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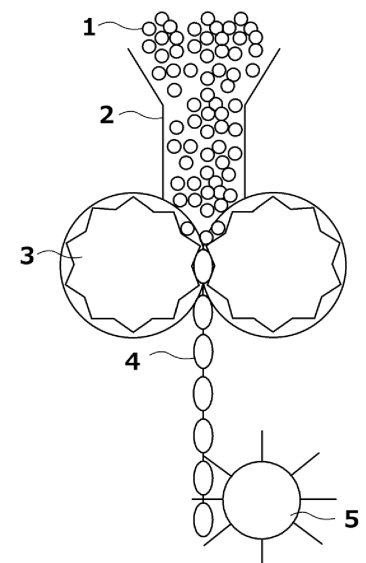
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(54) **METHOD FOR PRODUCING REDUCED IRON BRIQUETTES**

(57) Proposed is a method for producing a reduced iron briquette that can improve both the apparent density and strength thereof when briquetting reduced iron through hot briquetting. The method for producing a reduced iron briquette of the present invention is a method for producing a reduced iron briquette including performing hot briquetting on a reduced iron aggregate including pellet-shaped reduced iron containing an iron component, using briquetting rolls, and thus briquetting the reduced iron aggregate, the method also including performing hot briquetting on the reduced iron aggregate by changing a rotation speed of the briquetting rolls and/or a gap between the briquetting rolls in accordance with a T.Fe content of the pellet-shaped reduced iron. As a preferred embodiment, the rotation speed of the briquetting rolls is changed to be slower and/or the gap between the briquetting rolls is changed to be narrower as the proportion of gangue components is higher.

[Fig. 3]



Description

Technical Field

- 5 **[0001]** The present invention relates to a method for producing a reduced iron briquette, and more specifically, to a method for obtaining a reduced iron briquette through hot briquetting.

Background Art

- 10 **[0002]** Hot briquetted iron (hereinafter also referred to as "HBI") is attracting attention as a raw material to be charged into a furnace that can address the dual challenges of achieving an operation with a high pig-iron production rate and reducing CO₂ emissions. HBI is a briquetted product produced by hot-briquetting reduced iron, i.e., direct reduced iron (hereinafter also referred to as "DRI"). DRI has a porous structure where oxygen of an oxide (FexOy) within a target material has been removed through a reduction reaction. Compared to its pre-reduction state, DRI has a higher proportion of total Fe (T.Fe) and a larger specific surface area, resulting in high reactivity. Thus, if DRI is stored in an oxygen atmosphere, such as ambient air, it reacts with oxygen, leading to potential heat generation or ignition due to the heat of oxidation. Therefore, storing DRI in an inert gas atmosphere (e.g., nitrogen gas) is desirable, which poses a challenge in terms of storage.

- 20 **[0003]** One solution to the challenge of storing DRI is to process it into HBI. Processing DRI into HBI reduces reactivity by reducing voids between DRI particles while compressing the internal pores of DRI in a hot working temperature range, where processing is easier than at room temperature, thereby reducing the specific surface area. This also reduces the risk of heat generation and ignition. Conventionally, techniques described in Patent Literature 1 and Patent Literature 2 are known for producing HBI.

- 25 **[0004]** Patent Literature 1 discloses a technique for producing high-strength, weather-resistant HBI suitable as a raw material for a blast furnace charge, by setting the average C (carbon) content in the surface portion and in the central portion to predetermined values. In addition, Patent Literature 2 discloses an apparatus and method for producing molten iron, in which reduced iron fine and a calcined auxiliary raw material are hot-briquetted.

Citation List

- 30 Patent Literature

[0005]

- 35 Patent Literature 1: Japanese Patent No. 5059379
Patent Literature 2: Japanese Patent No. 4202326

Summary of Invention

- 40 Technical Problem

- [0006]** However, the technique described in Patent Literature 1 relates to a method for producing inexpensive, high-strength, weather-resistant HBI, and it specifies the average C content in the surface portion and the interior of DRI. Therefore, while high strength can be achieved, there is no mention of achieving high density. In addition, the technology described in Patent Literature 2 specifies the optimal production conditions in feeding into an electric furnace or a blast furnace. Specifically, Patent Literature 2 discloses the desirable particle size distribution of HBI (in briquetted form) immediately before it is charged into an electric furnace or a blast furnace after the briquetting of DRI. However, Patent Literature 2 fails to disclose any specific means for achieving such a desirable particle size distribution. Therefore, the technology described in Patent Literature 2 does not necessarily achieve high density of HBI, posing risks associated with long-distance transport.

- 50 **[0007]** The present invention has been made in view of the foregoing circumstances, and an object of the present invention is to propose a method for producing a reduced iron briquette that can improve both the apparent density and strength thereof when briquetting reduced iron through hot briquetting.

- 55 Solution to Problem

- [0008]** The method for producing a reduced iron briquette of the present invention is a method for producing a reduced iron briquette including performing hot briquetting on a reduced iron aggregate composed of pellet-shaped reduced iron

containing an iron component, using briquetting rolls to form a briquette, in which hot briquetting is performed on the reduced iron aggregate by adjusting a rotation speed of the briquetting rolls and/or a gap between the briquetting rolls in accordance with a T.Fe content of the pellet-shaped reduced iron.

[0009] It should be noted that the method for producing a reduced iron briquette according to the present invention with the foregoing configuration may include the following features that are considered to be more preferable solution means.

(1) The rotation speed of the briquetting rolls is adjusted to be lower and/or the gap between the briquetting rolls is adjusted to be narrower as the T.Fe content decreases.

(2) The T.Fe content of the pellet-shaped reduced iron is less than 85 mass%.

Advantageous Effects of Invention

[0010] According to the method for producing a reduced iron briquette of the present invention, it is possible to obtain a reduced iron briquette with improved apparent density and strength by performing hot briquetting on a reduced iron aggregate while adjusting the rotation speed of briquetting rolls or the gap between the briquetting rolls in accordance with the T.Fe content of pellet-shaped reduced iron contained in the reduced iron aggregate.

Brief Description of Drawings

[0011]

[Fig. 1] is a graph illustrating an embodiment of the relationship between the apparent density and porosity of HBI according to the grade of each raw material.

[Fig. 2] is a graph illustrating an embodiment of the relationship between the T.Fe content and the gangue component content in each of standard-grade ore and low-grade ore.

[Fig. 3] is a schematic view for illustrating an embodiment of an apparatus configuration for implementing a method for producing a reduced iron briquette of the present invention.

[Fig. 4] is a schematic view for illustrating a case where the apparent density of a reduced iron briquette fails to meet a development target.

[Fig. 5] (a) and (b) are schematic views for illustrating examples where the gap between briquetting rolls is changed in the method for producing a reduced iron briquette of the present invention.

[Fig. 6] (a) and (b) are graphs respectively illustrating the relationship between the porosity and the rotation speed of the briquetting rolls and the relationship between the apparent density and the porosity in the method for producing a reduced iron briquette of the present invention.

[Fig. 7] (a) and (b) are graphs respectively illustrating the relationship between the porosity and the gap between the briquetting rolls, and the relationship between the apparent density and the porosity in the method for producing a reduced iron briquette of the present invention.

[Fig. 8] is a graph illustrating the relationship between the T.Fe content of DRI and the porosity required for HBI obtained by briquetting the DRI in the method for producing a reduced iron briquette of the present invention.

Description of Embodiments

[0012] Hereinafter, an embodiment of the present invention will be specifically described. It should be noted that the following embodiment merely illustrates examples of an apparatus and method for embodying the technical idea of the present invention. Thus, the configuration of the present invention is not limited thereto. That is, the technical idea of the present invention may be variously modified within the technical scope recited in the claims.

<Regarding development targets of method for producing reduced iron briquette of the present invention>

[0013] For the maritime transport of HBI, international regulations (IMSBC Code: International Maritime Solid Bulk Cargoes Code) exist, requiring compliance with "an apparent density of 5.0 g/cm³ or greater and a briquetting temperature of 650°C or greater." This requirement is one of the important development indicators for establishing the HBI technology.

[0014] Fig. 1 is a conceptual graph of the relationship between the porosity and apparent density of HBI according to the grade of each raw material. It is known that the porosity and apparent density of HBI have a negative correlation. The graph of HBI obtained by briquetting reduced iron (with a T.Fe content of about 90 mass%) of standard-grade iron ore is based on examples A, B, and C of commercially available HBI products on the market. These HBI products have a porosity of 27% or less and achieve the target value (5.0 g/cm³) specified in the apparent density standard of the IMSBC Code for maritime transport. Regarding low-grade ore, compared to standard-grade ore, the proportion of gangue components (CaO, Al₂O₃,

SiO₂, and MgO) in DRI is higher, and the T.Fe content (proportion of Fe components in the DRI) is lower. Since gangue components have a lower true density than iron, the density of HBI tends to decrease as the grade of ore is degraded. Regarding low-grade and ultra-low-grade ore, it is difficult to achieve the target apparent density unless the porosity can be reduced more than with standard-grade ore. Therefore, to establish a briquetting technology, it is important to determine the necessary briquetting conditions (briquetting temperature and briquetting pressure) according to the ore grade (i.e., T.Fe).

[0015] It should be noted that, in Fig. 1, each of the graphs for low-grade ore and ultra-low-grade ore was determined through calculation by, for example, progressively reducing the T.Fe content in increments from the actual graph for standard-grade ore (having a T.Fe content of approximately 90 mass%). The T.Fe content in both low-grade ore and ultra-low-grade ore is less than 85 mass%. In Fig. 1, the target apparent density of HBI can be achieved by setting the porosity of the HBI to 20% or less for low-grade ore and 15% or less for ultra-low-grade ore. Fig. 2 illustrates the relationship between the T.Fe content and the gangue component content in each of standard-grade ore and low-grade ore. Fig. 2 exhibits that the proportion of gangue components varies depending on the grade of DRI. Specifically, as the grade of DRI decreases, the T.Fe content decreases and the proportion of gangue components increases.

[0016] Fig. 8 is a graph illustrating the relationship between the T.Fe content of DRI as a raw material and the porosity of HBI. Fig. 8 shows that, as the T.Fe content of DRI decreases (i.e., as the grade is lower), the porosity of HBI decreases.

<Regarding method for measuring T.Fe Content>

[0017] Before describing the method and apparatus for producing a reduced iron briquette of the present invention, a method for measuring the T.Fe content will be described. First, a predetermined amount of sample is taken, and the sample is then decomposed to obtain a solution, using either a method (a) or (b) below.

(a) The sample is decomposed with hydrochloric acid in the presence of tin(II) chloride and filtered. The residue is then treated with sulfuric acid and hydrofluoric acid, is melted using potassium disulfate, and is mixed with the filtrate.

(b) The sample is melted with sodium carbonate and sodium peroxide, and the melt is dissolved in warm water. The precipitate is filtered and then dissolved in hydrochloric acid.

[0018] A major portion of iron(III) in the obtained solution is reduced to iron(II) using tin(II) chloride, and the remaining iron(III) is reduced using titanium(III) chloride. Excess titanium(III) chloride is quantitatively oxidized with potassium dichromate. The acid concentration of the solution is adjusted with a mixed acid of sulfuric acid and phosphoric acid, and then, titration is performed with a potassium dichromate solution using sodium diphenylamine-4-sulfonate as an indicator. The T.Fe content in the sample is quantitatively calculated from the titer obtained with dichromate. Such a measurement method is performed in accordance with JIS M 8212 "Gravimetric and Volumetric Analysis," but may also be performed in accordance with other standards or specifications.

<Regarding method for producing reduced iron briquette of the present invention>

[0019] In view of the foregoing development targets, the present invention is characterized by changing the rotation speed of the briquetting rolls and/or the gap between the briquetting rolls according to the grade of a raw material used, in particular, the T.Fe content, in order to improve the apparent density and strength of HBI, thereby solving the foregoing issues. These are all conditions on the briquetting machine side and are independent of a method that maintains the chemical composition within specified upper and lower limits. Thus, these conditions allow for evaluation with the briquetting conditions influencing only the briquetting characteristics, without depending on the control of the raw material properties. It should be noted that "high density" as referred to in the present patent is a relative expression based on the apparent density of commercial HBI. In addition, commercial HBI is defined as HBI having an apparent density of 5.0 g/cm³ or greater.

[0020] Fig. 3 is a schematic view for illustrating an embodiment of an apparatus configuration for implementing the method for producing a reduced iron briquette of the present invention. In the embodiment of the apparatus configuration of the present invention illustrated in Fig. 3, heated DRI 1 at a briquetting temperature is fed into a hopper 2. The heated DRI 1 fed into the hopper 2 is subjected to briquetting at briquetting rolls 3 to form HBI 4. The thus obtained HBI 4 is fed into a separator 5.

[0021] The heated DRI 1 is fed into the hopper 2, and is then supplied by being pushed into the gap between the briquetting rolls 3 through the rotation of a screw feeder. The briquetting rolls 3 include a pair of briquetting rolls with the same diameter. Each briquetting roll 3 has a pocket portion carved into its outer peripheral surface, each having the shape of a briquetted product to be obtained. The heated DRI 1 pushed from the hopper 2 is sequentially loaded into the pocket portions. With the rotation of the briquetting rolls, the heated DRI 1 is pressurized and compressed by the briquetting rolls 3. A continuous supply of the raw material and synchronous rotation of the briquetting rolls enable HBI 4 to be produced in

accordance with the production speed (rotation speed of the rolls). Immediately after the briquetting, the HBI 4 is formed as an interconnected mass composed of individual pieces. Then, the HBI 4 in the interconnected state is separated into individual pieces by the separator 5.

[0022] To produce briquetted products stably, it is necessary to establish appropriate production conditions for the briquetting machine. Typical parameters of briquetting machines include the briquetting (raw material) temperature, the briquetting pressure, the rotation speed of rolls, the pocket shape, and the gap between the rolls. In the present invention, to efficiently produce high-density HBI, the rotation speed of the briquetting rolls and/or the gap between the briquetting rolls are/is changed according to the proportion of gangue components in the pellet-shaped reduced iron aggregate to be subjected to briquetting.

<Regarding rotation speed of briquetting rolls>

[0023] The rotation speed of the briquetting rolls influences the compactability of briquetted products to be obtained. For example, if the briquetting rolls are rotated at a speed faster than the reference speed, the time during which the roll surface and the raw material are in contact with each other becomes shorter than that at the reference rotation speed. This makes it difficult to apply the load (pressure) required to achieve low porosity. Fig. 4 is a schematic view for illustrating a case where the apparent density of a reduced iron briquette fails to meet the development target. As illustrated in this embodiment, after the briquetting using the briquetting rolls, two types of HBI 4 are produced: HBI 4-1 that is a reduced iron briquette with an apparent density meeting the development target, and HBI 4-2 that is a reduced iron briquette with an apparent density not meeting the development target. Therefore, in the present invention, the apparent density of the HBI 4 to be obtained through briquetting is increased by setting the rotation speed of the briquetting rolls lower than the typical reference rotation speed, thereby increasing the contact time compared to that at the conventional reference rotation speed.

<Regarding gap between briquetting rolls>

[0024] When the gap between the briquetting rolls is changed, the number of DRI particles entering the pockets and rolls varies correspondingly. The briquetting pressure applied to each DRI particle also varies. Reducing the gap between the briquetting rolls can increase the briquetting pressure applied to each DRI particle, thereby increasing the apparent density of the resulting HBI. Figs. 5(a) and 5(b) are schematic views for illustrating examples where the gap between the briquetting rolls is changed in the method for producing a reduced iron briquette of the present invention. Fig. 5(a) illustrates an example where the gap between the briquetting rolls is set at the reference roll positions for normal operation, and HBI 4-2, which is a reduced iron briquette having an apparent density that does not meet the development target as illustrated in Fig. 4, is present. Fig. 5(b) illustrates an example where the gap between the briquetting rolls is set narrower than that at the reference roll positions in Fig. 5(a), so that no HBI 4-2, which is a reduced iron briquette having an apparent density that does not meet the development target, is present, and only HBI 4-1, which is a reduced iron briquette having an apparent density that meets the development target, is present. Herein, there is a limitation in reducing the gap between the rolls. If the gap is made too narrow, excessive pressure may cause internal cracks in the briquetted product to be obtained, which in turn may reduce its strength. Thus, an appropriate briquetting pressure level is desirable.

[0025] The foregoing description has separately explained the influence of changing the rotation speed of the briquetting rolls and the influence of changing the gap between the briquetting rolls. It is obvious that the present invention can also be implemented by changing both the rotation speed of the briquetting rolls and the gap between the briquetting rolls simultaneously, as well as by changing them individually.

[0026] As described above, according to the present invention, production of high-density HBI through briquetting is possible by changing the rotation speed of the briquetting rolls and/or the gap between the briquetting rolls according to the proportion of gangue components in the aggregate of the pellet-shaped material to be subjected to briquetting.

[0027] It should be noted that the present invention is particularly effective as the grade of the raw material used is lower. Herein, the term "low-grade raw material" refers, for example, to pellet-shaped reduced iron with a T.Fe content of less than 85 mass%. Alternatively, the "low-grade raw material" may be pellet-shaped reduced iron with an even lower iron content, such as a T.Fe content of less than 83 mass% or 80 mass%. As a further alternative, the initial raw material before pelletization, which has a T.Fe content of 63 mass% or less, may be defined as a "low-grade raw material."

Examples

[0028] Assume the following prerequisites for DRI/HBI.

- The particle weight of DRI: 5.0 g/particle
- The particle size of DRI: $\Phi 10$ to 15 mm/particle
- The dimensions of HBI: (long side: 100 mm $\times$ short side: 50 mm $\times$ thickest portion: 30 mm)/piece

- The shape of HBI: pillow-shaped
- The weight of HBI: 500 g/piece

[0029] The total amount of DRI loaded per pocket equals one piece of HBI. Thus, one piece of HBI includes (500 g/piece)/(5.0 g/particle) = 100 DRI particles/piece.

[0030] However, the porosity within the briquetted DRI that forms HBI and the percentage of voids between the DRI particles vary depending on the DRI briquetting conditions. The percentage of voids within a pocket, both immediately before DRI is compressed and when DRI is loaded into the pocket, can be quantitatively evaluated based on parameters such as the particle size distribution index and the harmonic mean diameter.

[0031] Figs. 6(a) and 6(b) are graphs respectively illustrating the relationship between the porosity and the rotation speed of the briquetting rolls and the relationship between the apparent density and the porosity in the method for producing a reduced iron briquette of the present invention. According to an embodiment of the present invention illustrated in Figs. 6(a) and (b), provided that the reference rotation speed of the briquetting rolls is 10 rpm as illustrated in Fig. 6(a), the porosity of the HBI obtained through briquetting becomes 20%. As illustrated in Fig. 6(b), at a porosity of 20%, the apparent density was below the target value of 5.0 g/cm³. At this point, it was found that changing the rotation speed of the briquetting rolls to 5 rpm enabled the briquetted HBI to achieve a porosity of 10% and an apparent density equal to or greater than the target value of 5.0 g/cm³.

[0032] Figs. 7(a) and 7(b) are graphs respectively illustrating the relationship between the porosity and the gap between the briquetting rolls and the relationship between the apparent density and the porosity in the method for producing a reduced iron briquette of the present invention. According to an embodiment of the present invention illustrated in Figs. 7(a) and 7(b), provided that the reference value of the gap between the briquetting rolls is 3 mm as illustrated in Fig. 7(a), the porosity of the HBI obtained through briquetting becomes 20%. As illustrated in Fig. 7(b), at a porosity of 20%, the apparent density was below the target value of 5.0 g/cm³. At this point, it was found that changing the gap between the briquetting rolls to 1 mm enabled the briquetted HBI to achieve a porosity of 10% and an apparent density of 5.0 g/cm³ or greater.

[0033] A certain correlation is found between the T.Fe content of DRI and the porosity required for HBI produced by briquetting the DRI. Table 1 below summarizes the T.Fe content in each of five samples of DRI and the porosity required for HBI produced by briquetting the DRI.

[Table 1]

	Grade	T.Fe content (mass%)	Porosity (%)
Sample 1	Standard-grade	92.2	24
Sample 2	Standard-grade	92.4	25
Sample 3	Low grade	85.2	17
Sample 4	Low grade	84.0	16
Sample 5	Low grade	84.4	17

[0034] Fig. 8 is a graph based on Table 1, illustrating the relationship between the T.Fe content of DRI and the porosity required for HBI produced by briquetting the DRI in the method for producing a reduced iron briquette of the present invention. As illustrated in Fig. 8, for example, regarding low-grade DRI with a T.Fe content of about 84 mass%, compared to standard-grade DRI with a T.Fe content of about 92 mass%, the porosity (i.e., the porosity satisfying the apparent density required by IMSBC) required for HBI produced by briquetting the DRI is as low as about 17%.

[0035] According to the graph of Fig. 8, the relationship between the T.Fe content of DRI and the porosity required for HBI produced by briquetting the DRI can be formulated with Expression (1) below.

$$Y = 1.0062X - 68.338... \text{ Expression (1)}$$

Y: Porosity (%) required for HBI produced by briquetting DRI

X: T.Fe content (mass%) of DRI

Reference Signs List

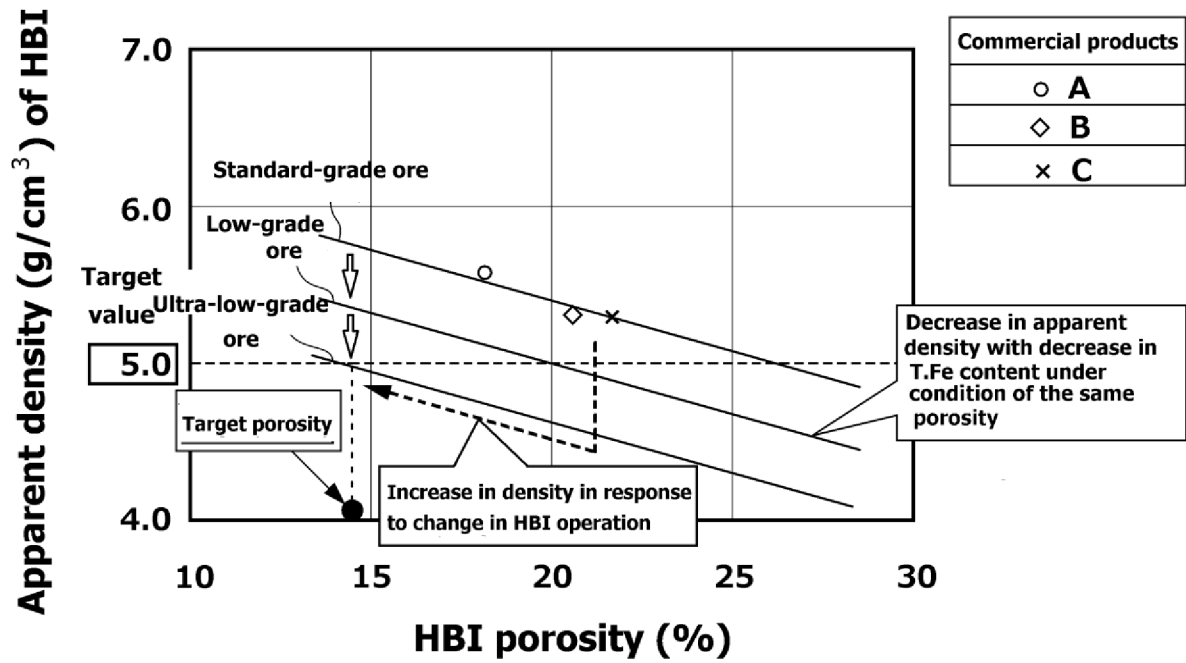
[0036]

	1	heated DRI
	2	hopper
	3	briquetting roll
	4, 4-1, 4-2	HBI
5	5	separator

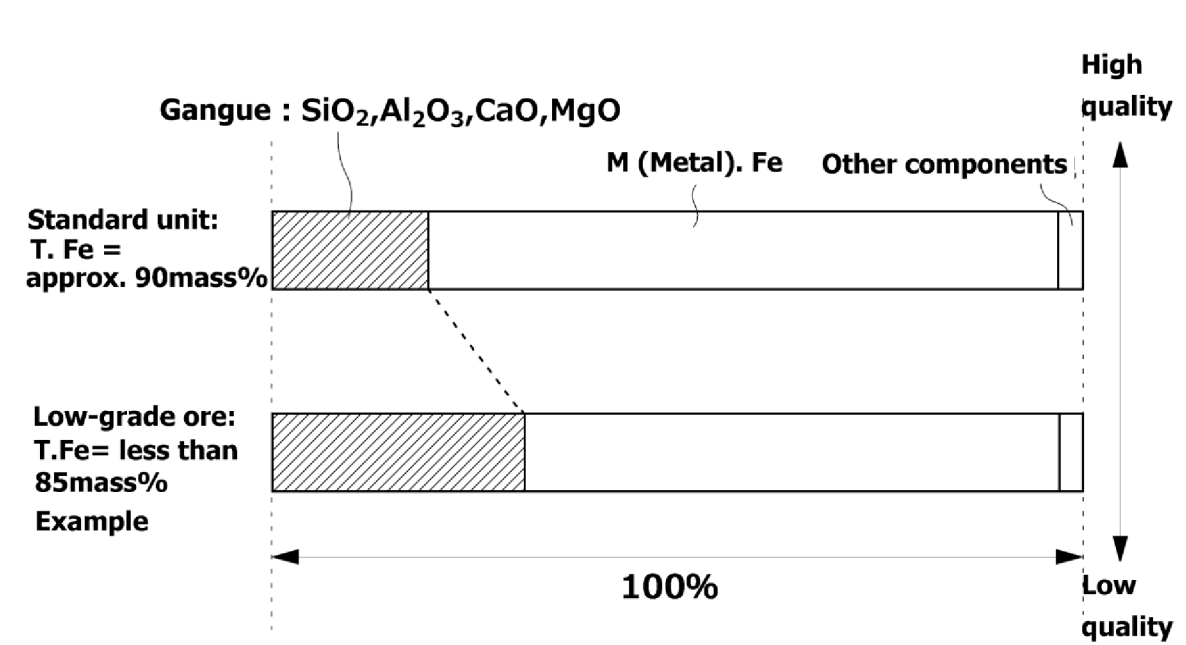
Claims

1. A method for producing a reduced iron briquette comprising performing hot briquetting on a reduced iron aggregate composed of pellet-shaped reduced iron containing an iron component, using briquetting rolls to form a briquette, **characterized in that** hot briquetting is performed on the reduced iron aggregate by varying a rotation speed of the briquetting rolls and/or a gap between the briquetting rolls in accordance with a T.Fe content of the pellet-shaped reduced iron.
2. The method for producing a reduced iron briquette according to claim 1, wherein the rotation speed of the briquetting rolls is adjusted to be lower and/or the gap between the briquetting rolls is adjusted to be narrower as the T.Fe content decreases.
3. The method for producing a reduced iron briquette according to claim 1 or 2, wherein the T.Fe content of the pellet-shaped reduced iron is less than 85 mass%.

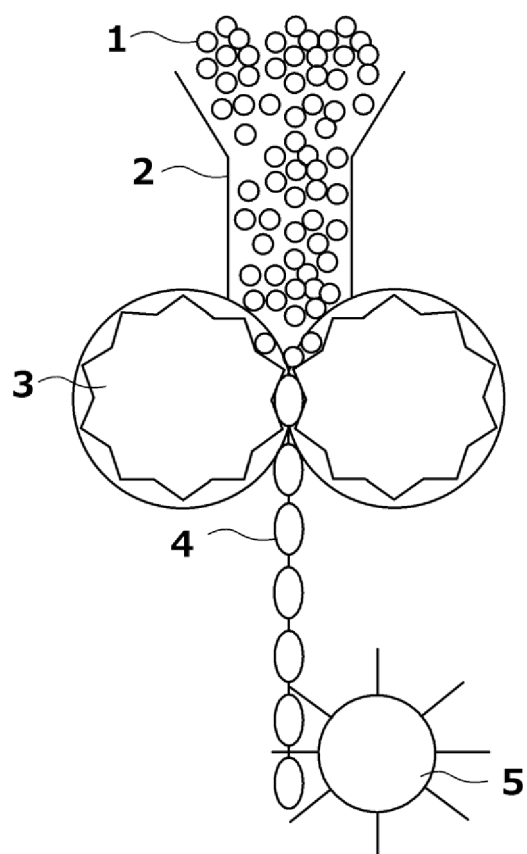
[Fig. 1]



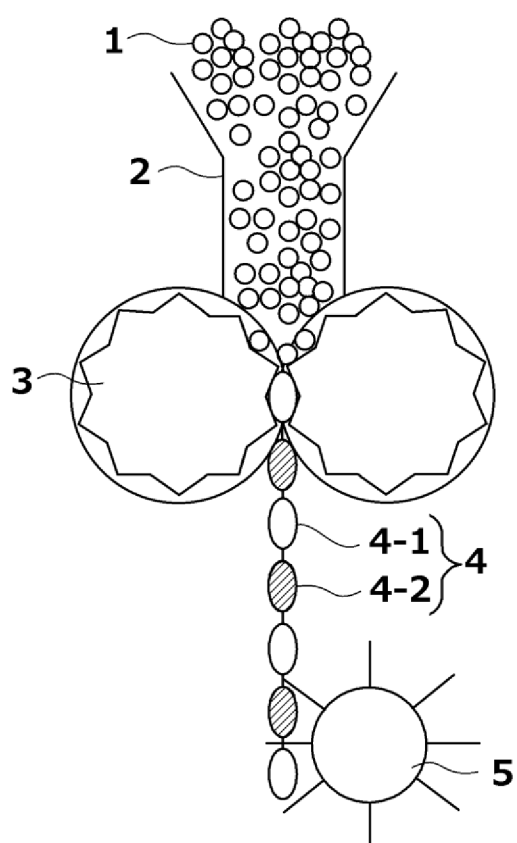
[Fig. 2]



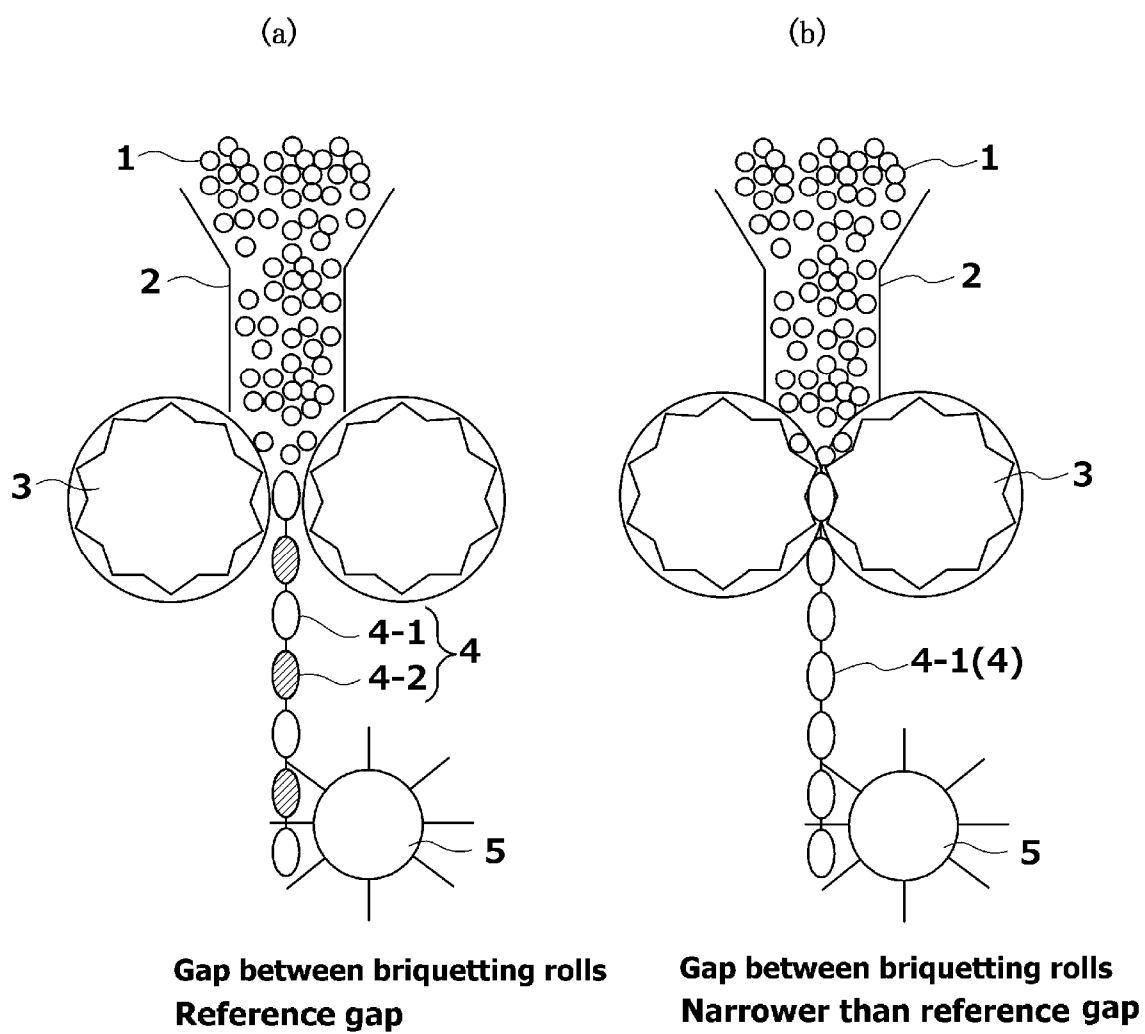
[Fig. 3]



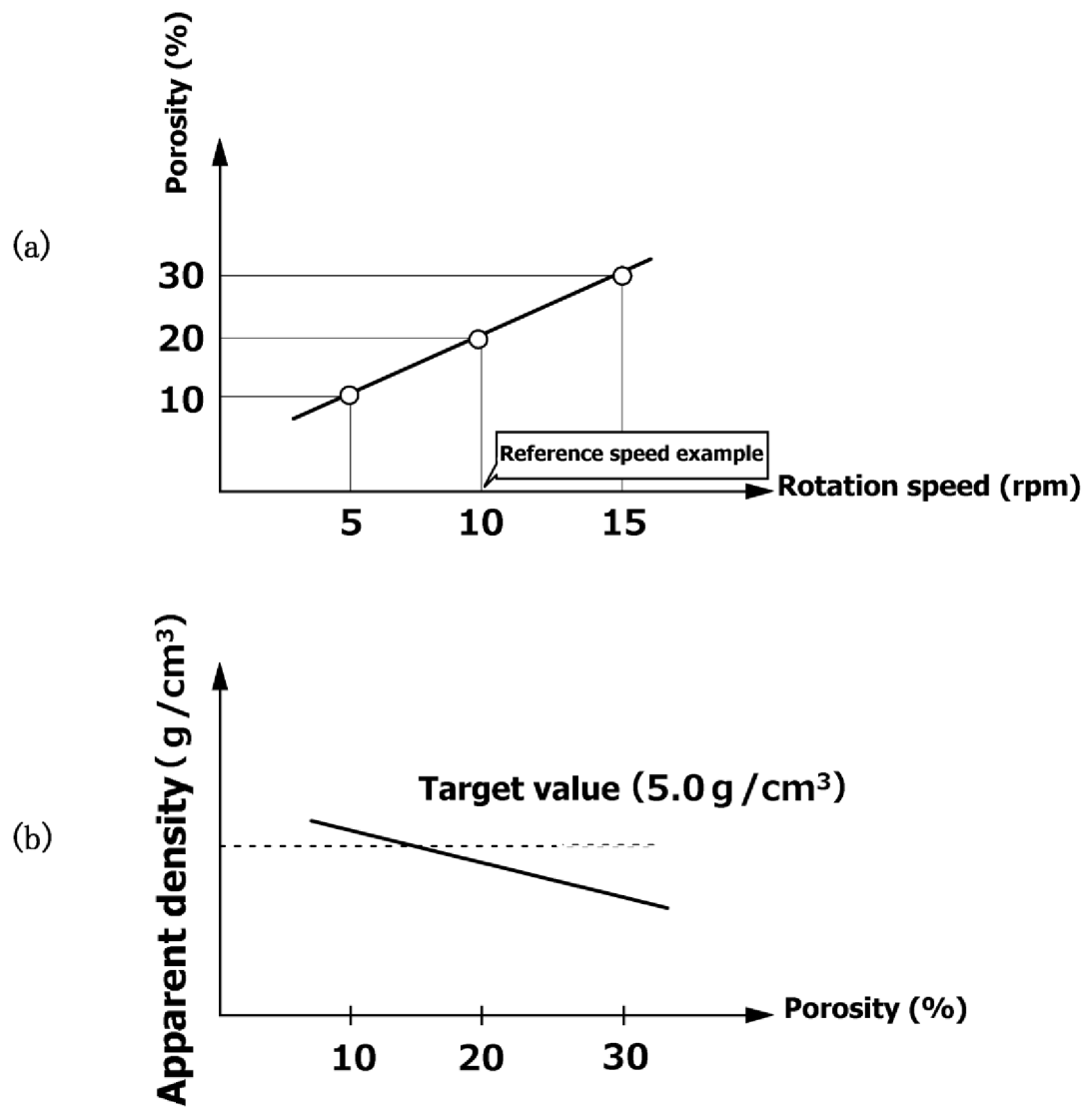
[Fig. 4]



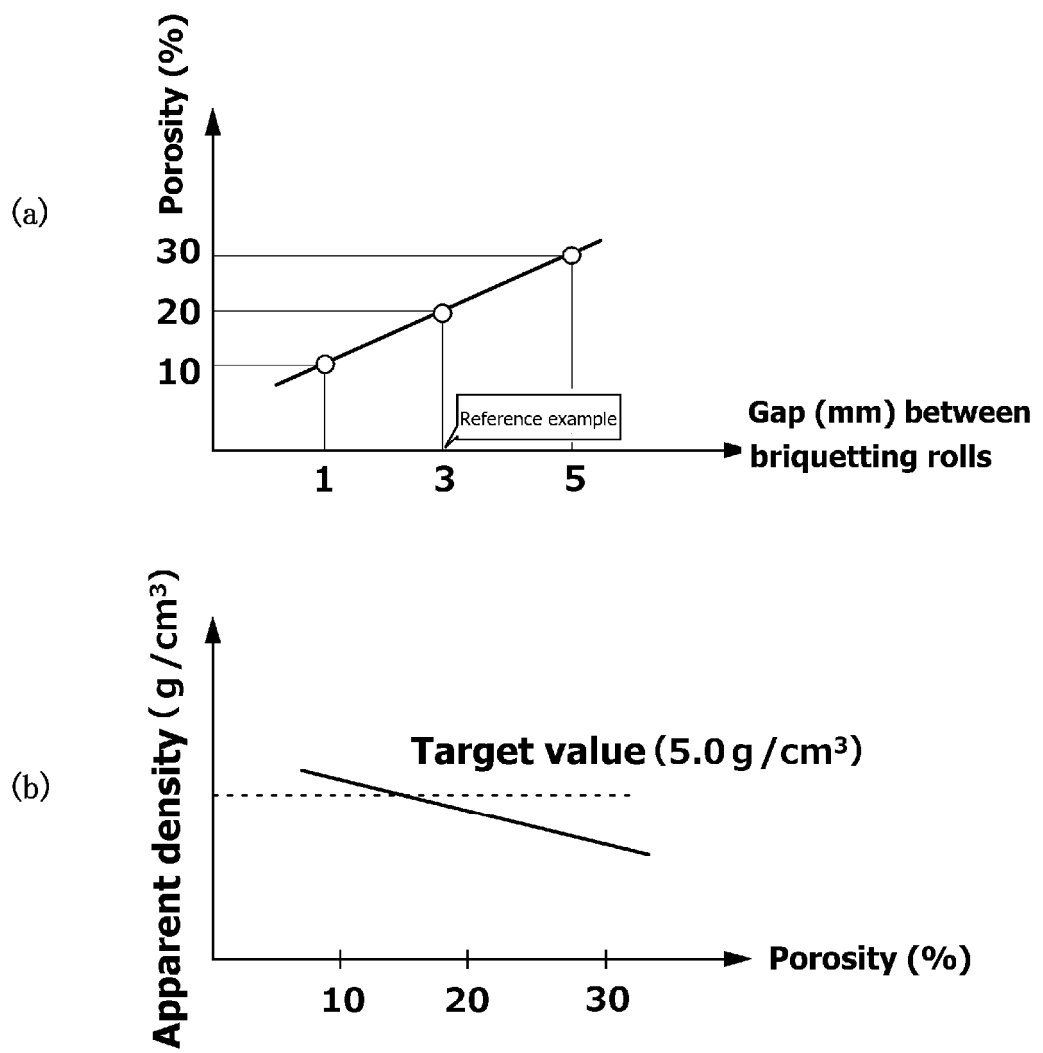
[Fig. 5]



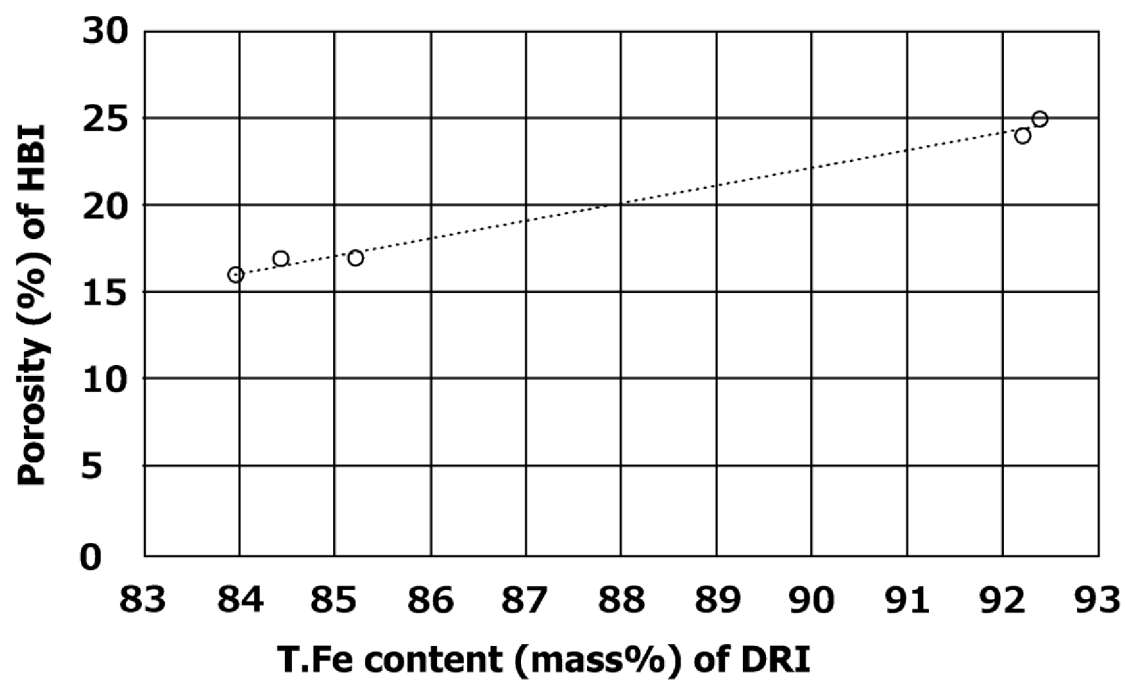
[Fig. 6]



[Fig. 7]



[Fig. 8]



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2024/029096

A. CLASSIFICATION OF SUBJECT MATTER

C22B 1/248(2006.01)j
FI: C22B1/248

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)
C22B1/248

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 1971-2024
Registered utility model specifications of Japan 1996-2024
Published registered utility model applications of Japan 1994-2024

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	US 5547357 A (MASCHINENFABRIK KOPPERN GMBH & CO. KG) 20 August 1996 (1996-08-20) column 13, lines 1-7	1-3
A	JP 2019-157253 A (NIPPON STEEL NISSHIN CO., LTD.) 19 September 2019 (2019-09-19) paragraph [0012]	1-3
A	JP 2010-7163 A (SUMITOMO METAL INDUSTRIES, LTD.) 14 January 2010 (2010-01-14) paragraphs [0076]-[0077]	1-3
A	JP 2015-218351 A (KABUSHIKI KAISHA KOBE SEIKO SHO) 07 December 2015 (2015-12-07) paragraphs [0058]-[0092]	1-3

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

11 October 2024

Date of mailing of the international search report

29 October 2024

Name and mailing address of the ISA/JP

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Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/JP2024/029096

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)		
US	5547357	A	20 August 1996	DE	9318843	U1			
JP	2019-157253	A	19 September 2019	(Family: none)					
JP	2010-7163	A	14 January 2010	(Family: none)					
JP	2015-218351	A	07 December 2015	US	2017/0073781	A1			
				paragraphs [0060]-[0093]					
				WO	2015/174450	A1			
				CN	106414778	A			
				RU	2016146945	A			

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 5059379 B [0005]
- JP 4202326 B [0005]