001		0.380			0.340				0.496			0.039	755	839	COMPARATIVE EXAMPLE
AV	0.43	0.08	2.79	0.020	0.0036	0.011	0.008	0.135	0.71	0.0005							0.523							699	770	COMPARATIVE EXAMPLE
AW	0.44	0.90	0.90	0.009	0.0001	0.005	0.004	0.426	1.24	0.0021	0.457		0.532	0.367		0.186	0.120							759	807	COMPARATIVE EXAMPLE
AX	0.45	0.54	0.27	0.001	0.0055	0.014	0.002	0.027	0.02	0.0034	0.227	0.008	0.454		0.029		0.189		0.177		0.503		0.192	733	813	COMPARATIVE EXAMPLE
AY	0.47	0.93	2.42	0.021	0.0012	0.058	0.004	0.477	1.70	0.0024		0.245			0.257		0.064	0.082		0.221	0.053			754	796	COMPARATIVE EXAMPLE
AZ	0.51	0.08	0.14	0.005	0.0010	0.023	0.004	0.016	1.00	0.0032	0.304			0.400	0.394	0.014	0.045	0.137	0.471			0.082	0.433	743	790	COMPARATIVE EXAMPLE
BA	0.51	0.75	2.58	0.008	0.0095	0.074	0.003	0.220	0.26	0.0023		0.058	0.365	0.016	0.192					0.505	0.138		0.035	715	785	COMPARATIVE EXAMPLE
BB	0.52	0.19	0.82	0.002	0.0091	0.014	0.003	0.282	0.89	0.0024	0.373	0.287	0.303		0.429	0.410	0.208	0.001		0.013	0.054	0.507		734	770	COMPARATIVE EXAMPLE
BC	0.54	0.85	2.66	0.002	0.0104	0.023	0.008	0.312	0.41	0.0028			0.468	0.340	0.079				0.024	0.403		0.214	0.022	725	787	COMPARATIVE EXAMPLE
BD	0.55	0.26	2.16	0.011	0.0023	0.092	0.001	0.167	1.31	0.0004	0.097		0.030		0.512	0.085								732	770	COMPARATIVE EXAMPLE
BE	0.58	0.36	0.86	0.014	0.0073	0.069	0.006	0.009	0.83	0.0016		0.029		0.004	0.018		0.074					0.042		737	782	COMPARATIVE EXAMPLE
BF	0.62	0.03	0.93	0.015	0.0100	0.080	0.002	0.027	0.28	0.0020		0.007	0.034		0.201			0.281	0.138		0.344	0.117		716	758	COMPARATIVE EXAMPLE
BG	0.66	0.19	1.34	0.028	0.0044	0.018	0.004	0.464	0.80	0.0035		0.235	0.203		0.012		0.147	0.017				0.052		725	731	COMPARATIVE EXAMPLE
BH	0.68	0.98	1.94	0.004	0.0094	0.062	0.004	0.070	1.32	0.0006		0.057	0.150		0.045	0.512								746	782	COMPARATIVE EXAMPLE
BI	0.68	0.23	2.17	0.019	0.0072	0.006	0.005	0.197	0.70	0.0011	0.475	0.098	0.263	0.427	0.253	0.316	0.455	0.509						712	736	COMPARATIVE EXAMPLE
BJ	0.71	0.17	0.52	0.003	0.0064	0.008	0.008	0.046	0.20	0.0021		0.101			0.193	0.013			0.015			0.177	0.022	722	751	COMPARATIVE EXAMPLE

[0069] Then, in the same manner as in the first experiment, the coefficient of micro-friction of ferrite, and the spheroidized ratio and the average diameter of cementite of each of the high-carbon steel sheets were measured, and further, the evaluation of adhesion suppressive performance and the evaluation of crack sensitivity were performed. Results of them are listed in Table 4. An underline in Table 4 indicates that the item is out of the range of the present invention.

[Table 4]

SAMPLE No.	STEEL TYPE	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
31	Z	0.43	0.28	90.8	0.45	○	○	INVENTIVE EXAMPLE
32	AA	0.43	0.23	85.2	0.41	○	○	INVENTIVE EXAMPLE
33	AB	0.41	0.27	80.2	0.98	○	○	INVENTIVE EXAMPLE
34	AC	0.45	0.32	81.4	2.05	○	○	INVENTIVE EXAMPLE
35	AD	0.41	0.28	86.4	0.62	○	○	INVENTIVE EXAMPLE
36	AE	0.43	0.31	82.3	1.24	○	○	INVENTIVE EXAMPLE
37	AF	0.42	0.23	84.5	1.02	○	○	INVENTIVE EXAMPLE
38	AG	0.43	0.30	91.2	0.31	○	○	INVENTIVE EXAMPLE
39	AH	0.42	0.28	82.2	1.71	○	○	INVENTIVE EXAMPLE
40	AI	0.42	0.31	94.1	0.31	○	○	INVENTIVE EXAMPLE
41	AJ	0.43	0.26	91.3	0.89	○	○	INVENTIVE EXAMPLE
42	AK	0.40	0.34	93.9	0.64	○	○	INVENTIVE EXAMPLE
43	AL	0.41	0.24	87.2	0.39	○	○	INVENTIVE EXAMPLE

(continued)

SAMPLE No.	STEEL TYPE	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
44	AM	0.43	0.31	90.5	0.45	×	○	COMPARATIVE EXAMPLE
45	AN	0.45	0.30	85.4	0.36	×	○	COMPARATIVE EXAMPLE
46	AO	0.45	0.25	83.0	0.75	○	×	COMPARATIVE EXAMPLE
47	AP	0.44	0.26	86.3	0.64	○	×	COMPARATIVE EXAMPLE
48	AQ	0.58	0.25	85.2	0.54	×	×	COMPARATIVE EXAMPLE
49	AR	0.42	0.31	89.1	0.42	○	×	COMPARATIVE EXAMPLE
50	AS	0.40	0.23	79.0	1.39	○	×	COMPARATIVE EXAMPLE
51	AT	0.44	0.33	85.7	1.35	○	×	COMPARATIVE EXAMPLE
52	AU	0.44	0.32	84.0	0.43	○	×	COMPARATIVE EXAMPLE
53	AV	0.73	0.25	98.1	0.56	×	○	COMPARATIVE EXAMPLE
54	AW	0.44	0.23	80.9	0.52	○	×	COMPARATIVE EXAMPLE
55	AX	0.42	0.27	84.7	1.82	○	×	COMPARATIVE EXAMPLE
56	AY	0.41	0.30	64.0	0.24	○	×	COMPARATIVE EXAMPLE

(continued)

SAMPLE No.	STEEL TYPE	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
57	AZ	0.43	0.23	67.4	1.05	○	×	COMPARATIVE EXAMPLE
58	BA	0.43	0.28	92.9	0.57	○	×	COMPARATIVE EXAMPLE
59	BB	0.42	0.31	89.6	0.80	○	×	COMPARATIVE EXAMPLE
60	BC	0.42	0.22	92.0	0.42	○	×	COMPARATIVE EXAMPLE
61	BD	0.46	0.23	95.0	0.46	○	×	COMPARATIVE EXAMPLE
62	BE	0.69	0.27	89.6	0.58	×	×	COMPARATIVE EXAMPLE
63	BF	0.43	0.31	90.6	2.32	○	×	COMPARATIVE EXAMPLE
64	BG	0.44	0.22	96.7	0.73	○	×	COMPARATIVE EXAMPLE
65	BH	0.42	0.32	85.0	0.37	○	×	COMPARATIVE EXAMPLE
66	BI	0.41	0.29	98.9	0.63	○	×	COMPARATIVE EXAMPLE
67	BJ	0.42	0.25	88.3	1.64	○	×	COMPARATIVE EXAMPLE

[0070] As listed in Table 4, Samples No. 31 to No. 43 were each within the range of the present invention, thus being able to obtain good adhesion suppressive performance and crack sensitivity.

[0071] On the other hand, in Sample No. 44, the C content of Steel type AM was too low, and thus the amount of cementite was insufficient, sufficient lubricity was not able to be obtained, and adhesion to the metal mold occurred during forming. In Sample No. 45, the Cu content of Steel type AN was too high, and thus a flaw occurred during hot-rolling and adhesion originating from the flaw occurred. In Sample No. 46, the Ca content of Steel type AO was too high, and thus coarse oxides of Ca were formed and a crack originating from the coarse oxide of Ca occurred during the compression test. In Sample No. 47, the Mo content of Steel type AP was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 48, the B content of Steel type AQ was too low, and thus the coefficient of micro-friction of ferrite was low and adhesion and cracking during the compression test occurred. In Sample No. 49, the Nb content of Steel type AR was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 50, the Mn content of Steel type AS was too low, and thus pearlite transformation occurred during cooling in the annealing, the spheroidized ratio of cementite was low, and a crack originating from acicular cementite occurred during the compression test. In Sample No. 51, the Ce content of Steel type AT was too high, and thus coarse oxides of Ce were formed and a crack originating from the coarse oxide of Ce occurred during the compression test. In Sample No. 52, the B content of Steel type AU was too high, and thus boride was formed and a crack originating from the boride occurred during the compression test. In Sample No. 53, the Ni content of Steel type AV was too high, and thus the coefficient of micro-friction of ferrite was high and adhesion occurred. In Sample No. 54, the V content of Steel type AW was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 55, the Zr content of Steel type AX was too high, and thus coarse oxides of Zr were formed and a crack originating from the coarse oxide of Zr occurred during the compression test. In Sample No. 56, the Cr content of Steel type AY was too high, and thus spheroidizing of cementite during annealing was hindered, coarsening of cementite was suppressed, and a crack originating from micro acicular cementite occurred during the compression test. In Sample No. 57, the Mn content of Steel type AZ was too low, and thus pearlite transformation occurred during cooling in the annealing, the spheroidized ratio of cementite was low, and a crack originating from acicular cementite occurred during the compression test. In Sample No. 58, the Y content of Steel type BA was too high, and thus coarse oxides of Y were formed and a crack originating from the coarse oxide of Y occurred during the compression test. In Sample No. 59, the La content of Steel type BB was too high, and thus coarse oxides of La were formed and a crack originating from the coarse oxide of La occurred during the compression test. In Sample No. 60, the S content of Steel type BC was too high, and thus coarse sulfides being non-metal inclusions were formed and a crack originating from the coarse sulfide occurred during the compression test. In Sample No. 61, the W content of Steel type BD was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 62, the Ti content of Steel type BE was too low, and thus BN precipitated, the amount of solid-solution B was insufficient, the coefficient of micro-friction of ferrite was low, and adhesion and cracking during the compression test occurred. In Sample No. 63, the Si content of Steel type BF was too low, and thus cementite became coarse excessively and a crack originating from the coarse cementite occurred during the compression test. In Sample No. 64, the P content of Steel type BG was too high, and thus segregation of B to the interface between ferrite and cementite was hindered and cracking occurred during the compression test. In Sample No. 65, the Ta content of Steel type BH was too high, and thus the ductility of ferrite was low and a crack originating from transgranular fracture of ferrite occurred during the compression test. In Sample No. 66, the Mg content of Steel type BI was too high, and thus coarse oxides of Mg were formed and a crack originating from the coarse oxide of Mg occurred during the compression test. In Sample No. 67, the C content of Steel type BJ was too high, and thus the amount of cementite was excessive and a crack originating from the cementite occurred during the compression test.

[0072] Fig. 1 illustrates the relationship between the coefficient of micro-friction of ferrite and the B content of Samples No. 1 to No. 2.5 and No. 31 to No. 67 except for Samples No. 11, No. 51, No. 53, and No. 62. As illustrated in Fig. 1, when the B content is 0.0004% or more, the coefficient of micro-friction of ferrite is significantly low as compared to the case when it is less than 0.0004%.

(Third experiment)

[0073] In a third experiment, hot-rolling and annealing were performed under various conditions on the steel types that were within the range of the present invention (Steel types A to I and Steel types Z to AL) out of the steel types used in the first experiment and the steel types used in the second experiment so as to manufacture high-carbon steel sheets. Conditions of them are listed in Table 5 to Table 7. An underline in Table 5 to Table 7 indicates that the numeric value is out of the range of the present invention.

[Table 5]

SAMPLE No.	STEEL TYPE	CONDITIONS IN HOT-ROLLING			CONDITIONS IN ANNEALING			REMARKS
		SLAB HEATING TEMPERATURE (°C)	FINISH ROLLING TEMPERATURE (°C)	COILING TEMPERATURE (°C)	RETENTION TEMPERATURE (°C)	RETENTION TIME (hr)	COLLING RATE (°C/hr)	
71	A	1116	871	540	786	51.4	56.7	COMPARATIVE EXAMPLE
72	B	1149	841	646	745	18.4	58.6	INVENTIVE EXAMPLE
73	C	1113	879	706	747	9.7	26.7	COMPARATIVE EXAMPLE
74	D	1006	940	681	757	34.7	33.6	INVENTIVE EXAMPLE
75	E	1149	889	605	756	2.2	13.9	COMPARATIVE EXAMPLE
76	F	993	902	554	759	3.6	30.7	COMPARATIVE EXAMPLE
77	G	1068	891	684	742	26.8	3.8	INVENTIVE EXAMPLE
78	H	1044	874	685	736	56.2	53.2	INVENTIVE EXAMPLE
79	I	1083	845	590	748	46.3	40.7	INVECTIVE EXAMPLE
80	Z	1120	914	616	751	6.5	1.3	INVENTIVE EXAMPLE
81	AA	1122	880	714	765	43.0	58.9	COMPARATIVE EXAMPLE
82	AB	1113	844	583	752	55.3	2.7	INVENTIVE EXAMPLE
83	AC	1088	863	695	749	7.6	38.0	INVENTIVE EXAMPLE

(continued)

SAMPLE No.	STEEL TYPE	CONDITIONS IN HOT-ROLLING			CONDITIONS IN ANNEALING			REMARKS
		SLAB HEATING TEMPERATURE (°C)	FINISH ROLLING TEMPERATURE (°C)	COILING TEMPERATURE (°C)	RETENTION TEMPERATURE (°C)	RETENTION TIME (hr)	COLLING RATE (°C/hr)	
84	AD	1065	850	547	741	18.3	68.1	COMPARATIVE EXAMPLE
85	AE	1095	904	680	750	36.5	48.6	INVENTIVE EXAMPLE
86	AF	1118	949	521	776	57.9	7.5	COMPARATIVE EXAMPLE
87	AG	1024	859	435	766	58.7	5.5	COMPARATIVE EXAMPLE
88	AH	1078	874	620	754	18.8	21.3	INVENTIVE EXAMPLE
89	AI	1028	861	615	753	3.1	21.2	INVENTIVE EXAMPLE
90	AJ	1136	915	689	767	46.8	27.6	INVENTIVE EXAMPLE
91	AK	1098	936	645	760	37.1	8.1	INVENTIVE EXAMPLE
92	AL	1099	901	691	754	29.7	12.7	INVENTIVE EXAMPLE

[Table 6]

SAMPLE No.	STEEL TYPE	CONDITIONS IN HOT-ROLLING			CONDITIONS IN ANNEALING			REMARKS
		SLAB HEATING TEMPERATURE (°C)	FINISH ROLLING TEMPERATURE (°C)	COILING TEMPERATURE (°C)	RETENTION TEMPERATURE (°C)	RETENTION TIME (hr)	COLLING RATE (°C/hr)	
101	A	1104	873	527	<u>721</u>	38.3	32.0	COMPARATIVE EXAMPLE
102	B	1060	983	560	757	56.8	17.3	COMPARATIVE EXAMPLE
103	C	1129	865	625	732	4.9	42.7	INVENTIVE EXAMPLE
104	D	<u>1175</u>	863	548	767	12.6	30.7	COMPARATIVE EXAMPLE
105	E	1109	875	632	749	4.6	40.7	INVENTIVE EXAMPLE
106	F	1088	865	677	768	23.0	2.3	INVENTIVE EXAMPLE
107	G	1142	869	536	736	5.5	<u>62.3</u>	COMPARATIVE EXAMPLE
108	H	1064	848	640	739	14.8	29.0	INVENTIVE EXAMPLE
109	I	1064	847	621	745	7.8	24.5	INVENTIVE EXAMPLE
110	Z	1007	878	656	747	48.2	2.9	INVENTIVE EXAMPLE
111	AA	1051	943	699	768	6.2	1.2	INVENTIVE EXAMPLE
112	AB	<u>1158</u>	908	526	760	6.2	7.3	COMPARATIVE EXAMPLE
113	AC	1131	<u>823</u>	532	761	47.9	16.2	COMPARATIVE EXAMPLE

(continued)

SAMPLE No.	STEEL TYPE	CONDITIONS IN HOT-ROLLING			CONDITIONS IN ANNEALING			REMARKS
		SLAB HEATING TEMPERATURE (°C)	FINISH ROLLING TEMPERATURE (°C)	COILING TEMPERATURE (°C)	RETENTION TEMPERATURE (°C)	RETENTION TIME (hr)	COLLING RATE (°C/hr)	
114	AD	1047	847	605	730	22.5	25.2	INVENTIVE EXAMPLE
115	AE	1080	862	648	752	26.8	31.7	INVENTIVE EXAMPLE
116	AF	1102	885	666	741	17.0	42.8	INVENTIVE EXAMPLE
117	AG	1050	932	601	770	32.6	1.9	INVENTIVE EXAMPLE
118	AH	1025	875	540	718	26.3	41.3	COMPARATIVE EXAMPLE
119	AI	1078	936	625	750	17.1	58.1	INVECTIVE EXAMPLE
120	AJ	1079	881	671	764	9.7	28.7	INVENTIVE EXAMPLE
121	AK	1084	867	641	735	27.8	4.5	INVENTIVE EXAMPLE
122	AL	1116	890	531	742	4.5	9.3	INVENTIVE EXAMPLE

[Table 7]

SAMPLE No.	STEEL TYPE	CONDITIONS IN HOT-ROLLING			CONDITIONS IN ANNEALING			REMARKS
		SLAB HEATING TEMPERATURE (°C)	FINISH ROLLING TEMPERATURE (°C)	COILING TEMPERATURE (°C)	RETENTION TEMPERATURE (°C)	RETENTION TIME (hr)	COLLING RATE (°C/hr)	
131	A	1096	870	511	764	54.5	10.2	INVENTIVE EXAMPLE
132	B	1097	886	479	768	18.7	0.4	COMPARATIVE EXAMPLE
133	C	1107	835	502	762	6.1	56.6	INVENTIVE EXAMPLE
134	D	1022	857	464	755	4.8	45.2	INVENTIVE EXAMPLE
135	E	1087	801	453	743	17.6	54.7	COMPARATIVE EXAMPLE
136	F	1069	858	576	761	34.0	49.8	INVENTIVE EXAMPLE
137	G	1032	931	444	738	35.9	16.5	COMPARATIVE EXAMPLE
138	H	1096	843	497	749	62.6	42.7	COMPARATIVE EXAMPLE
139	I	1046	895	536	754	48.1	24.5	INVENTIVE EXAMPLE
140	Z	1123	920	489	755	2.6	58.5	COMPARATIVE EXAMPLE
141	AA	1082	865	495	731	34.8	33.3	INVENTIVE EXAMPLE
142	AB	1058	924	482	749	26.5	24.3	INVENTIVE EXAMPLE
143	AC	1123	904	524	743	35.3	35.6	INVENTIVE EXAMPLE

(continued)

SAMPLE No.	STEEL TYPE	CONDITIONS IN HOT-ROLLING			CONDITIONS IN ANNEALING			REMARKS
		SLAB HEATING TEMPERATURE (°C)	FINISH ROLLING TEMPERATURE (°C)	COILING TEMPERATURE (°C)	RETENTION TEMPERATURE (°C)	RETENTION TIME (hr)	COLLING RATE (°C/hr)	
144	AD	1077	877	498	741	10.4	0.8	COMPARATIVE EXAMPLE
145	AE	1008	939	574	753	22.1	28.7	INVENTIVE EXAMPLE
146	AF	1034	962	482	751	41.0	7.4	COMPARATIVE EXAMPLE
147	AG	1133	916	457	732	4.5	24.0	INVECTIVE EXAMPLE
148	AH	1037	884	561	748	59.0	9.4	INVENTIVE EXAMPLE
149	AI	979	847	508	752	59.9	4.6	COMPARATIVE EXAMPLE
150	AJ	1126	933	479	748	68.3	3.3	COMPARATIVE EXAMPLE
151	AK	1138	893	598	752	26.9	3.2	INVENTIVE EXAMPLE
152	AL	1063	865	584	746	40.3	2.6	INVENTIVE EXAMPLE

[0074] Then, in the same manner as in the first experiment, the coefficient of micro-friction of ferrite, and the spheroidized ratio and the average diameter of cementite of each of the high-carbon steel sheets were measured, and further, the evaluation of adhesion suppressive performance and the evaluation of crack sensitivity were performed. Results of them are listed in Table 8 to Table 10. An underline in Table 8 to Table 10 indicates that the item is out of the range of the present invention.

[Table 8]

SAMPLE No.	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
71	0.72	0.33	86.8	2.2.5	×	×	COMPARATIVE EXAMPLE
72	0.43	0.31	87.9	1.15	○	○	INVENTIVE EXAMPLE
73	0.64	0.27	78.3	0.63	×	×	COMPARATIVE EXAMPLE
74	0.44	0.28	88.3	0.90	○	○	INVENTIVE EXAMPLE
75	0.63	0.24	84.3	0.29	×	×	COMPARATIVE EXAMPLE
76	0.59	0.24	90.3	0.42	×	×	COMPARATIVE EXAMPLE
77	0.49	0.28	80.9	0.99	○	○	INVENTIVE EXAMPLE
78	0.44	0.31	94.3	0.54	○	○	INVENTIVE EXAMPLE
79	0.43	0.29	93.1	0.59	○	○	INVENTIVE EXAMPLE
80	0.48	0.28	80.8	0.98	○	○	INVENTIVE EXAMPLE
81	0.71	0.23	75.4	2.12	×	×	COMPARATIVE EXAMPLE
82	0.44	0.22	87.1	0.65	○	○	INVENTIVE EXAMPLE
83	0.47	0.34	82.0	1.25	○	○	INVENTIVE EXAMPLE
84	0.61	0.34	62.3	1.04	×	×	COMPARATIVE EXAMPLE

(continued)

SAMPLE No.	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
85	0.46	0.29	91.2	0.33	○	○	INVENTIVE EXAMPLE
86	0.73	0.25	83.6	2.36	×	×	COMPARATIVE EXAMPLE
87	0.64	0.23	98.9	1.16	×	○	COMPARATIVE EXAMPLE
88	0.47	0.30	93.0	0.92	○	○	INVENTIVE EXAMPLE
89	0.45	0.28	94.8	0.63	○	○	INVENTIVE EXAMPLE
90	0.45	0.27	97.1	0.43	○	○	INVENTIVE EXAMPLE
91	0.44	0.32	96.5	0.68	○	○	INVENTIVE EXAMPLE
92	0.45	0.28	90.4	0.46	○	○	INVENTIVE EXAMPLE

[Table 9]

SAMPLE No.	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
101	0.72	0.31	82.3	0.77	×	×	COMPARATIVE EXAMPLE
102	0.61	0.22	82.8	1.18	×	○	COMPARATIVE EXAMPLE
103	0.42	0.26	81.3	0.61	○	○	INVENTIVE EXAMPLE
104	0.71	0.26	92.2	0.89	×	○	COMPARATIVE EXAMPLE
105	0.44	0.24	95.3	0.69	○	○	INVENTIVE EXAMPLE
106	0.42	0.30	94.9	0.45	○	○	INVENTIVE EXAMPLE
107	0.61	0.31	64.1	0.95	×	×	COMPARATIVE EXAMPLE
108	0.43	0.32	95.4	0.53	○	○	INVENTIVE EXAMPLE
109	0.42	0.26	89.8	0.56	○	○	INVENTIVE EXAMPLE
110	0.44	0.34	88.0	1.01	○	○	INVENTIVE EXAMPLE
111	0.44	0.34	84.2	2.07	○	○	INVENTIVE EXAMPLE
112	0.69	0.25	89.6	0.63	×	○	COMPARATIVE EXAMPLE
113	0.59	0.32	85.5	1.29	×	×	COMPARATIVE EXAMPLE
114	0.47	0.23	84.0	1.03	○	○	INVENTIVE EXAMPLE

(continued)

SAMPLE No.	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
115	0.48	0.28	92.8	0.33	○	○	INVENTIVE EXAMPLE
116	0.45	0.30	90.0	1.73	○	○	INVENTIVE EXAMPLE
117	0.44	0.26	99.8	0.34	○	○	INVENTIVE EXAMPLE
118	$\underline{0.63}$	0.25	85.9	0.83	×	×	COMPARATIVE EXAMPLE
119	0.47	0.23	93.9	0.66	○	○	INVENTIVE EXAMPLE
120	0.45	0.28	95.9	0.41	○	○	INVENTIVE EXAMPLE
121	0.46	0.24	87.9	0.65	○	○	INVENTIVE EXAMPLE
122	0.39	0.25	80.6	0.43	○	○	INVENTIVE EXAMPLE

[Table 10]

SAMPLE No.	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
131	0.39	0.32	83.6	0.81	○	○	INVENTIVE EXAMPLE
132	0.68	0.33	97.2	2.45	×	×	COMPARATIVE EXAMPLE
133	0.40	0.24	89.9	0.63	○	○	INVENTIVE EXAMPLE
134	0.40	0.24	87.2	0.86	○	○	INVENTIVE EXAMPLE
135	0.66	0.31	88.1	0.74	×	×	COMPARATIVE EXAMPLE
136	0.44	0.24	91.6	0.45	○	○	INVENTIVE EXAMPLE
137	0.59	0.26	86.5	0.99	×	○	COMPARATIVE EXAMPLE
138	0.66	0.22	92.5	2.55	×	×	COMPARATIVE EXAMPLE
139	0.38	0.32	97.5	0.59	○	○	INVENTIVE EXAMPLE
140	0.60	0.22	82.7	0.22	×	×	COMPARATIVE EXAMPLE
141	0.40	0.27	85.9	2.07	○	○	INVENTIVE EXAMPLE
142	0.40	0.33	86.0	0.64	○	○	INVENTIVE EXAMPLE
143	0.40	0.23	89.1	1.27	○	○	INVENTIVE EXAMPLE
144	0.54	0.27	81.6	2.38	×	×	COMPARATIVE EXAMPLE

(continued)

SAMPLE No.	COEFFICIENT OF MICRO-FRICTION OF FERRITE	COEFFICIENT OF MICRO-FRICTION OF CEMENTITE	SPHEROIDIZED RATIO OF CEMENTITE (%)	AVERAGE DIAMETER OF CEMENTITE (μm)	ADHESION SUPPRESSIVE PERFORMANCE	CRACK SENSITIVITY	REMARKS
145	0.43	0.31	93.5	0.33	○	○	INVENTIVE EXAMPLE
146	0.62	0.24	82.4	1.77	×	○	COMPARATIVE EXAMPLE
147	0.37	0.31	81.0	0.30	○	○	INVENTIVE EXAMPLE
148	0.40	0.32	90.4	0.93	○	○	INVENTIVE EXAMPLE
149	0.72	0.33	94.5	0.68	×	×	COMPARATIVE EXAMPLE
150	0.58	0.29	84.7	2.46	×	×	COMPARATIVE EXAMPLE
151	0.43	0.23	94.5	0.67	○	○	INVENTIVE EXAMPLE
152	0.44	0.25	80.4	0.46	○	○	INVENTIVE EXAMPLE

[0075] As listed in Table 8, Samples No. 72, No. 74, No. 77 to No. 80, No. 82, No. 83, No. 85, and No. 88 to No. 92 were each within the range of the present invention, thus being able to obtain good adhesion suppressive performance and crack sensitivity. As listed in Table 9, Samples No. 103, No. 105, No. 106, No. 108 to No. 111, No. 114 to No. 117, and No. 120 to No. 122 were each also within the range of the present invention, thus being able to obtain good adhesion suppressive performance and crack sensitivity. As listed in Table 10, Samples No. 131, No. 133, No. 134, No. 136, No. 139, No. 141 to No. 143, No. 145, No. 147, No. 148, No. 151, and No. 152 were each also within the range of the present invention, thus being able to obtain good adhesion suppressive performance and crack sensitivity.

[0076] On the other hand, in Sample No. 71, the annealing retention temperature was too high, and thus volume expansion was large, a hot-rolled coil was uncoiled to cause abrasions, and a tightening mark caused by a tightening band also occurred. Further, the thickness of the film of crystals of B greatly varied and the coefficient of micro-friction of ferrite was large. Therefore, adhesion occurred. Further, cementite became coarse excessively and a crack originating from the coarse cementite occurred during the compression test. In Sample No. 73, the coiling temperature was too high, and thus coarse lamellar pearlite was formed in the hot-rolled steel sheet, spheroidizing of cementite during annealing was hindered, and the spheroidized ratio of cementite was low. Further, large irregularities were formed with removal of scales and the coefficient of microfriction of ferrite was large. Therefore, adhesion and cracking during the compression test occurred. In Sample No. 75, the annealing retention time was too short, and thus the coefficient of micro-friction of ferrite was large and the average diameter of cementite was small. Therefore, adhesion and cracking during the compression test occurred. In Sample No. 76, the slab heating temperature was too low, and thus segregations of B, Mn, and others were not eliminated and the coefficient of micro-friction of ferrite was large. Therefore, adhesion and cracking during the compression test occurred. In Sample No. 81, the coiling temperature was too high, and thus adhesion and cracking during the compression test occurred similarly to Sample No. 73. In Sample No. 84, the cooling rate was too high, and thus pearlite transformation occurred during cooling and a crack originating from acicular cementite occurred during the compression test. Further, a good film of crystals of B was not formed on the surface of the high-carbon steel sheet, the coefficient of micro-friction of ferrite was high, and adhesion occurred. In Sample No. 86, the annealing retention temperature was too high, and thus adhesion and cracking during the compression test occurred, similarly to Sample No. 81. In Sample No. 87, the coiling temperature was too low, and thus as a result of removal of scales, the surface of the steel sheet became rough and adhesion occurred.

[0077] In Sample No. 101, the annealing retention temperature was too low, and thus the segregation of B to the interface between ferrite and austenite was suppressed, the coefficient of micro-friction of ferrite was large, and adhesion occurred. Further, the segregation of B to the interface between ferrite and cementite was also suppressed and cracking occurred during the compression test. In Sample No. 102, the finish rolling temperature was too high, and thus large irregularities were formed with removal of scales and the coefficient of micro-friction of ferrite was large. Therefore, adhesion occurred. In Sample No. 104, the slab heating temperature was too high, and thus B atoms were oxidized during slab heating and the coefficient of micro-friction of ferrite was large. Therefore, adhesion occurred. In Sample No. 107, the cooling rate was too high, and thus pearlite transformation occurred during cooling and a crack originating from acicular cementite occurred during the compression test. Further, a good film of crystals of B was not formed on the surface of the high-carbon steel sheet, the coefficient of micro-friction of ferrite was high, and adhesion occurred. In Sample No. 112, the slab heating temperature was too high, and thus adhesion occurred, similarly to Sample No. 104. In Sample No. 113, the finish rolling temperature was too low, and thus anisotropy of the structure was strong and a crack originating from a nonuniform structure occurred during the compression test. Further, as a result of removal of scales, the surface of the steel sheet became rough and adhesion occurred. In Sample No. 118, the annealing retention temperature was too low, and thus adhesion and cracking during the compression test occurred, similarly to Sample No. 101 .

[0078] In Sample No. 132, the cooling rate was too low, and thus the thickness of the film of crystals of B greatly varied and the coefficient of micro-friction of ferrite was large. Therefore, adhesion occurred. Further, cementite became coarse excessively and a crack originating from the coarse cementite occurred during the compression test. In Sample No. 135, the finish rolling temperature was too low, and thus anisotropy of the structure was strong and a crack originating from a nonuniform structure occurred during the compression test. Further, as a result of removal of scales, the surface of the steel sheet became rough and adhesion occurred. In Sample No. 137, the coiling temperature was too low, and thus as a result of removal of scales, the surface of the steel sheet became rough and adhesion occurred. In Sample No. 138, the annealing retention time was too long, and thus volume expansion was large, a hot-rolled coil was uncoiled to cause abrasions, and a tightening mark caused by a tightening band also occurred. Further, the thickness of the film of crystals of B greatly varied and the coefficient of micro-friction of ferrite was large. Therefore, adhesion occurred. Further, cementite became coarse excessively and a crack originating from the coarse cementite occurred during the compression test. In Sample No. 140, the annealing retention time was too short, and thus the coefficient of micro-friction of ferrite was large and the average diameter of cementite was small. Therefore, adhesion and cracking during the compression test occurred. In Sample No. 144, the cooling rate was too low, and thus adhesion and cracking during the compression test occurred, similarly to Sample No. 132. In Sample No. 146, the finish rolling temperature was too high, and thus, large irregularities were formed with removal of scales and the coefficient of micro-friction of ferrite was large. Therefore, adhesion occurred. In Sample No. 149, the slab heating temperature was too low, and thus segregations of B, Mn, and others were not eliminated and the coefficient of micro-friction of ferrite was large. Therefore, adhesion and cracking during the compression test occurred. In Sample No. 150, the annealing retention time was too long, and thus adhesion and cracking during the compression test occurred, similarly to Sample No. 138.

[0079] Fig. 7 illustrates the relationship between the coefficient of micro-friction of ferrite and the B content in the samples out of the examples in the first experiment or third experiment. As illustrated in Fig. 7, when the B content is 0.0008% or more, the coefficient of micro-friction of ferrite is much lower as compared to the case when it is less than 0.0008%.

INDUSTRIAL APPLICABILITY

[0080] The present invention may be utilized in, for example, manufacturing industries and application industries of high-carbon steel sheets used for various steel products, such as a driving system component for automobile, a saw, a knife, and others.

Claims

1. A high-carbon steel sheet, comprising:

a chemical composition represented by, in mass%:

C: 0.30% to 0.70%,
Si: 0.07% to 1.00%,
Mn: 0.20% to 3.00%,
Ti: 0.010% to 0.500%,
Cr: 0.01% to 1.50%,
B: 0.0004% to 0.0035%,
P: 0.025% or less,
Al: 0.100% or less,
S: 0.0100% or less,
N: 0.010% or less,
Cu: 0.500% or less,
Nb: 0.000% to 0.500%,
Mo: 0.000% to 0.500%,
V: 0.000% to 0.500%,
W: 0.000% to 0.500%,
Ta: 0.000% to 0.500%,
Ni: 0.000% to 0.500%,
Mg: 0.000% to 0.500%,
Ca: 0.000% to 0.500%,
Y: 0.000% to 0.500%,
Zr: 0.000% to 0.500%,
La: 0.000% to 0.500%,
Ce: 0.000% to 0.500%, and
balance: Fe and impurities; and

a structure represented by:

a spheroidized ratio of cementite: 80% or more; and
an average diameter of cementite: 0.3 μm to 2.2 μm, wherein
a coefficient of micro-friction of ferrite on a surface of the steel sheet is less than 0.5.

2. The high-carbon steel sheet according to claim 1, wherein
in the chemical composition,

Nb: 0.001% to 0.500%,

Mo: 0.001% to 0.500%,
V: 0.001% to 0.500%,
W: 0.001% to 0.500%,
Ta: 0.001% to 0.500%,
Ni: 0.001% to 0.500%,
Mg: 0.001% to 0.500%,
Ca: 0.001% to 0.500%,
Y: 0.001% to 0.500%,
Zr: 0.001% to 0.500%,
La: 0.001% to 0.500%, or
Ce: 0.001% to 0.500%, or

any combination thereof is satisfied.

3. A method of manufacturing a high-carbon steel sheet, comprising:

hot-rolling of a slab so as to obtain a hotrolled steel sheet;
pickling of the hot-rolled steel sheet; and
annealing of the hot-rolled steel sheet after the pickling,
the slab comprising a chemical composition represented by, in mass%:

C: 0.30% to 0.70%,
Si: 0.07% to 1.00%,
Mn: 0.20% to 3.00%,
Ti: 0.010% to 0.500%,
Cr: 0.01% to 1.50%,
B: 0.0004% to 0.0035%,
P: 0.025% or less,
Al: 0.100% or less,
S: 0.0100% or less,
N: 0.010% or less,
Cu: 0.500% or less,
Nb: 0.000% to 0.500%,
Mo: 0.000% to 0.500%,
V: 0.000% to 0.500%,
W: 0.000% to 0.500%,
Ta: 0.000% to 0.500%,
Ni: 0.000% to 0.500%,
Mg: 0.000% to 0.500%,
Ca: 0.000% to 0.500%,
Y: 0.000% to 0.500%,
Zr: 0.000% to 0.500%,
La: 0.000% to 0.500%,
Ce: 0.000% to 0.500%, and
balance: Fe and impurities, wherein

in the hot-rolling,
the slab is heated at a temperature of 1000°C or more and less than 1150°C,
a finish rolling temperature is 830°C or more and 950°C or less, and
a coiling temperature is 450°C or more and 700°C or less, and
the annealing comprises:

retaining the hot-rolled steel shout at a temperature of 730°C or more and 770°C or less for 3 hours or more and 60 hours or less; and
then cooling the hot-rolled steel sheet down to 650°C at a cooling rate of 1°C/hr or more and 60°C/hr or less.

4. The method of manufacturing the high-carbon steel sheet according to claim 3, wherein
in the chemical composition,

Nb: 0.001% to 0.500%,
Mo: 0.001% to 0.500%,
V: 0.001% to 0.500%,
W: 0.001% to 0.500%,
Ta: 0.001% to 0.500%,
Ni: 0.001% to 0.500%,
Mg: 0.001% to 0.500°,
Ca: 0.001% to 0.500%,
Y: 0.001% to 0.500%,
Zr: 0.001% to 0.500%,
La: 0.001% to 0.500%, or
Ce: 0.001% to 0.500%, or

any combination thereof is satisfied.

FIG. 1

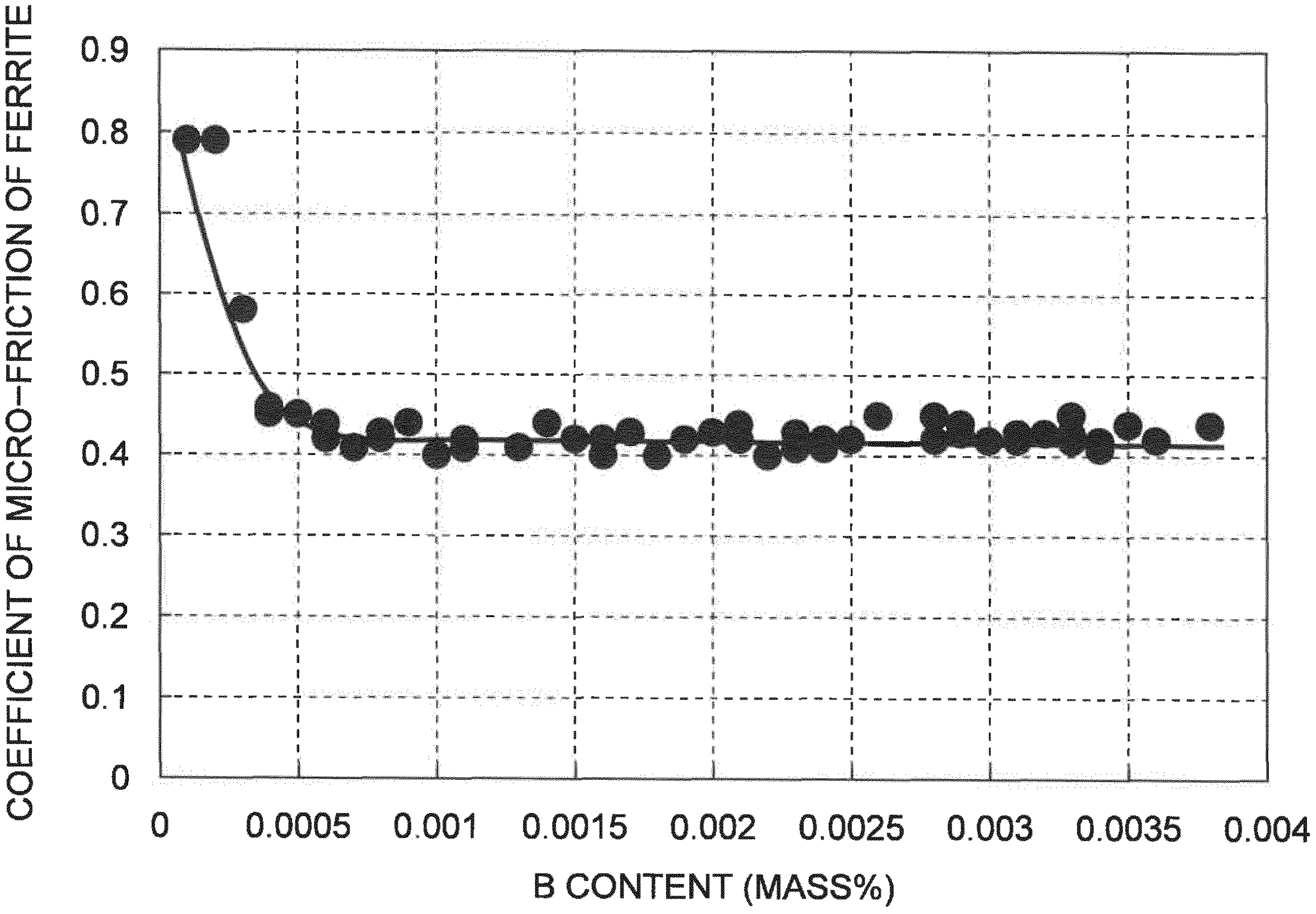

COEFFICIENT OF MICRO–FRICTION OF FERRITE
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
0.004
B CONTENT (MASS%)

FIG. 2

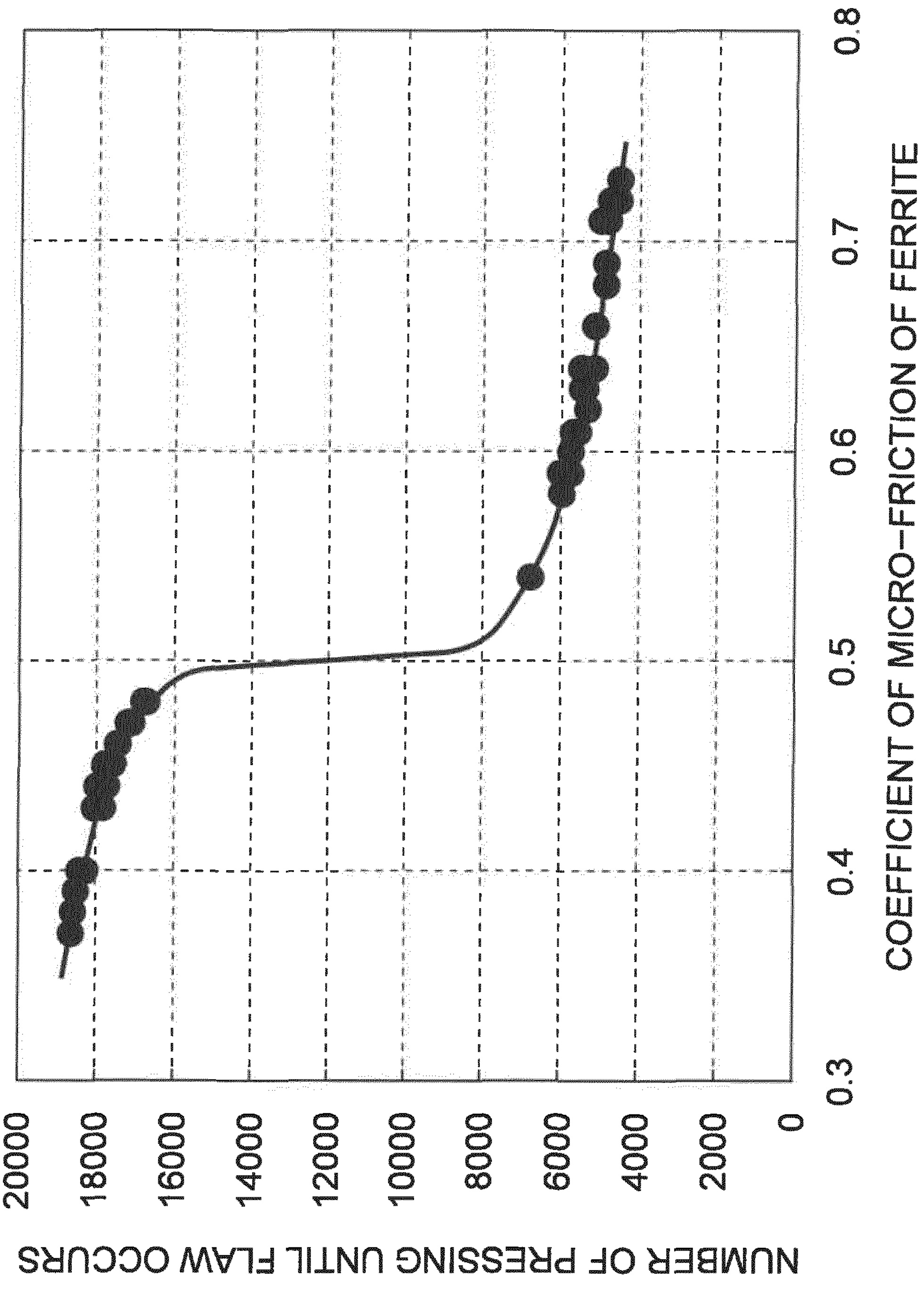

NUMBER OF PRESSING UNTIL FLAW OCCURS
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0.3
0.4
0.5
0.6
0.7
0.8
COEFFICIENT OF MICRO–FRICTION OF FERRITE

FIG. 3A

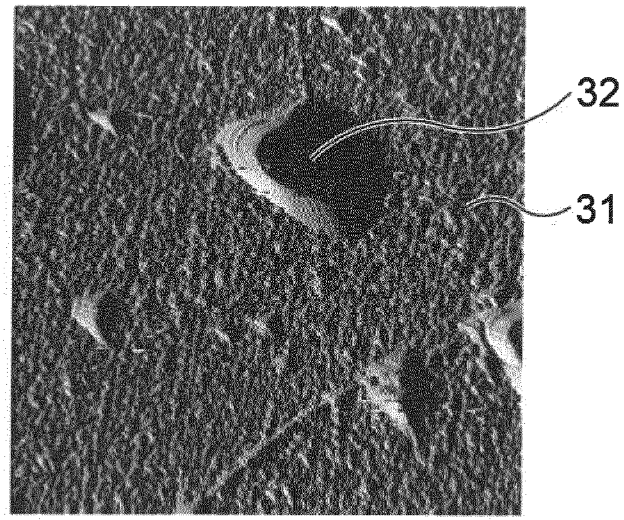


FIG. 3B

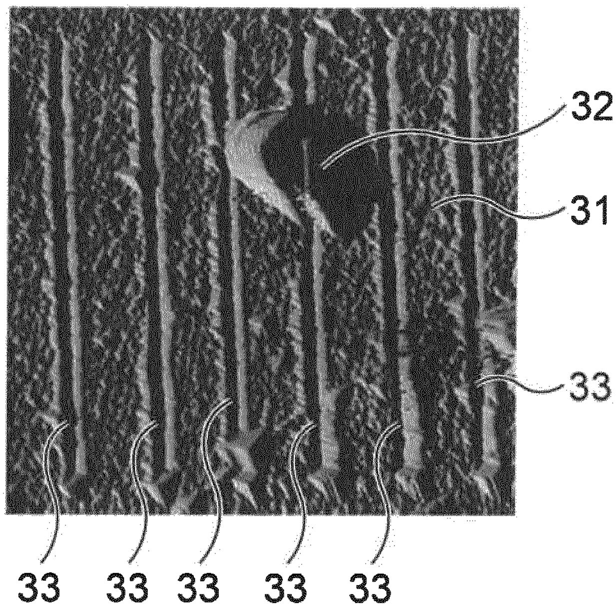


FIG. 4

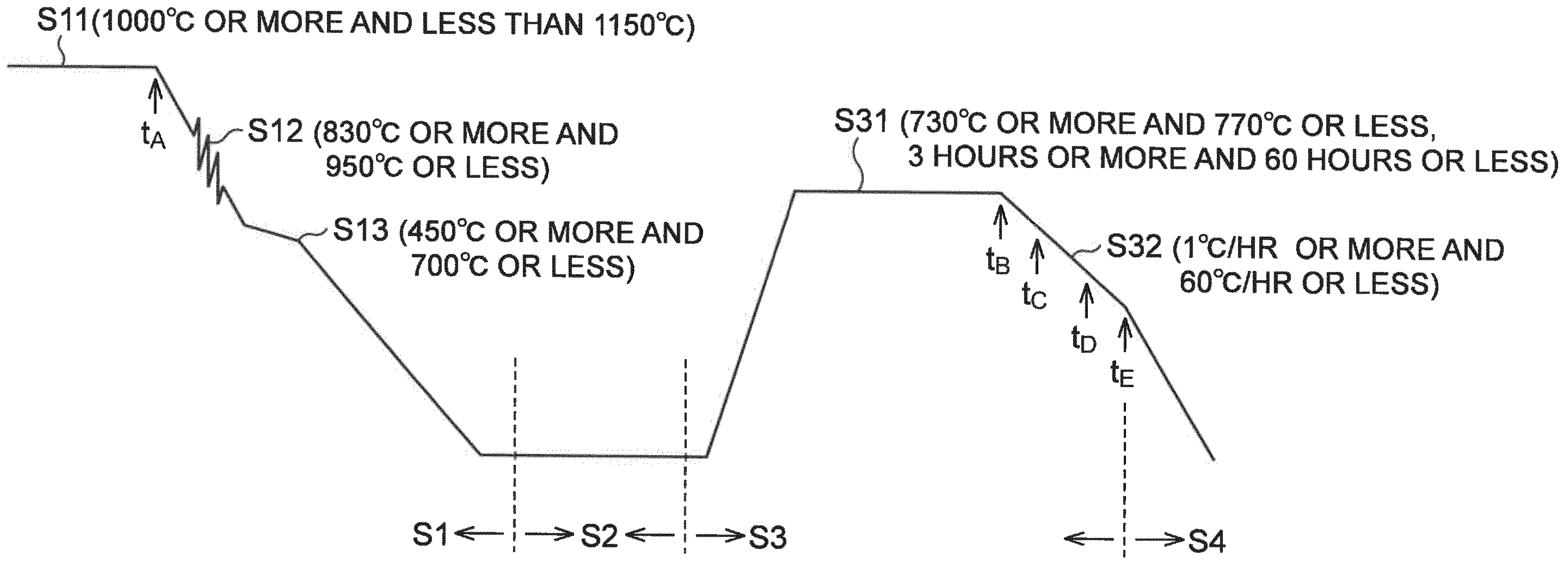

S11(1000°C OR MORE AND LESS THAN 1150°C)
t_A
S12 (830°C OR MORE AND 950°C OR LESS)
S13 (450°C OR MORE AND 700°C OR LESS)
S31 (730°C OR MORE AND 770°C OR LESS, 3 HOURS OR MORE AND 60 HOURS OR LESS)
t_B
t_C
S32 (1°C/HR OR MORE AND 60°C/HR OR LESS)
t_D
t_E
S1
S2
S3
S4

FIG. 5A

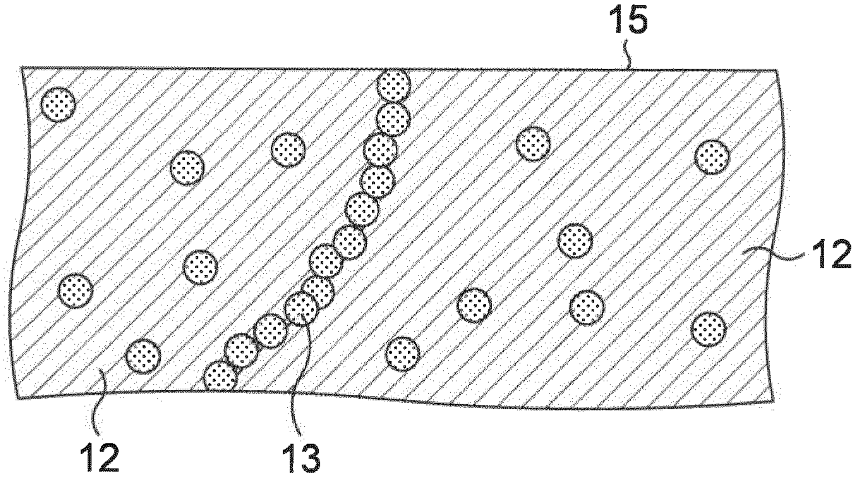


FIG. 5B

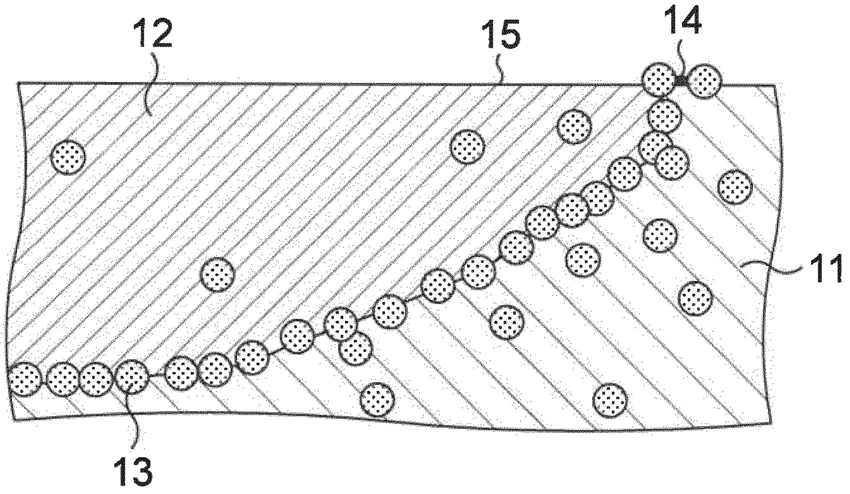


FIG. 5C

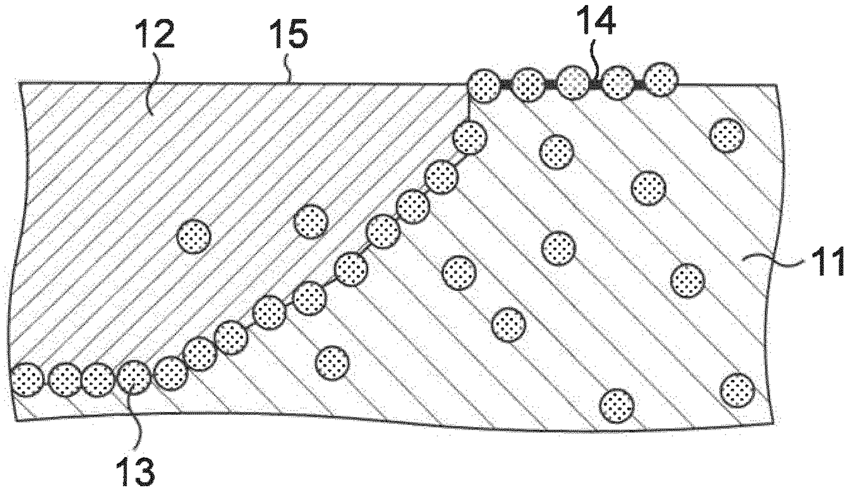


FIG. 5D

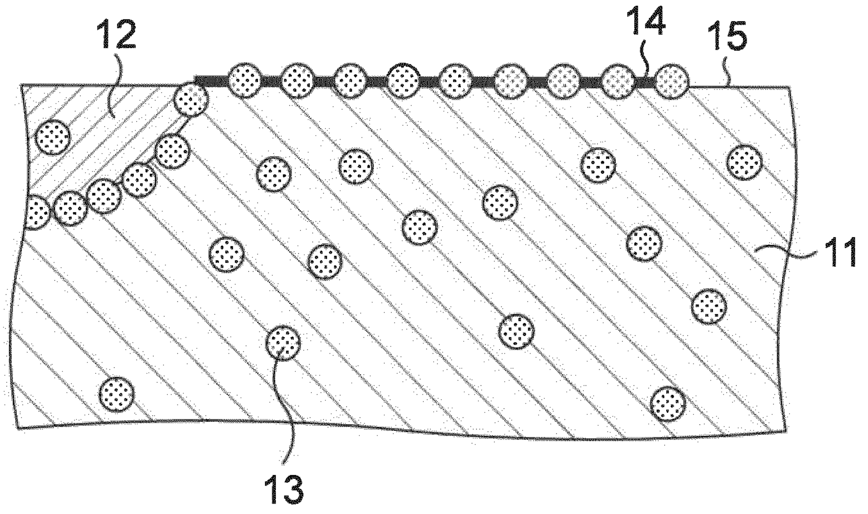


FIG. 5E

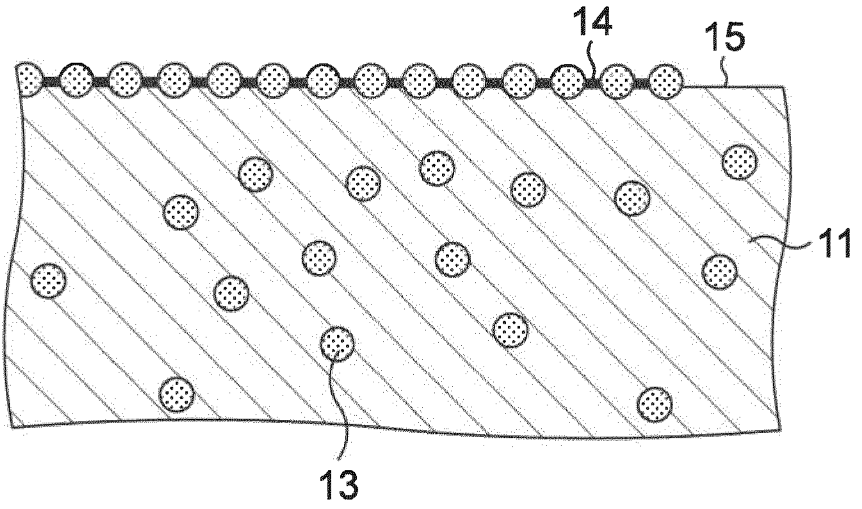


FIG. 6A

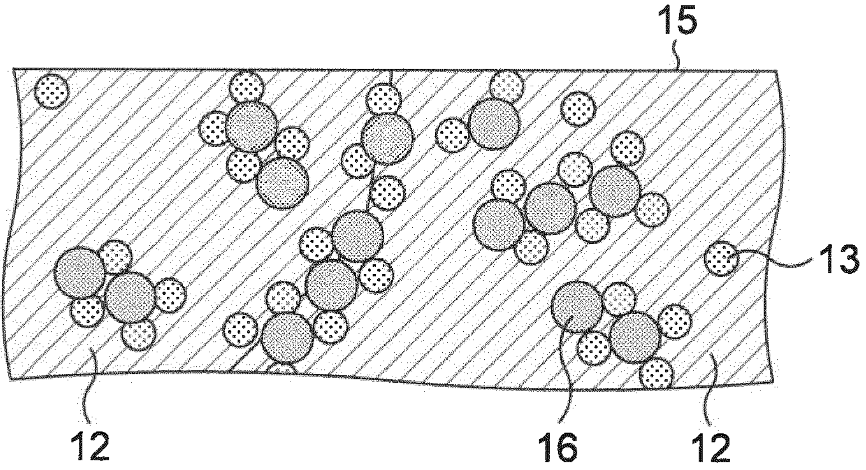


FIG. 6B

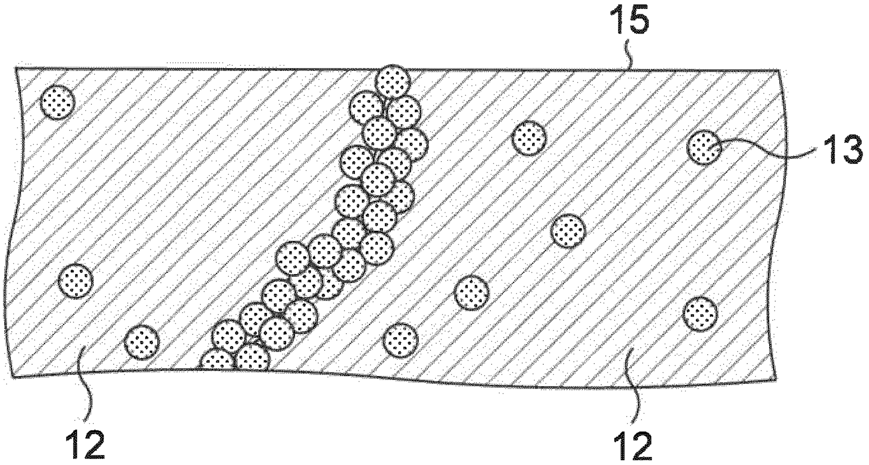


FIG. 6C

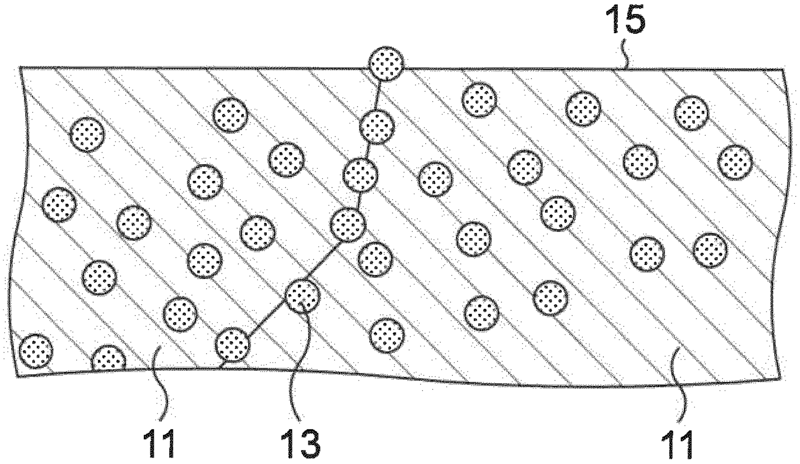


FIG. 6D

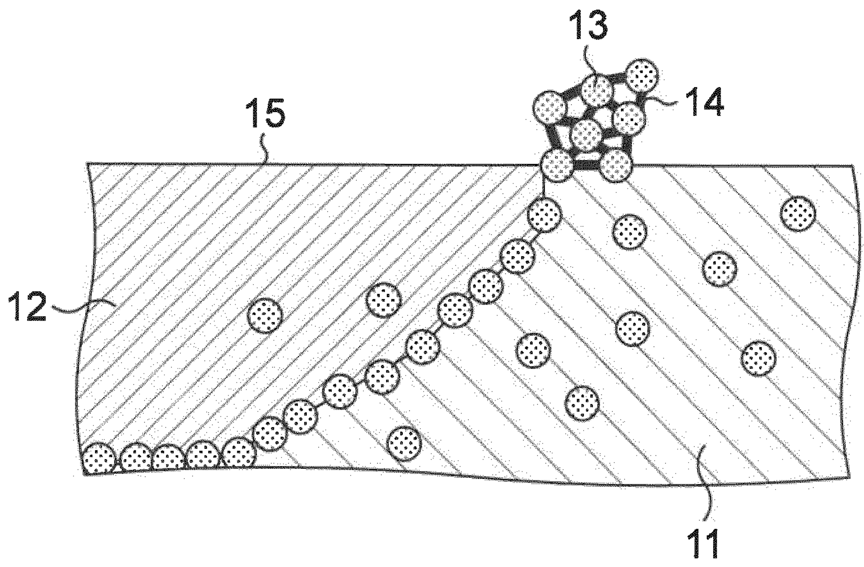


FIG. 6E

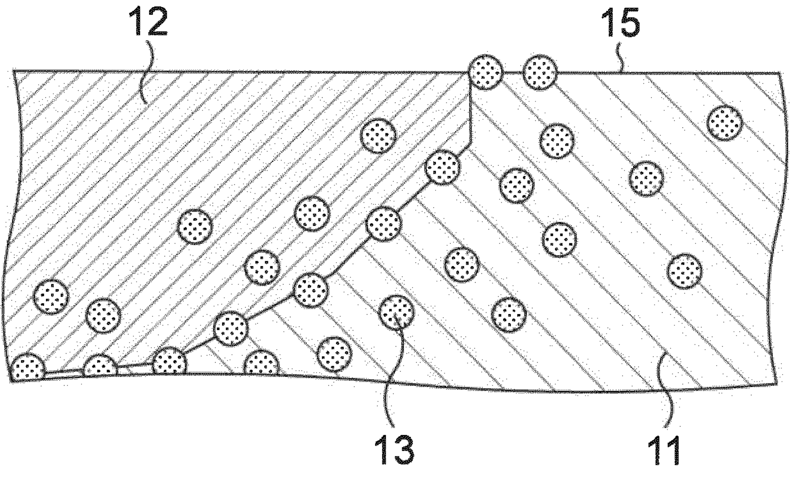


FIG. 6F

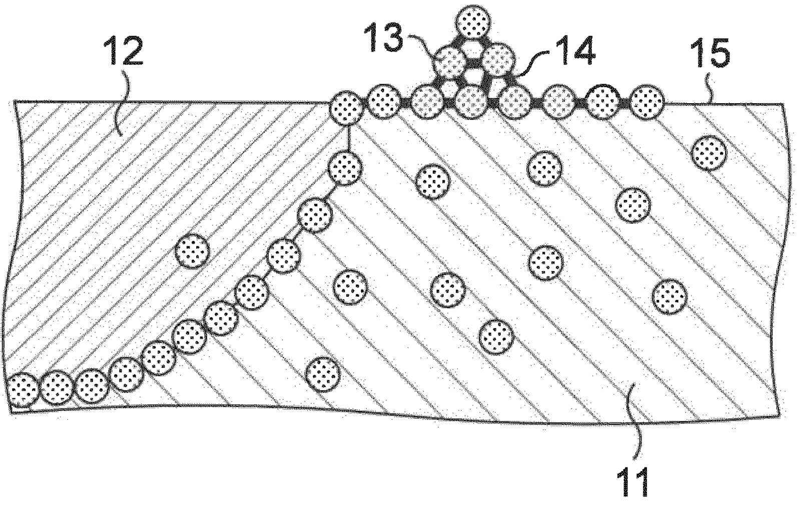


FIG. 6G

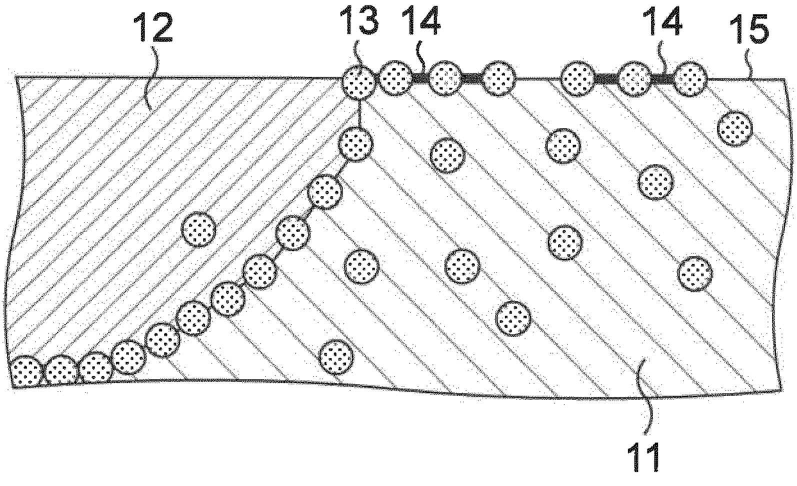
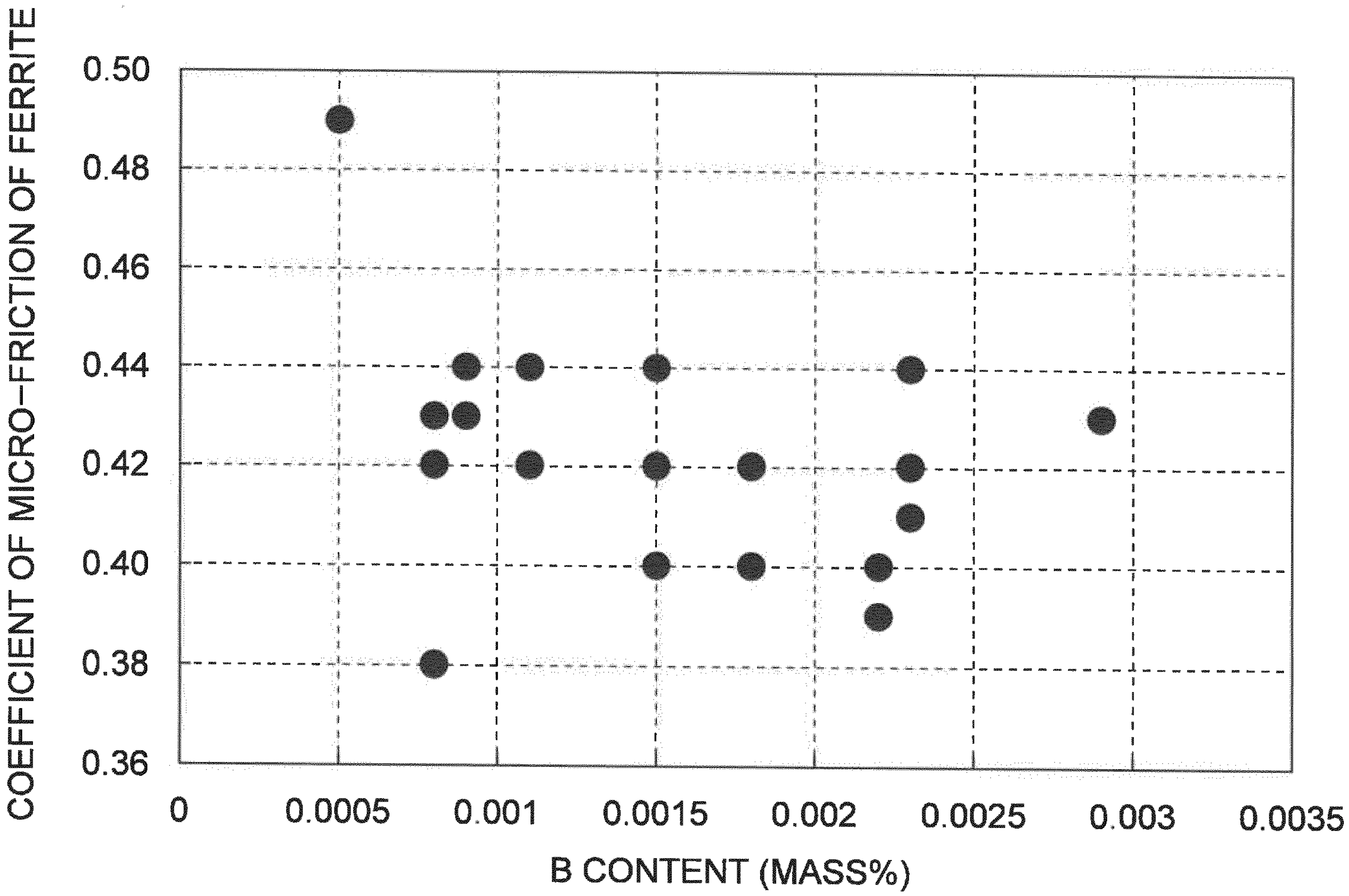


FIG. 7


COEFFICIENT OF MICRO−FRICTION OF FERRITE
0.50
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0
0.0005
0.001
0.0015
0.002
0.0025
0.003
0.0035
B CONTENT (MASS%)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/077544

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C21D8/02*(2006.01)i, *C21D9/46*(2006.01)i, *C22C38/58*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00, C21D8/02, C21D9/46, C22C38/58

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2015
Kokai Jitsuyo Shinan Koho	1971-2015	Toroku Jitsuyo Shinan Koho	1994-2015

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2012-241216 A (JFE Steel Corp.), 10 December 2012 (10.12.2012), entire text & US 2014/0069556 A1 & EP 2711439 A1 & WO 2012/157267 A1 & TW 201307581 A & CN 103534378 A & KR 10-2014-0014276 A	1-4
A	JP 2012-241217 A (JFE Steel Corp.), 10 December 2012 (10.12.2012), entire text & US 2014/0076469 A1 & EP 2712944 A1 & WO 2012/157268 A1 & TW 201303032 A & CN 103562425 A & KR 10-2014-0005359 A	1-4

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier application or patent but published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 05 January 2015 (05.01.15)	Date of mailing of the international search report 13 January 2015 (13.01.15)
Name and mailing address of the ISA/ Japan Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/077544

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2009-299189 A (Nisshin Steel Co., Ltd.), 24 December 2009 (24.12.2009), entire text (Family: none)	1-4
A	JP 5048168 B1 (Nippon Steel Corp.), 27 July 2012 (27.07.2012), entire text; all drawings (Family: none)	1-4
A	JP 2006-336063 A (Nippon Steel & Sumikin Stainless Steel Corp.), 14 December 2006 (14.12.2006), claims; 0002 to 0004, 0008 to 0016 (Family: none)	1-4
A	JP 2005-232486 A (Nippon Steel & Sumikin Stainless Steel Corp.), 02 September 2005 (02.09.2005), claims; 0011 to 0021 (Family: none)	1-4
A	JP 2011-12317 A (Nippon Steel Corp.), 20 January 2011 (20.01.2011), entire text; all drawings (Family: none)	1-4

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- JP 2009215612 A **[0006]**
- JP 2011168842 A **[0006]**
- JP 2010255066 A **[0006]**
- JP 2000034542 A **[0006]**
- JP 2000265240 A **[0006]**
- JP 10147816 A **[0006]**