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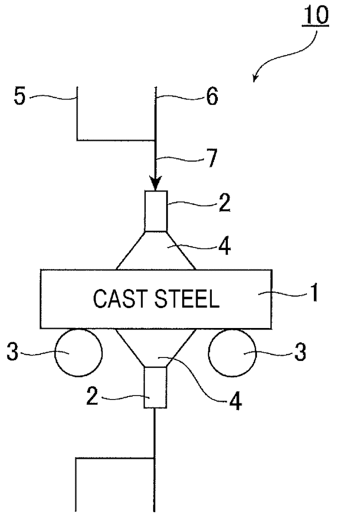
(54) CU-SN CONTAINING STEEL MANUFACTURING METHOD

(57) A method for producing Cu-Sn-containing steel is provided that can be hot-worked at low cost without surface cracking even when a heating furnace with a low heating capacity is used for the hot working.

A method for producing Cu-Sn-containing steel includes a hot heating step of attaching a flux to a surface of a Cu-Sn-containing cast steel in such an amount that the mass per unit area is 50 g/m^2 or more and 5000 g/m^2 or less, and heating the Cu-Sn-containing cast steel at a temperature of 1000°C or above and 1400°C or below, the flux including at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components and being such that the liquid phase ratio at 1000°C is 10 mass% or more; and a hot working step of hot working the Cu-Sn-containing cast steel.

FIG. 2



Description

Technical Field

[0001] The present invention relates to a method for producing Cu-Sn-containing steel that can eliminate or reduce the occurrence of cracking on the steel surface during hot working.

[0002] The recent increase in the demand for reducing the CO_2 emissions has led to the growing use of electric arc furnaces in the steelmaking process. Due to the need of saving the production cost, the raw materials used in the steelmaking process are scraps containing large amounts of tramp elements, in particular, scraps containing large amounts of Cu and Sn.

[0003] However, tramp elements are difficult to remove in the refining step and inevitably remain in the steel. When cast steel contains residual tramp elements (for example, Cu and Sn) after the refining step (hereinafter, such cast steel will be written as "Cu-Sn-containing cast steel" or simply as "cast steel"), a Cu-Sn melt occurs in a superficial layer during the hot heating step. The Cu-Sn melt gives rise to red shortness in the hot working step, such as rolling. Thus, cracks (cracking) occur on the surface of the steel resulting from the hot working step (hereinafter written as "Cu-Sn-containing steel" or simply as "steel"), making it difficult to produce final hot-rolled steel sheets with excellent surface properties.

[0004] At the time of high-temperature oxidation of Cu-Sn-containing cast steel, a Cu-Sn enriched melt is precipitated in a superficial layer of the cast steel and causes surface defects on the Cu-Sn-containing steel. It is conventionally known that this precipitation is suppressed by the addition of a predetermined amount of Ni to the Cu-Sn-containing cast steel, and thereby the occurrence of cracking on the cast steel surface can be prevented. However, the addition of Ni is costly and destroys the merits offered by the use of scraps containing much tramp elements.

[0005] Because the Cu-Sn melt that causes surface defects on Cu-Sn-containing steel occurs only in a superficial layer of the Cu-Sn-containing cast steel, the prevention technique of surface cracking has been proposed based on surface modification of the Cu-Sn-containing cast steel.

[0006] Patent Literature 1 discloses a method in which the surface of a cast steel is melted by plasma heating using a DC arc plasma vibrated with an AC magnetic field, and Ni is added only to a superficial portion. Furthermore, Patent Literature 2 discloses a method in which a flux including SiO_2 is attached to the surface of a Cu-Sn-containing cast steel from continuous casting while the cast steel temperature is in the range of 1150°C and above, thereby forming a scale of a FeO-SiO_2-based low-melting oxide fluid, and a Cu-Sn melt is incorporated into the fluid, thus suppressing the occurrence of red shortness on the surface.

Citation List

Patent Literature

[0007]

PTL 1: Japanese Patent No. 5454132
PTL 2: Japanese Unexamined Patent Application Publication No. 6-297025

Summary of Invention

Technical Problem

[0008] While the method disclosed in Patent Literature 1 can reduce the cost associated with the addition of Ni, the installation of the AC magnetic field and arc plasma facilities entails enormous costs of the initial investment. Moreover, the method disclosed in Patent Literature 2 is problematic in that the method cannot be applied to hot working at temperatures below 1150°C.

[0009] Furthermore, while Patent Literature 2 refers to the prevention of cracking during hot working in the temperature range of 1150°C and above, no reference is made as to problems that will be encountered when a heating furnace with a low heating capacity is used. Specifically, low-temperature heating does not allow a flux spread on the surface of a Cu-Sn-containing cast steel to form a liquid phase sufficiently and makes it difficult to remove the flux completely together with the scale in the downstream descaling step. The flux remaining on the surface of the Cu-Sn-containing cast steel causes a poor appearance of the cast steel.

[0010] The present invention has been made in view of the circumstances discussed above. It is therefore an object of the present invention to provide a method for producing Cu-Sn-containing steel that can be hot-worked at low cost without surface cracking even when a heating furnace with a low heating capacity is used for the hot working.

Solution to Problem

[0011] Main configurations of the present invention for solving the above problems are as follows.

[1] A method for producing Cu-Sn-containing steel, including a hot heating step of attaching a flux to a surface of a Cu-Sn-containing cast steel in such an amount that the mass per unit area is 50 g/m^2 or more and 5000 g/m^2 or less, and heating the Cu-Sn-containing cast steel at a temperature of 1000°C or above and 1400°C or below, the flux including at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components and being such that the liquid phase ratio at 1000°C is 10 mass% or more; and a hot working step of hot working the Cu-Sn-containing cast steel.

[2] A method for producing Cu-Sn-containing steel, including a hot heating step of heating a Cu-Sn-containing cast steel at a temperature of 1000°C or above and 1400°C or below; and a hot working step of attaching a flux to a surface of the Cu-Sn-containing cast steel in such an amount that the mass per unit area is 50 g/m^2 or more and 5000 g/m^2 or less, and hot working the Cu-Sn-containing cast steel, the flux including at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components and being such that the liquid phase ratio at 1000°C is 10 mass% or more.

[3] The method for producing Cu-Sn-containing steel according to [1] or [2], wherein the flux further includes an incidental oxide, fluoride, carbonate, or metal component.

[4] The method for producing Cu-Sn-containing steel according to any one of [1] to [3], wherein the flux is attached as a pre-melt to the surface of the Cu-Sn-containing cast steel.

Advantageous Effects of Invention

[0012] According to the present invention, Cu-Sn-containing steel can be hot-worked at low cost without surface cracking even when a heating furnace with a low heating capacity is used for the hot working.

Brief Description of Drawings

[0013]

[Fig. 1] Fig. 1 is a set of views illustrating actions of a flux on a Cu-Sn melt.

[Fig. 2] Fig. 2 is a schematic view illustrating an outline of a flux spray device.

Description of Embodiments

[0014] A method for implementing the present invention will be described below. First, Fig. 1 will be discussed to describe the behavior of a Cu-Sn melt that occurs in a superficial layer of a Cu-Sn-containing cast steel that has been heated to a high temperature and has been surface-oxidized (hereinafter, this state of the Cu-Sn-containing cast steel will be written as "hot oxidized state"), and also a flux attached to the surface of the Cu-Sn-containing cast steel.

[0015] Fig. 1(a) illustrates a state of the surface of a Cu-Sn-containing cast steel without any flux attached. Fig. 1(b) illustrates a state of the surface of a Cu-Sn-containing cast steel to which a flux having a liquid phase ratio of 80% in a high-temperature atmosphere has been attached. Fig. 1(c) illustrates a state of the surface of a Cu-Sn-containing cast steel to which a flux having a liquid phase ratio of 5% in a high-temperature atmosphere has been attached.

[0016] Here, Fig. 1(a) schematically illustrates a state of the interface between the Cu-Sn-containing cast steel in a hot oxidized state and a scale. As illustrated in Fig. 1(a), Fe, which is oxidized more easily than Cu and Sn, forms a scale layer on the surface of the cast steel, and Cu and Sn are concentrated in a superficial layer of the cast steel. The melting point of Cu is 1085°C and is further lowered by the enrichment of Sn. As a result, the Cu-Sn-enriched phase forms a liquid phase in a high-temperature atmosphere of 1000°C or above, and the melt (hereinafter, written as "Cu-Sn melt") penetrates into grain boundaries in the Cu-Sn-containing cast steel. The Cu-Sn melt serves as origins of embrittlement at the time of hot working, such as rolling, and cracks extend to a greater depth with increasing amount of the Cu-Sn melt.

[0017] Fig. 1(b) schematically illustrates a state of the interface between the Cu-Sn-containing cast steel and a scale when a flux has been attached that has a liquid phase ratio of 80% in a high-temperature atmosphere. The scale formed by oxidation reacts and mixes with the liquid phase of the flux and, as illustrated in Fig. 1(b), the flux and the scale are mixed (forming a mixed phase) on the surface of the cast steel. The Cu-Sn melt present in a superficial layer of the cast steel is incorporated into the liquid phase of the mixed phase and can be removed without penetration of the Cu-Sn melt into grain boundaries in the Cu-Sn-containing cast steel.

[0018] Fig. 1(c) schematically illustrates a state of the interface between the Cu-Sn-containing cast steel and a scale when a flux has been attached that has a liquid phase ratio of 5% in a high-temperature atmosphere. In the state illustrated in Fig. 1(c), the flux does not sufficiently form a liquid phase, and oxidation proceeds while the scale formed on the surface of the cast steel does not sufficiently react and mix with the flux. As a result, the cast steel surface and the flux are separated by the scale, and the Cu-Sn melt penetrates into grain boundaries in the Cu-Sn-containing cast steel similarly to the hot oxidized state illustrated in Fig. 1(a).

[0019] As described with reference to Figs. 1(a) to 1(c), the cast steel surface and the flux should not be separated by a scale in order to ensure that the Cu-Sn melt present in a superficial layer of the cast steel in the hot oxidized state will be removed. That is, the flux needs to be sufficiently liquefied in a high-temperature atmosphere, such as in a heating furnace.

[0020] The scale on the surface of the Cu-Sn-containing cast steel is removed (hereinafter, written as "descaled or descaling") before the Cu-Sn-containing cast steel that has the hot oxidized surface is subjected to hot working.

[0021] If, however, the flux does not form a liquid phase sufficiently as illustrated in Fig. 1(c), it is impossible to remove (clean away) the flux completely together with the scale by the subsequent descaling. The flux that remains on the surface of the Cu-Sn-containing cast steel causes a poor appearance of the cast steel that is produced. Thus, in order to ensure that the flux will be removed completely together with the scale by descaling, the flux needs to be highly liquefied on the surface of the Cu-Sn-containing cast steel even when the heating furnace that is used has a low heating capacity.

[0022] To ensure that the liquid phase ratio in a high-temperature atmosphere at 1000°C will be 10 mass% or more, the present invention focuses on a flux that includes at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components. Here, "Na_2O-FeO" includes both Na_2O and FeO components, "Na_2O-SiO_2" includes both Na_2O and SiO_2 components, "Na_2O-TiO_2" includes both Na_2O and TiO_2 components, and "Li_2O-SiO_2" includes both Li_2O and SiO_2 components.

[0023] The liquid phase ratio of the flux may be determined using an equilibrium diagram obtained by experiments or thermodynamic calculations. Alternatively, a sample may be held at a predetermined temperature to reach thermodynamic equilibrium and then frozen by, for example, water cooling, and a cross section of the sample may be analyzed to estimate the liquid phase ratio.

[0024] In addition to at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components, the flux may further include incidental oxide, fluoride, carbonate, and metal components as long as the composition of the flux allows the liquid phase ratio at 1000°C to be 10 mass% or more.

[0025] A flux based on, for example, SiO_2, CaO, Li_2O, Na_2O, F, MgO, or Al_2O_3 is known as a continuous casting mold flux. Even such a flux can be applied to the present invention as long as the liquid phase ratio at 1000°C is 10 mass% or more.

[0026] The base material of the flux including at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components may be an oxide or may be, for example, a carbonate or a fluoride. These base materials may be mixed. The flux may be attached as a pre-melt to the surface of the Cu-Sn-containing cast steel.

[0027] The flux may be attached (supplied) to the surface of the Cu-Sn-containing cast steel in an appropriate manner, such as by application or spraying, without limitation to any particular technique. The flux may be in the form of powder or slurry. The flux may be applied as a solution or a suspension in water or other liquid. Alternatively, the flux may be mixed together with an inorganic or organic miscible polymer or a solvent similarly to a general paint agent.

[0028] Here, a flux supply device 10 will be described with reference to Fig. 2. Fig. 2 is a schematic view illustrating an outline of the flux supply device 10. As illustrated in Fig. 2, a cast steel 1 is placed on placement or conveying rollers 3 for the supply of a flux 4. The flux supply device 10 has spray guns 2 arranged above and below the cast steel 1 placed on the rollers 3 in order to supply the flux 4 uniformly to the surface of the cast steel 1 located therebetween. A flux powder 5 and jet air 6 are mixed together through a supply pipe 7 and are supplied to the spray guns 2. The amount of the flux 4 attached to the surface of the cast steel 1 may be controlled by controlling the amount of the flux 4 supplied through the supply pipe 7 and the line speed.

[0029] The amount of the flux attached to the surface of the cast steel is preferably such that the mass per unit area of the surface of the Cu-Sn-containing cast steel is 50 g/m^2 or more and 5000 g/m^2 or less. If the amount of the flux attached is less than 50 g/m^2, the flux cannot sufficiently incorporate the Cu-Sn melt and cracks disadvantageously occur on the steel surface after hot working. If the amount of the flux attached is more than 5000 g/m^2, the excess of the flux adheres to, for example, the rollers 3 and causes early deterioration of the flux supply device 10. The excess supply of the flux also disadvantageously leads to economic problems, such as cost increase. The amount of the flux attached to the surface of the cast steel is more preferably 100 g/m^2 or more and 2500 g/m^2 or less, and still more preferably 500 g/m^2 or more and 1000 g/m^2 or less.

[0030] The cast steel (the Cu-Sn-containing cast steel) to which the flux will be or has been supplied is subjected to heat treatment at a temperature of 1000°C or above and 1400°C or below and is subsequently subjected to hot rolling (hot working). If the heating temperature is below 1000°C, high deformation resistance is encountered during hot working to cause a decrease in rolling efficiency. If the heating temperature exceeds 1400°C, predetermined steel material properties may not be obtained. The heating temperature for the cast steel (the Cu-Sn-containing cast steel) is more preferably 1000°C or above and 1300°C or below, and still more preferably 1000°C or above and below 1150°C. This heating temperature is applicable to a heating furnace with a low heating capacity. The residence time in the heating furnace (the heating time) is preferably 2 hours or more for uniform heating of the cast steel. Because long heating time raises the manufacturing cost, the residence time in the heating furnace is preferably 5 hours or less.

EXAMPLES

[0031] EXAMPLES of hot heating and hot working performed based on the method for producing Cu-Sn-containing steel according to the present embodiment will be described below.

[0032] First, various fluxes were applied to the surface of a Cu-Sn-containing cast steel (a carbon steel) containing 1.0 mass% Cu and 0.1 mass% Sn, and the cast steels were charged into a heating furnace and were heated (hot heated) for 3 hours at a furnace atmosphere temperature of 1010°C. Next, the Cu-Sn-containing cast steels that had been heated were hot-worked by rough rolling and finish rolling. Cu-Sn-containing steels (hot-rolled steel sheets) having a thickness of 2.3 mm were thus produced. Table 1 describes the fluxes applied to the surface of the Cu-Sn-containing cast steel.

[Table 1]

Flux No.	Flux components [mass%]														Liquid phase ratio at 1000°C [mass%]
	SiO_2	CaO	Na_2O	F	Li_2O	FeO	Fe_2O_3	TiO_2	K_2O	P_2O_5	PbO	B_2O_3	BaO	MnO	
A1			56.3			43.4	0.3								100.0
A2	68.6		31.4												100.0
A3			76.0					24.0							100.0
A4	32.2				67.8										100.0
A5	45.5								54.5						100.0
A6								66.3	33.7						100.0
A7									48.0	52.0					100.0
A8							64.0			36.0					100.0
A9	65.0									35.0					100.0
A10	16.0										84.0				100.0
A11		29.9								70.1					100.0
A12												59.5	40.5		100.0
A13						55.0	0.2					44.8			100.0
A14									37.5			62.5			100.0
A15												58.8		41.2	100.0
A16			67.2									32.8			100.0
A17	41.3											58.7			100.0
A18	36.6	35.3	19.1	9.0											100.0
A19	16.4				83.6										50.2
A20	50.0		50.0												10.0
B	100.0														0.0
C1			13.2			86.4	0.4								5.1
C2								73.3	26.7						2.1

[0033] Table 1 describes the components contained in the flux and the contents (mass%). The fluxes with flux Nos. "A1 to A20" are fluxes having a liquid phase ratio of 10 mass% or more at an atmosphere temperature of 1000°C. The flux with flux number "B" is a SiO_2 flux disclosed in Patent Literature 2. The fluxes with flux numbers "C1 and C2" are fluxes having a liquid phase ratio of less than 10 mass% at an atmosphere temperature of 1000°C.

[0034] The liquid phase ratios of the fluxes with flux Nos. "A1 to A20" and "C1 and C2" were determined in the following manner. First, 10 g of a sample obtained by mixing the flux components described in Table 1 was added to a platinum crucible, melted by being held in an electric resistance furnace at 1600°C for 1 hour, and then held at 1000°C for 48 hours. Subsequently, the lateral side of the platinum crucible containing the sample was water-cooled to freeze the sample. A cross section of the frozen sample was observed with an optical microscope to measure the cross-sectional liquid phase ratio.

[0035] Surface cracking in the Cu-Sn-containing steels (the hot-rolled steel sheets) produced in this EXAMPLE was studied (evaluated) in the following manner. First, ten sheets of the Cu-Sn-containing steel, each 1 m in width and 1 m in length, were randomly sampled in the rolling direction, and the 1 m × 1 m area (face) of each sheet was crosscut at 100 mm intervals and was divided into 100 equal squares. Next, the number of cracked squares was counted to determine the count per m^2. The results of the ten sheets were averaged. Surface cracking was rated as "good" when the cracking frequency was 0.3 squares/m^2 or less and was rated as "bad" when the cracking frequency was more than 0.3 squares/m^2.

[0036] Table 2 describes the results of evaluation (INVENTIVE EXAMPLES 1 to 20 and COMPARATIVE EXAMPLES 1 to 5) of the Cu-Sn-containing steels (the hot-rolled steel sheets) produced by performing the heating step in a heating furnace (the hot heating step) and the rolling step (the hot working step) using the fluxes described in Table 1.

[Table 2]

EXAMPLES	Flux No.	Amount attached [g/m^2]	Cracking occurrence
INV. EX. 1	A1	1541	Good
INV. EX. 2	A2	1402	Good
INV. EX. 3	A3	582	Good
INV. EX. 4	A4	544	Good
INV. EX. 5	A5	1896	Good
INV. EX. 6	A6	3281	Good
INV. EX. 7	A7	1764	Good
INV. EX. 8	A8	1389	Good
INV. EX. 9	A9	1576	Good
INV. EX. 10	A10	1519	Good
INV. EX. 11	A11	2080	Good
INV. EX. 12	A12	2175	Good
INV. EX. 13	A13	2675	Good
INV. EX. 14	A14	1788	Good
INV. EX. 15	A15	2692	Good
INV. EX. 16	A16	2698	Good
INV. EX. 17	A17	1207	Good
INV. EX. 18	A18	551	Good
INV. EX. 19	A19	2905	Good
INV. EX. 20	A20	1450	Good
COMP. EX. 1	C1	1686	Bad
COMP. EX. 2	C2	1375	Bad
COMP. EX. 3	A1	48	Bad
COMP. EX. 4	A2	11	Bad

(continued)

EXAMPLES	Flux No.	Amount attached [g/m^2]	Cracking occurrence
COMP. EX. 5	B	2834	Bad

[0037] As described in Table 1 and Table 2, the "cracking occurrence" was "good" when use was made of the fluxes having a liquid phase ratio of 10 mass% or more at an atmosphere temperature of 1000°C (the fluxes with flux Nos. "A1 to A20"). As shown by the results of INVENTIVE EXAMPLES 1 to 20, it was confirmed that the "cracking occurrence" was "good" when the amount of the flux attached to the surface of the Cu-Sn-containing cast steel was such that the mass per unit area was 544 g/m^2 or more and 3281 g/m^2 or less.

[0038] The "cracking occurrence" was "bad" every time when the flux that was used had a liquid phase ratio of less than 10 mass% at an atmosphere temperature of 1000°C (COMPARATIVE EXAMPLES 1 and 2).

[0039] Furthermore, it was confirmed that even when the flux had a liquid phase ratio of 10 mass% or more at an atmosphere temperature of 1000°C, the "cracking occurrence" was "bad" when the amount (mass) of the flux applied to the surface of the Cu-Sn-containing cast steel was 48 g/m^2 or less per unit area (COMPARATIVE EXAMPLES 3 and 4). Furthermore, it was confirmed that when the flux consisted solely of SiO_2, the "cracking occurrence" was "bad" even though the amount (mass) applied to the surface of the Cu-Sn-containing cast steel was 2834 g/m^2 per unit area (COMPARATIVE EXAMPLE 5).

[0040] In the next EXAMPLE, a Cu-Sn-containing cast steel (a carbon steel) containing 1.0 mass% Cu and 0.1 mass% Sn was charged into a heating furnace and was heated for 3 hours at a furnace atmosphere temperature of 1010°C. Subsequently, various fluxes (see Table 1) were applied to the surface of the Cu-Sn-containing cast steel that had been heated. Such Cu-Sn-containing cast steels were subjected to rough rolling and finish rolling. Cu-Sn-containing steels (hot-rolled steel sheets) having a thickness of 2.3 mm were thus produced. While EXAMPLE 1 has illustrated that the steel was heated and rolled after the flux had been applied, EXAMPLE 2 will illustrate that heating precedes flux application and rolling.

[0041] Table 3 describes the results of evaluation (INVENTIVE EXAMPLES 21 to 40 and COMPARATIVE EXAMPLES 6 to 10) of the Cu-Sn-containing steels (the hot-rolled steel sheets) produced by performing the heating step in a heating furnace (the hot heating step) and the rolling step (the hot working step) using the fluxes described in Table 1.

[Table 3]

EXAMPLES	Flux No.	Amount attached [g/m^2]	Cracking occurrence
INV. EX. 21	A1	1541	Good
INV. EX. 22	A2	1402	Good
INV. EX. 23	A3	582	Good
INV. EX. 24	A4	544	Good
INV. EX. 25	A5	1896	Good
INV. EX. 26	A6	3281	Good
INV. EX. 27	A7	1764	Good
INV. EX. 28	A8	1389	Good
INV. EX. 29	A9	1576	Good
INV. EX. 30	A10	1519	Good
INV. EX. 31	A11	2080	Good
INV. EX. 32	A12	2175	Good
INV. EX. 33	A13	2675	Good
INV. EX. 34	A14	1788	Good
INV. EX. 35	A15	2692	Good
INV. EX. 36	A16	2698	Good
INV. EX. 37	A17	1207	Good

(continued)

EXAMPLES	Flux No.	Amount attached [g/m^2]	Cracking occurrence
INV. EX. 38	A18	551	Good
INV. EX. 39	A19	2905	Good
INV. EX. 40	A20	1450	Good
COMP. EX. 6	C1	1686	Bad
COMP. EX. 7	C2	1375	Bad
COMP. EX. 8	A1	48	Bad
COMP. EX. 9	A2	11	Bad
COMP. EX. 10	B	2834	Bad

[0042] As described in Table 1 and Table 3, the "cracking occurrence" was "good" when use was made of the fluxes having a liquid phase ratio of 10 mass% or more at an atmosphere temperature of 1000°C (the fluxes with flux Nos. "A1 to A20"). As shown by the results of INVENTIVE EXAMPLES 21 to 40, it was confirmed that the "cracking occurrence" was "good" when the amount of the flux attached to the surface of the Cu-Sn-containing cast steel was such that the weight per unit area was 544 g/m^2 or more and 3281 g/m^2 or less.

[0043] The "cracking occurrence" was "bad" every time when the flux that was used had a liquid phase ratio of less than 10 mass% at an atmosphere temperature of 1000°C (COMPARATIVE EXAMPLES 6 and 7).

[0044] Furthermore, it was confirmed that even when the flux had a liquid phase ratio of 10 mass% or more at an atmosphere temperature of 1000°C, the "cracking occurrence" was "bad" when the amount (mass) of the flux applied to the surface of the Cu-Sn-containing cast steel was 48 g/m^2 or less per unit area (COMPARATIVE EXAMPLES 8 and 9). Furthermore, it was confirmed that when the flux consisted solely of SiO_2, the "cracking occurrence" was "bad" even though the amount (mass) applied to the surface of the Cu-Sn-containing cast steel was 2834 g/m^2 per unit area (COMPARATIVE EXAMPLE 10).

[0045] In the next EXAMPLE, some types of the fluxes were applied to the surface of a Cu-Sn-containing cast steel (a carbon steel) containing 1.0 mass% Cu and 0.1 mass% Sn. The amount applied per unit area was 2500 g/m^2. The Cu-Sn-containing cast steels coated with the flux were charged into a heating furnace and were heated at varied furnace atmosphere temperatures (heating temperatures) for varied amounts of heating time. The Cu-Sn-containing cast steels extracted from the heating furnace were descaled. The descaled Cu-Sn-containing cast steels were hot-worked by rough rolling and finish rolling. Cu-Sn-containing steels (hot-rolled steel sheets) having a thickness of 2.3 mm were thus produced.

[0046] The Cu-Sn-containing steels thus produced were studied (evaluated) for surface cracks in the same manner as the previous EXAMPLES. Specifically, ten sheets of the Cu-Sn-containing steel, each 1 m in width and 1 m in length, were randomly sampled in the rolling direction, and the 1 m × 1 m area (face) of each sheet was crosscut at 100 mm intervals and was divided into 100 equal squares. Next, the number of cracked squares was counted to determine the count per m^2. The results of the ten sheets were averaged. Surface cracking was rated as "good" when the cracking frequency was 0.3 squares/m^2 or less and was rated as "bad" when the cracking frequency was more than 0.3 squares/m^2.

[0047] Furthermore, this EXAMPLE studied (evaluated) the surface appearance in order to investigate the presence of residual flux on the surface of the descaled Cu-Sn-containing cast steels. In the study of surface appearance, ten sheets of the Cu-Sn-containing steel, each 1 m in width and 1 m in length, were randomly sampled in the rolling direction, and the 1 m × 1 m area (face) of each sheet was crosscut at 100 mm intervals and was divided into 100 equal squares. Next, the 100 mm × 100 m squares were visually inspected to measure the flux. The results were averaged to determine the residual flux area ratio per sheet. The surface appearance was rated as "good" when the average of the residual flux area ratios of the ten sheets was 0.1% or less and was rated as "bad" when the average was more than 0.1%.

[0048] Table 4 describes the results of evaluation (INVENTIVE EXAMPLES 41 to 47 and COMPARATIVE EXAMPLE 11) of the Cu-Sn-containing steels (the hot-rolled steel sheets) produced by performing the heating step in a heating furnace (the hot heating step) and the rolling step (the hot working step) using some of the fluxes described in Table 1.

[Table 4]

EXAMPLES	Flux No.	Heating temp. [°C]	Heating time [H]	Cracking occurrence	Surface appearance
INV. EX. 41	A18	1270	3	Good	Good

(continued)

EXAMPLES	Flux No.	Heating temp. [°C]	Heating time [H]	Cracking occurrence	Surface appearance
INV. EX. 42	A19	1270	3	Good	Good
INV. EX. 43	A20	1270	3	Good	Good
INV. EX. 44	A18	1140	3	Good	Good
INV. EX. 45	A19	1140	3	Good	Good
INV. EX. 46	A20	1140	3	Good	Good
INV. EX. 47	A20	1270	5	Good	Good
COMP. EX. 11	B	1270	3	Good	Bad

[0049] As demonstrated in INVENTIVE EXAMPLES 41 to 46, it was confirmed that when use was made of the fluxes having a liquid phase ratio of 10 mass% or more at an atmosphere temperature (a heating temperature) of 1000°C (the fluxes with flux Nos. "A18 to A20"), the "cracking occurrence" and the "surface appearance" were "good" even when the atmosphere temperature was 1270°C or 1140°C. Furthermore, as demonstrated in INVENTIVE EXAMPLE 47, it was confirmed that the "cracking occurrence" and the "surface appearance" were "good" even when the heating time (the residence time) at an atmosphere temperature of 1270°C was 5 hours.

[0050] When the flux that was used had a liquid phase ratio of less than 10 mass% at an atmosphere temperature of 1000°C (COMPARATIVE EXAMPLE 11), the "cracking occurrence" was "good" but the "surface appearance" was "bad".

[0051] When the Cu-Sn-containing cast steel was heated (the hot heating step) and rolled (the hot working step), the flux having a liquid phase ratio of 10 mass% or more at an atmosphere temperature of 1000°C was attached to the surface of the Cu-Sn-containing cast steel. As demonstrated above, the flux successfully suppressed the occurrence of cracks stemming from the penetration of a Cu-Sn melt into grain boundaries in the rolling step even when the atmosphere temperature in the heating furnace was 1150°C or below. Furthermore, little flux remained on the surface of the Cu-Sn-containing cast steel after descaling, and the cast steel was free from a poor appearance.

[0052] While EXAMPLES described above evaluated the production of hot-rolled steel sheets, similar effects were confirmed on steel bars, wire rods, and steel pipes produced from round billets or square billets as the cast steel with the attachment of the flux of the present invention. The flux offered similar effects even when attached by brush application.

[0053] While the results of the studies in EXAMPLES described above were obtained at 1010°C, it is needless to mention that similar effects can be obtained by adding the flux of the present invention also in the hot rolling test at a higher temperature, such as 1100°C, 1150°C, or 1250°C.

Reference Signs List

[0054]

1	cast steel
2	spray gun
3	roller
4	flux
5	flux powder
6	jet air
7	supply pipe
10	flux supply device

Claims

1. A method for producing Cu-Sn-containing steel, comprising:

a hot heating step of attaching a flux to a surface of a Cu-Sn-containing cast steel in such an amount that the mass per unit area is 50 g/m^2 or more and 5000 g/m^2 or less, and heating the Cu-Sn-containing cast steel at a temperature of 1000°C or above and 1400°C or below, the flux comprising at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components and being such that the liquid phase

ratio at 1000°C is 10 mass% or more; and
a hot working step of hot working the Cu-Sn-containing cast steel.

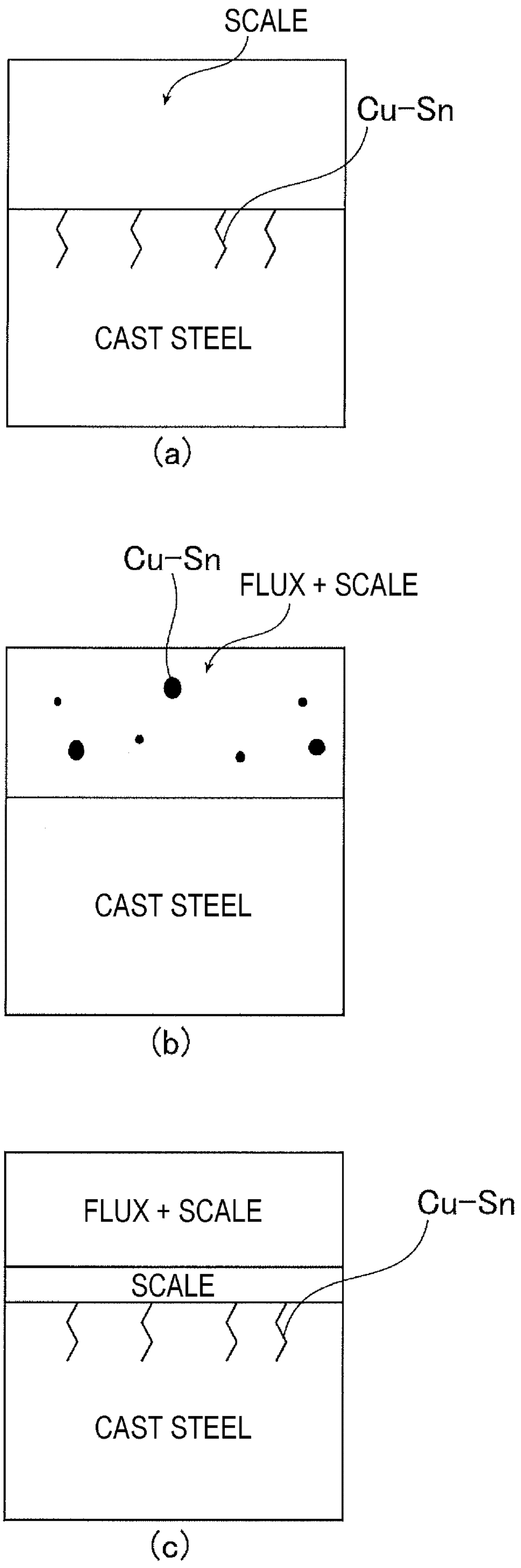
2. A method for producing Cu-Sn-containing steel, comprising:

a hot heating step of heating a Cu-Sn-containing cast steel at a temperature of 1000°C or above and 1400°C or below; and
a hot working step of attaching a flux to a surface of the Cu-Sn-containing cast steel in such an amount that the mass per unit area is 50 g/m^2 or more and 5000 g/m^2 or less, and hot working the Cu-Sn-containing cast steel, the flux comprising at least any of B_2O_3, P_2O_5, K_2O, PbO, Na_2O-FeO, Na_2O-SiO_2, Na_2O-TiO_2, and Li_2O-SiO_2 components and being such that the liquid phase ratio at 1000°C is 10 mass% or more.

3. The method for producing Cu-Sn-containing steel according to claim 1 or 2, wherein the flux further comprises an incidental oxide, fluoride, carbonate, or metal component.

4. The method for producing Cu-Sn-containing steel according to any one of claims 1 to 3, wherein the flux is attached as a pre-melt to the surface of the Cu-Sn-containing cast steel.

FIG. 1

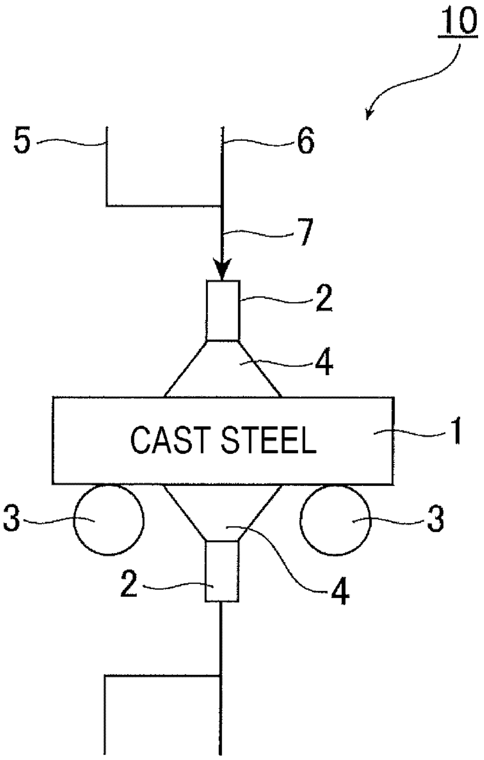

SCALE
Cu−Sn
CAST STEEL
Cu−Sn
FLUX + SCALE
CAST STEEL
FLUX + SCALE
SCALE
Cu−Sn
CAST STEEL

(a)

(b)

(c)

FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2022/044717

A. CLASSIFICATION OF SUBJECT MATTER

B21B 45/00(2006.01)i; ***C21D 1/70***(2006.01)i; ***C21D 9/00***(2006.01)i; ***C21D 9/46***(2006.01)i; ***C22C 38/00***(2006.01)i; ***C22C 38/16***(2006.01)i
FI: B21B45/00 A; C21D9/00 101A; C21D1/70 A; C21D9/46 S; C22C38/00 301W; C22C38/16

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)

B21B45/00-B21B45/08, B21B1/00-B21B1/46

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2023
Registered utility model specifications of Japan 1996-2023
Published registered utility model applications of Japan 1994-2023

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.
X	JP 6-297025 A (NIPPON STEEL CORP) 25 October 1994 (1994-10-25) paragraphs [0002]-[0020], fig. 1-4	1-4
A	US 2017/0066022 A1 (SIEMENS ENERGY INC.) 09 March 2017 (2017-03-09) paragraphs [0010]-[0029], figures	1-4
A	JP 55-126313 A (NIPPON STEEL CORP) 30 September 1980 (1980-09-30) p. 2, upper left column, line 2 to p. 3, lower left column, line 15, fig. 1-2	1-4
A	JP 2002-180192 A (SUMITOMO METAL IND LTD) 26 June 2002 (2002-06-26) paragraphs [0015]-[0062], fig. 1-2	1-4
A	JP 6-346084 A (SUMITOMO METAL IND LTD) 20 December 1994 (1994-12-20) paragraphs [0005]-[0037]	1-4

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

* Special categories of cited documents:
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"P" document published prior to the international filing date but later than the priority date claimed
"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
"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
"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
"&" document member of the same patent family

Date of the actual completion of the international search **02 February 2023**	Date of mailing of the international search report **14 February 2023**
Name and mailing address of the ISA/JP **Japan Patent Office (ISA/JP)** **3-4-3 Kasumigaseki, Chiyoda-ku, Tokyo 100-8915** **Japan**	Authorized officer Telephone No.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2022/044717

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
JP 6-297025 A	25 October 1994	(Family: none)	
US 2017/0066022 A1	09 March 2017	DE 102016116803 A1 CN 106521224 A	
JP 55-126313 A	30 September 1980	(Family: none)	
JP 2002-180192 A	26 June 2002	(Family: none)	
JP 6-346084 A	20 December 1994	(Family: none)	

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 5454132 B **[0007]**
- JP 6297025 A **[0007]**