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(54) **ROLLED H-SHAPED STEEL AND MANUFACTURING METHOD THEREOF**

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(57) **ABSTRACT**

Rolled H-shaped steel is characterized in that a top 5% average value of Mn concentrations in a most embrittled portion in a flange is 1.6 times or less an Mn concentration at a position of 1/6 in a flange width direction from an end face in the flange width direction and 1/4 in a flange thickness direction from a face of a flange positioned on a side opposite to that of a web, and a top 5% average value of Mn concentrations in a central segregation portion dispersed in a region 15 mm or more apart from a center of the flange width toward one end face or both end faces in the flange width direction and within 2 mm from a flange surface layer in the thickness direction is not less than 1.1 times nor more than 1.6 times the Mn concentration at the position of 1/6 in the flange width direction from the end face in the flange width direction and 1/4 in the flange thickness direction from the face of the flange positioned on the side opposite to that of the web.

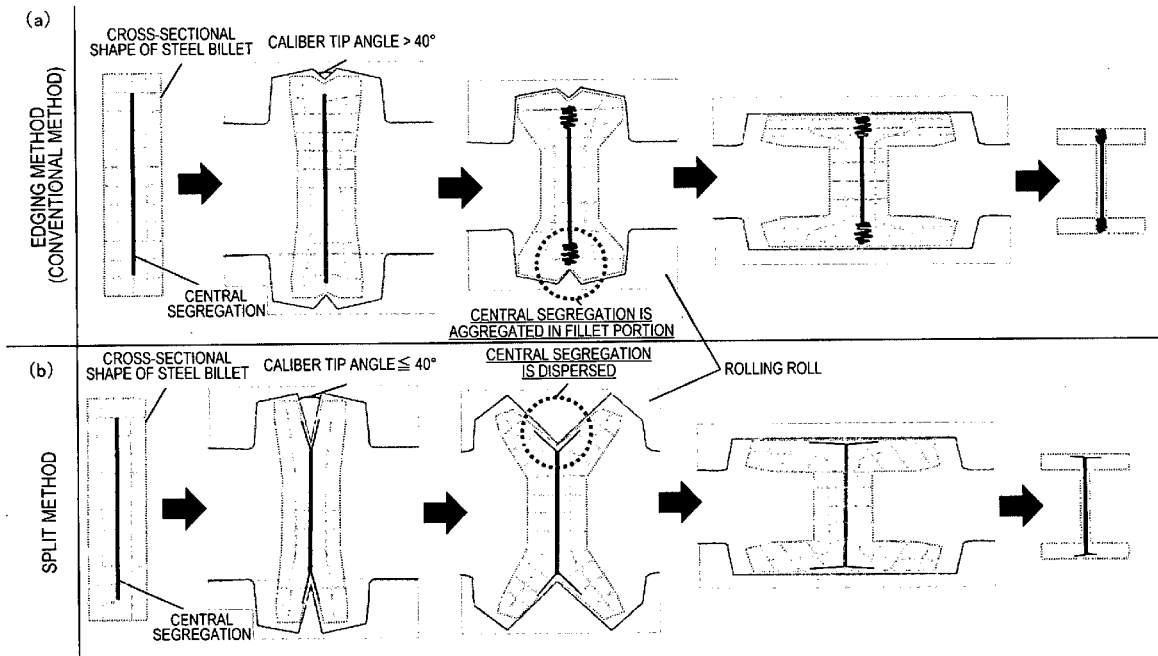


FIG. 1

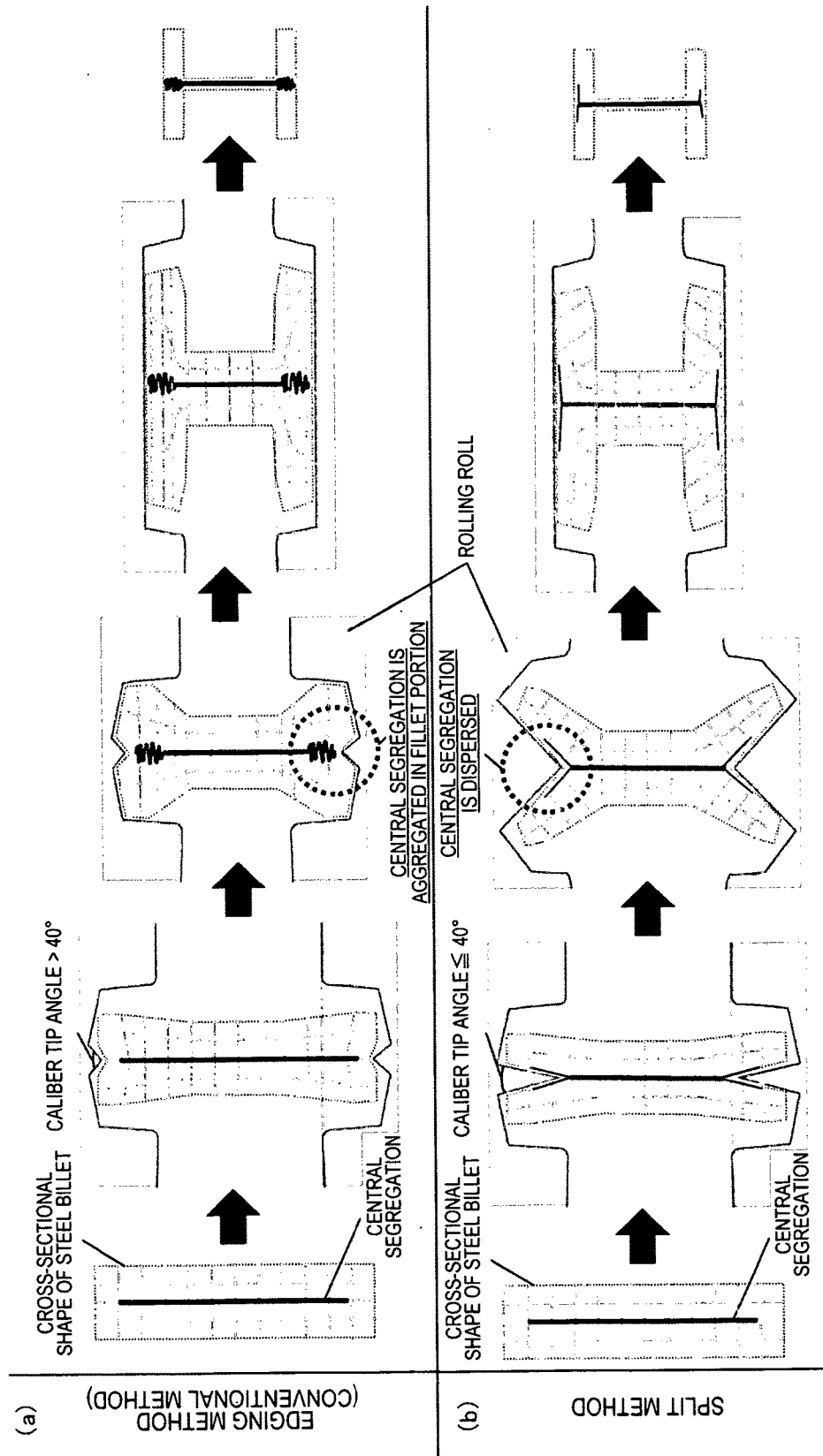


FIG.2

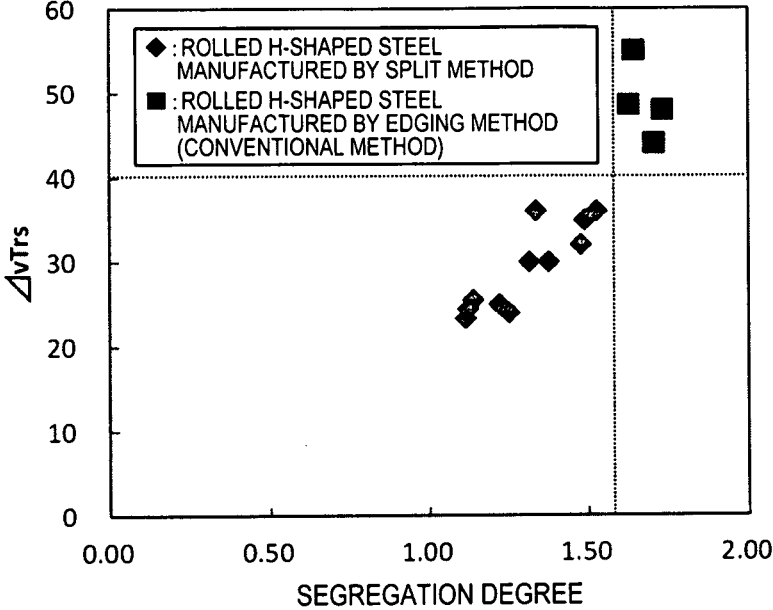


FIG.3

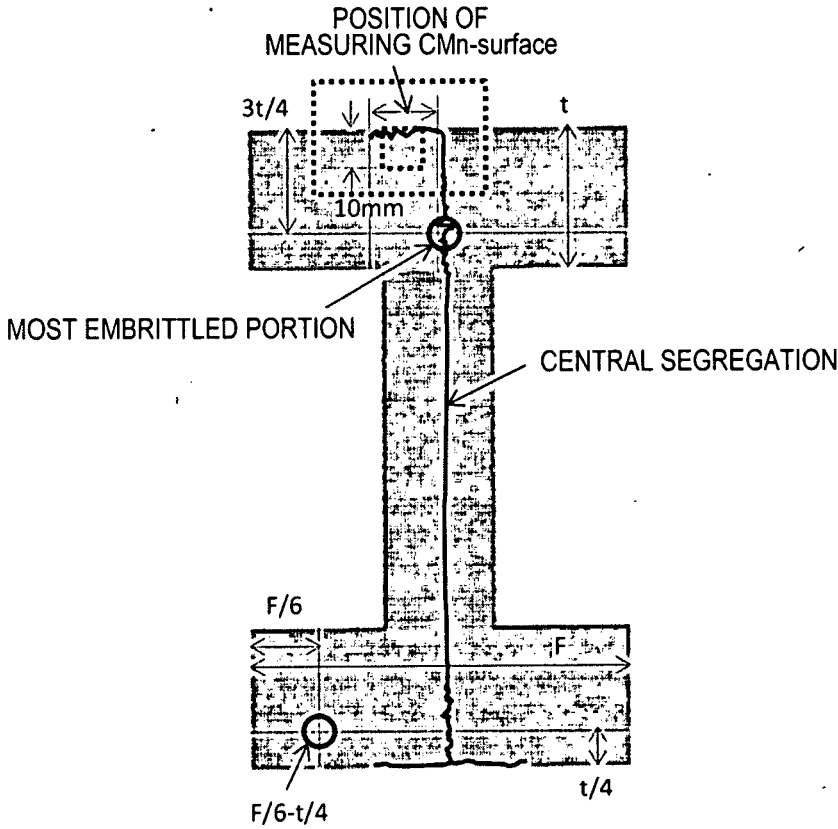


FIG.4

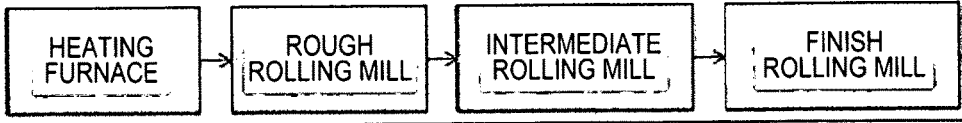
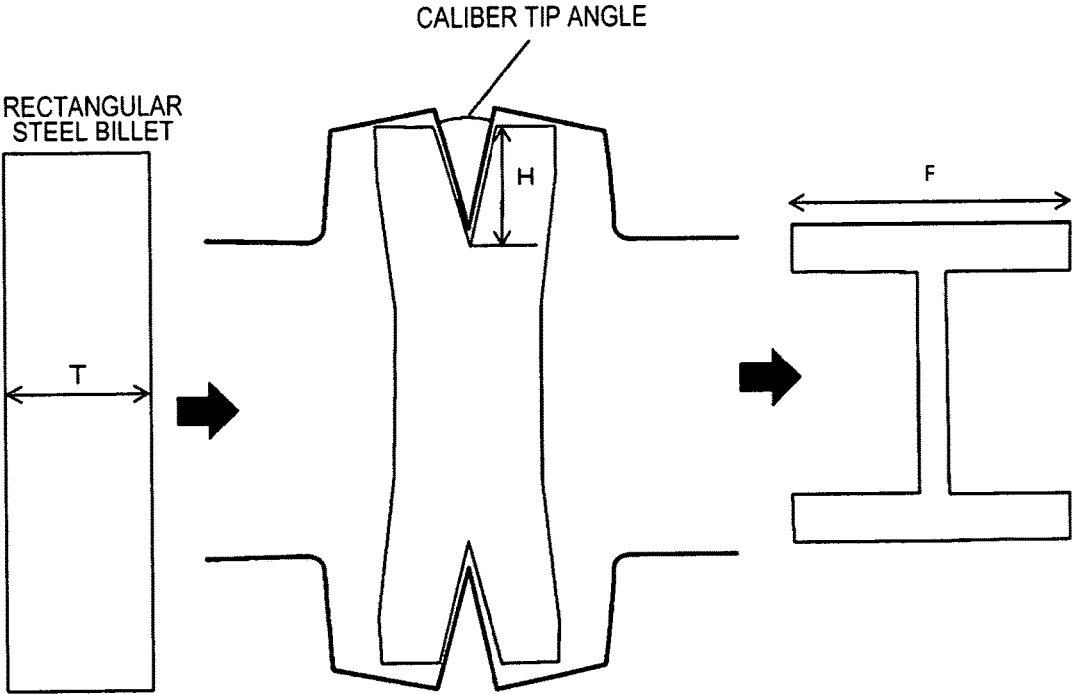


FIG.5



## ROLLED H-SHAPED STEEL AND MANUFACTURING METHOD THEREOF

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2016-166535, filed in Japan on Aug. 29, 2016, the entire contents of which are incorporated herein by reference.

### TECHNICAL FIELD

[0002] The present invention relates to rolled H-shaped steel manufactured by performing hot rolling on a steel billet, and a manufacturing method thereof.

### BACKGROUND ART

[0003] Conventionally, H-shaped steel has been widely used as a material of a construction structure, a civil engineering structure, an offshore structure, and the like, and H-shaped steels having various cross sections have been used. In particular, H-shaped steel using a slab having a rectangular cross section and obtained through continuous casting with high productivity as a steel material and manufactured by hot rolling, requires a low manufacturing cost, and is used in various fields. Conventionally, H-shaped steel manufactured from a slab has been manufactured by an edging method illustrated in FIG. 1(a). The edging method is a rolling method in which grooves for guiding a steel material to a caliber center of rolls are first formed on end portions of a slab, rolling is performed in a width direction of the slab, and the end portions of the slab are elongated in a thickness direction of the slab, to thereby form flange portions. In a central segregation portion formed when casting the slab, alloy elements including Mn are concentrated. By performing the rolling with the edging method, the central segregation portion is further aggregated at a part where a web and a flange intersect, which is a so-called "fillet portion", which sometimes exerts an adverse effect on toughness.

[0004] In view of such problems, in order to solve a macrosegregation (the aggregation of the central segregation portion), it is effective to perform heating at a high temperature for a certain period of time to diffuse Mn and the like, and there has been proposed a method in which heat treatment is performed on a steel billet before being subjected to hot rolling (refer to Patent Document 1, for example). Further, in order to facilitate the diffusion, it is effective to perform rolling to apply a strain, and then perform retention at a high temperature, and there has been proposed a method in which a steel billet is subjected to rough rolling, and then reheated before intermediate rolling (refer to Patent Documents 2 and 3, for example).

[0005] Further, there has been proposed a method of solving the macrosegregation other than the heat treatment (refer to Patent Documents 4 and 5, for example). Patent Document 4 discloses a method in which reduction is performed before solidification is completed in continuous casting. Meanwhile, Patent Document 5 discloses a method in which a caliber for performing edging in a slab width direction of a rough rolling mill is formed into a box caliber with a flat bottom, which is called as a wedge method.

## PRIOR ART DOCUMENT

### Patent Document

- [0006] [Patent Document 1] Japanese Laid-open Patent Publication No. 2012-180584
- [0007] [Patent Document 2] Japanese Laid-open Patent Publication No. H6-122921
- [0008] [Patent Document 3] Japanese Laid-open Patent Publication No. H6-122922
- [0009] [Patent Document 4] Japanese Laid-open Patent Publication No. H5-305395
- [0010] [Patent Document 5] Japanese Laid-open Patent Publication No. H7-88502

### DISCLOSURE OF THE INVENTION

#### Problems to Be Solved by the Invention

[0011] As described above, various countermeasures have been conventionally proposed in order to suppress the reduction in the toughness of the fillet portions of the rolled H-shaped steel caused by the macrosegregation. However, each countermeasure has a problem that the productivity is impaired with respect to the edging method being the conventional technique.

[0012] Accordingly, in view of such actual circumstance, the present invention has an object to provide rolled H-shaped steel and a manufacturing method thereof in which a macrosegregation of fillet portions is reduced without impairing the productivity with respect to the edging method being the conventional technique.

#### Means for Solving the Problems

[0013] The present invention is characterized in that it includes a step of creating splits by using a shaping caliber formed with projections which create splits vertically with respect to a width direction of a material to be rolled, and performing sequential bending by setting the splits as starting points. According to the step as described above, a central segregation portion is dispersed in the whole of flanges at a time of forming the flanges from a slab, resulting in that an aggregation of a central segregation portion at fillet portions can be suppressed without impairing the productivity.

[0014] The gist of the present invention is as follows.

[0015] [1] Rolled H-shaped steel is characterized in that it includes a chemical composition comprising : in mass %, C: 0.01 to 0.25%; Si: 0.05% to 0.50%; Mn: 0.40 to 2.50%; P: 0.050% or less; S: 0.050% or less; N: 0.020% or less; Cu: 0.70% or less; Ni: 0.70% or less; Cr: 0.50% or less; V: 0.12% or less; Mo: 0.30% or less; Nb: 0.08% or less; Ti: 0.05% or less; Al: 0.07% or less; REM: 0.010% or less; Ca: 0.0050% or less; and the balance: Fe and inevitable impurities, in which: a top 5% average value of Mn concentrations in a most embrittled portion in a flange is 1.6 times or less an Mn concentration at a position of 1/6 in a flange width direction from an end face in the flange width direction and 1/4 in a flange thickness direction from a face of a flange positioned on a side opposite to that of a web; and a top 5% average value of Mn concentrations in a central segregation portion dispersed in a region 15 mm or more apart from a center of the flange width toward one end face or both end faces in the flange width direction and within 2 mm from a flange surface layer in the thickness direction is

not less than 1.1 times nor more than 1.6 times the Mn concentration at the position of 1/6 in the flange width direction from the end face in the flange width direction and 1/4 in the flange thickness direction from the face of the flange positioned on the side opposite to that of the web.

**[0016]** [2] A manufacturing method of rolled H-shaped steel being a manufacturing method of manufacturing the rolled H-shaped steel described in [1] is characterized in that it includes heating a steel billet having a rectangular cross section to 1100 to 1350° C., and sequentially performing a rough rolling step, an intermediate rolling step, and a finish rolling step, in which: to a rolling mill which performs the rough rolling step, a plurality of calibers of three or more to shape a material to be rolled are provided; at least one of the plurality of calibers is a split-creating caliber provided to a pair of upper and lower rolls and formed with projections which create splits vertically with respect to a width direction of the material to be rolled; and in a subsequent stage of the split-creating caliber, a shaping caliber which sequentially bends divided parts formed by the split-creating caliber is provided.

**[0017]** [3] The manufacturing method of the rolled H-shaped steel described in [2] is characterized in that a tip angle of the projections formed in the split-creating caliber is 40° or less.

**[0018]** [4] The manufacturing method of the rolled H-shaped steel described in [2] or [3] is characterized in that a length H of the split created by the projection, a thickness T of the steel billet having the rectangular cross section, and a width F of a flange of the rolled H-shaped steel formed by the finish rolling step satisfy the following expression (1).

$$H \geq 0.5F - 0.5T \quad (1)$$

#### Effect of the Invention

**[0019]** According to the present invention, it becomes possible to obtain H-shaped steel excellent in toughness of fillet portions through simple steps without performing special heat treatment such as preliminary heating, and reheating, temperature retention, or the like after rolling. Therefore, it becomes possible to further improve reliability of a steel structure which uses rolled H-shaped steel as a member without impairing an economic efficiency, and as described above, the present invention contributes to the industry quite significantly.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0020]** FIGS. 1 are schematic explanatory diagrams regarding a comparison between an “edging method” and a “split method”.

**[0021]** FIG. 2 is a diagram illustrating a correlation between a segregation degree and a Charpy transition temperature difference  $\Delta VTrs$ .

**[0022]** FIG. 3 is a schematic explanatory diagram illustrating positions where a mechanical test and an observation of a metal structure are performed.

**[0023]** FIG. 4 is a schematic explanatory diagram illustrating manufacturing steps of H-shaped steel according to an embodiment of the present invention.

**[0024]** FIG. 5 is a schematic explanatory diagram illustrating rolls used for rough rolling and a shape of a material to be rolled.

#### BEST MODE FOR CARRYING OUT THE INVENTION

**[0025]** Hereinafter, an embodiment of the present invention will be described while referring to the drawings. Note that in the present specification and the drawings, components having substantially the same functional configurations are denoted by the same reference numerals to omit overlapped explanation.

**[0026]** The present inventors obtained a finding that, if splits are created when forming flange portions and the flange portions are bent to be manufactured, a segregation is dispersed in the whole of the flanges, resulting in that an aggregation of the segregation at fillet portions is improved. First, this finding will be briefly described.

**[0027]** Note that a manufacturing method of H-shaped steel according to the present embodiment in which flange portions are bent to perform rolling and shaping, is referred to as a “split method” in the present specification.

**[0028]** First, an outline of the aforementioned “split method” will be briefly described while referring to FIGS. 1. FIGS. 1 are schematic explanatory diagrams regarding a comparison between a so-called “edging method” being one of rough rolling methods in a conventional manufacturing method of H-shaped steel, and a so-called “split method” being a rough rolling method in the manufacturing method of the H-shaped steel according to the present embodiment.

**[0029]** As illustrated in FIG. 1(a), the edging method is a method in which grooves for guiding a slab to a caliber center are applied to end portions of the slab at a time of performing rough rolling when manufacturing H-shaped steel from the slab, and hot rolling is performed by using caliber rolls attached to a rough rolling mill. When the slab heated in a heating furnace is rolled in a width direction, and the end portions of the slab are elongated in a thickness direction of the slab, flange portions are formed. On the material to be rolled formed with the flange portions as described above, intermediate rolling with an intermediate rolling mill, finish rolling with a finish rolling mill, and the like are further performed to finely adjust a shape and a size of a product, to thereby manufacture a final H-shaped steel product.

**[0030]** On the other hand, as illustrated in FIG. 1(b), in the split method, grooves (splits) whose depth is deeper than that of the grooves in the aforementioned edging method are applied, with a split-creating caliber, to end faces of a slab at a time of performing rough rolling when manufacturing H-shaped steel from the slab. Subsequently, rolling and shaping are performed on the applied grooves so as to widen the end portions of the slab formed as divided parts, by using caliber rolls of a shaping caliber formed with projections to widen the grooves. A method of forming flange portions by performing such rolling and shaping in a widening manner a plurality of times while changing angles, for example, is the split method. On the material to be rolled formed with the flange portions as described above, intermediate rolling, finish rolling, and the like are further performed to manufacture a final H-shaped steel product.

**[0031]** When comparing the edging method with the split method illustrated in FIGS. 1, the present inventors focused attention on a central segregation portion being a part in which mainly an Mn concentration is high and which exists in a slab, and found out that there is a large difference in a state of aggregation or dispersion of the central segregation

portion of the slab between rough rolling performed by the edging method and rough rolling performed by the split method.

**[0032]** Specifically, as illustrated in FIG. 1(a), in the edging method, it is known that the central segregation portion is aggregated in fillet portions when a slab is rolled in a width direction by caliber rolls. On the other hand, as illustrated in FIG. 1(b), the split method employs a method such that a slab is not rolled in a width direction almost at all and flange portions are widened, so that rough rolling is performed in a state where the central segregation portion is dispersed in the whole of the flange portions and thus is not aggregated in fillet portions. It has become known that by setting a tip angle of projections of a split-creating caliber to an acute angle of 40° or less, in particular, it is possible to suppress the aggregation of the central segregation portion.

**[0033]** Further, the present inventors found out that, by using the split method, vTrs (Charpy transition temperature) becomes 0° C. or less at F/6 at which an average mechanical property of H-shaped steel is exhibited, and a difference between vTrs at F/6 and vTrs at a most embrittled portion at which the toughness becomes the worst due to the central segregation portion can be suppressed to within 40° C., as illustrated in FIG. 2. It can be inferred that this is because the embrittlement caused by MnS, island martensite (MA) being a hard phase, and upper bainite which exist in the central segregation portion in which mainly the Mn concentration is high, is suppressed.

**[0034]** Hereinbelow, rolled H-shaped steel according to the present embodiment and a manufacturing method thereof based on the findings as described above will be described in detail. Note that in the description hereinbelow, the description of “%” regarding a component means “mass %” unless otherwise specified.

**[0035]** First, a composition of components (a chemical composition) of H-shaped steel will be described.

**[0036]** (C: 0.01 to 0.25%)

**[0037]** C facilitates a generation of MA at a fillet portion to lower toughness. However, C can improve strength at a low price, and a complete removal of C leads to an increase in cost in terms of a steelmaking process, so that a C amount is set to 0.01% or more. On the other hand, if the C amount exceeds 0.25%, MA increases at a position of the fillet portion where a central segregation portion is aggregated to lower the toughness, so that the C amount is limited to 0.25% or less. The C amount is preferably set to 0.20% or less, and more preferably set to less than 0.17%.

**[0038]** (Si: 0.05 to 0.50% or less)

**[0039]** Si is a deoxidizing element and it also contributes to the improvement of the strength, but, it is an element which causes generation of MA, similarly to C. If an Si amount exceeds 0.50%, a hard phase is generated, which reduces the toughness of a base material and a weld heat-affected zone, so that the Si amount is limited to 0.50% or less. The Si amount is preferably 0.30% or less, more preferably set to 0.20% or less, and still more preferably set to 0.10% or less. However, if Si is not contained, a cost increases in terms of a deoxidizing process, so that Si is contained in an amount of 0.05% or more.

**[0040]** (Mn: 0.40 to 2.50%)

**[0041]** In H-shaped steel manufactured by the edging method, a central segregation portion of a slab is aggregated in fillet portions. Mn is likely to be aggregated in the central segregation portion in particular, and when a concentration

of Mn is locally increased, an increase in hardness is facilitated by a formation of MA being an embrittlement phase, an increase in upper bainite being a coarse structure, an increase in MnS, and an increase in hardenability. As a result of this, the toughness is lowered significantly. In particular, if Mn in an amount exceeding 2.50% is contained, the toughness of the base material and the weld heat-affected zone is impaired due to an increase in inclusions and the like in the fillet portions. For this reason, the Mn amount is limited to 2.50% or less. The Mn amount is preferably set to 2.00% or less, and more preferably set to 1.80% or less. On the other hand, Mn is an element effective for making a crystal grain diameter finer, so that Mn is contained in an amount of 0.40% or more.

**[0042]** (P: 0.050% or less)

**[0043]** P causes a weld crack and a reduction in the toughness due to a solidifying segregation, and thus an amount thereof should be reduced as much as possible. The P amount is preferably limited to 0.050% or less, and is more preferably 0.010% or less. Note that a lower limit of P may be 0.001% or more since a cost in the steelmaking process greatly increases if the P amount is lowered to less than 0.001%.

**[0044]** (S: 0.050% or less)

**[0045]** S forms MnS in a central segregation portion formed by the solidifying segregation, and it causes not only the weld crack and the reduction in the toughness but also a hydrogen crack and the like, and thus an amount thereof should be reduced as much as possible. The S amount is preferably limited to 0.050% or less, and is more preferably 0.010% or less. Note that a lower limit of S may be 0.001% or more since a cost in the steelmaking process greatly increases if the S amount is lowered to less than 0.001%.

**[0046]** In addition, it is also possible to make one or two or more of Cu, Ni, Cr, V, Mo, Nb, Ti, Al, and N to be contained as optional additive elements for the purpose of improving the strength and the toughness. Note that since the optional additive elements are not necessarily added, a lower limit value of a content of each optional additive element is 0%.

**[0047]** (Cu: 0.70% or less)

**[0048]** Cu is an element which contributes to the improvement of the strength. However, if a Cu amount exceeds 0.70%, the strength is excessively increased to lower the toughness, so that the Cu amount is limited to 0.70% or less. The Cu amount is preferably set to 0.50% or less, more preferably set to 0.30% or less, and still more preferably set to 0.10% or less. A lower limit of the Cu amount is preferably 0.01%.

**[0049]** (Ni: 0.70% or less)

**[0050]** Ni is an element which is quite effective for increasing the strength and the toughness. However, since Ni is an expensive element, in order to suppress an increase in an alloying cost, an Ni amount is limited to 0.70% or less, preferably set to 0.50% or less, more preferably set to 0.30% or less, and still more preferably set to 0.10% or less. The Ni amount is preferably 0.01% or more, and more preferably set to 0.02% or more.

**[0051]** (Cr: 0.50% or less)

**[0052]** Cr is also an element which contributes to the improvement of the strength. However, if Cr in an amount exceeding 0.50% is added, a carbide is generated, which may impair the toughness, so that the Cr amount is limited

to 0.50% or less, and preferably set to 0.30% or less. A lower limit of the Cr amount is preferably set to 0.01%.

**[0053]** (V: 0.12% or less)

**[0054]** V is an element which forms a nitride (VN), and it may be contained in an amount of 0.01% or more for increasing the strength of the base material. The V amount is preferably set to 0.02% or more, and more preferably set to 0.03% or more. On the other hand, since V is an expensive element, an upper limit of the V amount is limited to 0.12%, and preferably limited to 0.08%.

**[0055]** (Mo: 0.30% or less)

**[0056]** Mo is an element which increases the hardenability to contribute to the improvement of the strength. However, if Mo in an amount exceeding 0.30% is added, a precipitation of Mo carbide ( $\text{Mo}_2\text{C}$ ) or a generation of MA at the fillet portion is facilitated, and the toughness of the weld heat-affected zone in particular sometimes deteriorates, so that the Mo amount is limited to 0.30% or less, and preferably set to 0.15% or less. A lower limit of the Mo amount is preferably 0.01%.

**[0057]** (Nb: 0.08% or less)

**[0058]** Nb is an element which makes ferrite finer to improve the toughness.

**[0059]** However, if Nb in an amount exceeding 0.08% is added, a ferrite transformation is excessively suppressed to facilitate the generation of MA, so that the Nb amount is limited to 0.08% or less, preferably set to 0.05% or less, and more preferably set to 0.03% or less.

**[0060]** (Ti: 0.05% or less)

**[0061]** Ti is an element which forms TiN, and if a Ti amount exceeds 0.05%, TiN becomes coarse and becomes a starting point of a brittle fracture, so that the Ti amount is limited to 0.05% or less. The Ti amount is preferably set to 0.03% or less, and more preferably set to 0.02% or less. A lower limit of the Ti amount may be 0%, but, a fine TiN makes a contribution to make a structure finer, so that Ti in an amount of 0.005% or more may be contained.

**[0062]** (Al: 0.07% or less)

**[0063]** Al is a deoxidizing element, and if an Al amount exceeds 0.07%, the toughness of the base material and the weld heat-affected zone is lowered by inclusions, so that the Al amount is limited to 0.07% or less. The Al amount is preferably 0.05% or less, more preferably set to 0.04% or less, and still more preferably set to 0.03% or less. A lower limit of the Al amount is not defined, and may be 0%, but, since Al is a useful deoxidizing element, Al in an amount of 0.01% or more may be contained.

**[0064]** (N: 0.020% or less)

**[0065]** N is an element which lowers the toughness of the base material and the weld heat-affected zone. If an N amount exceeds 0.020%, low-temperature toughness is impaired by solid-solution N and a formation of coarse precipitates, so that the N amount is limited to 0.020% or less. The N amount is preferably set to 0.010% or less, and more preferably set to 0.007% or less. On the other hand, if the N amount is tried to be reduced to less than 0.002%, a cost in the steelmaking process is increased, so that the N amount may be 0.002% or more. From a viewpoint of cost, the N amount may be 0.003% or more.

**[0066]** Besides, one or two of REM and Ca may be contained as optional additive elements for the purpose of controlling a form of inclusions.

**[0067]** (REM: 0.010% or less, Ca: 0.0050% or less)

**[0068]** REM and Ca are deoxidizing elements, and they also contribute to control of a form of a sulfide, so that they

may be added. However, since oxides of REM and Ca are easily floated in molten steel, an amount of REM and an amount of Ca contained in the steel are limited to 0.010% or less and 0.0050% or less, respectively. A lower limit of each of the REM amount and the Ca amount is preferably set to 0.0005%.

**[0069]** Next, a metal structure and properties of the rolled H-shaped steel according to the present invention will be described. FIG. 3 is a schematic explanatory diagram illustrating positions where a mechanical test and an observation of a metal structure are performed. Hereinafter, explanation will be made on results obtained by performing verification on a metal structure and properties mainly at the positions illustrated in FIG. 3.

**[0070]** As illustrated in FIG. 3, a position of 1/6 in a flange width direction from an end face in the flange width direction in a flange and 1/4 in a flange thickness direction from a face of the flange positioned on a side opposite to that of a web (namely, a lateral surface), is in the middle of a flange end portion where a temperature is likely to lower when performing hot rolling and a flange center portion where the temperature is unlikely to lower. Further, there is no chance that the central segregation portion is observed at this part. Therefore, it can be considered that at the position, average chemical components and mechanical properties of H-shaped steel are exhibited based on a temperature distribution.

**[0071]** Note that in the present specification, the position is represented as "F/6-t/4" by using a flange width F and a flange thickness t.

**[0072]** The H-shaped steel according to the present embodiment suppresses a material variation in the flanges. For this reason, the observation of the metal structure and the measurement of the mechanical properties (strength and Charpy absorbed energy) of the H-shaped steel are performed by collecting a sample piece from each of a position of a most embrittled portion in the vicinity of F/2-3t/4 and a position of F/6-t/4 of the H-shaped steel illustrated in FIG. 3.

**[0073]** The position of the most embrittled portion is not fixed with respect to a horizontal direction of the drawing, namely, the flange width direction, depending on a situation when performing rough rolling of flanges. Accordingly, a part where the central segregation portion is aggregated is made to appear by a nital etchant, and then a part at which a straight line indicating a position of 3/4 in the flange thickness direction from a face of the flange positioned on a side opposite to that of a web (3t/4) and the part where the above-described central segregation portion is aggregated intersect is set as a position of the most embrittled portion. From the most embrittled portion whose position is specified, the sample piece is collected, and the observation of the metal structure and the measurement of the mechanical properties are carried out.

**[0074]** The metal structure of the rolled H-shaped steel of the present invention is evaluated by an optical microscope, a scanning electron microscope (SEM), and an electron probe micro analyzer (EPMA). By using the optical microscope, a visual field of 10 mm×10 mm in which the most embrittled portion illustrated in FIG. 3 is set as a center, is identified. In the identified visual field, an electrolytic polishing is performed, and then an Mn concentration at the set position of the most embrittled portion is measured under conditions of an acceleration voltage of 20 kV, a beam shape

of a band shape with a length of 20  $\mu\text{m}$ , and a step of 20  $\mu\text{m}$ . Among 500 points $\times$ 500 points in the visual field, an average value of 12500 points to be values of top 5% or more (this is referred to as a “top 5% average value”) is determined, and set as an Mn concentration (CMn-max) at the most embrittled portion.

**[0075]** Meanwhile, the sample is collected from the position of F/6-t/4, and a value of an Mn concentration determined by analyzing chemical components of the sample according to JIS G0404 (2014 edition), is set as an Mn concentration (CMn) at the position of F/6-t/4. Besides, a value (CMn-max)/(CMn) as a result of dividing (CMn-max) by (CMn), is evaluated as a segregation degree.

**[0076]** A target value of the strength of the rolled H-shaped steel according to the present invention is set based on the steel material standard EN10225 adopted in the European region. It is desirable that a yield point (YP) or 0.2% yield strength and a tensile strength (TS) measured at room temperature by using the sample piece collected from the position of F/6-t/4 are 325 MPa or more and 450 MPa or more, respectively. A target value of the toughness is set to  $\Delta vTrs$  40° C.

**[0077]** FIG. 2 is a diagram illustrating a correlation between a segregation degree and a Charpy transition temperature difference  $\Delta vTrs$  in H-shaped steel. The segregation degree in FIG. 2 indicates a concentration ratio of Mn between the most embrittled portion and the position of F/6-t/4 described above while referring to FIG. 3.

**[0078]** As illustrated in FIG. 2, in rolled H-shaped steel manufactured by a conventional edging method, the segregation degree exceeds 1.6, and the Charpy transition temperature difference  $\Delta vTrs$  between the most embrittled portion and the position of F/6-t/4 exceeds 40° C. In this state, since a large amount of Mn is segregated in the most embrittled portion, MnS, island martensite (MA) being a hard phase, upper bainite, and the like are formed, and it becomes impossible to suppress the embrittlement. On the other hand, in rolled H-shaped steel manufactured by the split method, the Charpy transition temperature difference  $\Delta vTrs$  between the most embrittled portion and the position of F/6-t/4 is 40° C. or less. Specifically, in the state where the segregation degree is 1.6 or less, the aggregation of the central segregation portion is suppressed, and it is possible to obtain rolled H-shaped steel with better uniformity in a cross section of flanges, when compared to a conventional product.

**[0079]** Note that when a seismic force or the like is applied to a steel structure building used under a general temperature condition, in order to satisfy predetermined mechanical properties without causing a brittle fracture of H-shaped steel being a member of the steel structure building, it is desirable that  $vTrs$  at the position of F/6-t/4 is 0° C. or less.

**[0080]** As described above, in the rolled H-shaped steel according to the present invention, the segregation degree illustrated in FIG. 2 is preferably 1.6 or less. It is more preferable that the segregation degree is 1.5 or less, since as the segregation degree is lowered, the aggregation of the central segregation portion is further suppressed and the embrittlement characteristic becomes better. Further, there is no chance that the segregation degree becomes less than 1.0 in terms of a characteristic of numeric value, and the segregation degree is preferably 1.0 or more or 1.1 or more, for example.

**[0081]** Next, a manufacturing method of the H-shaped steel according to the present embodiment will be described. In the present embodiment, a rectangular steel billet excellent in productivity is heated and hot rolling composed of a

rough rolling step, an intermediate rolling step, and a finish rolling step is performed through steps illustrated in FIG. 4, and accelerated cooling is performed by a water cooler, to thereby manufacture the H-shape steel. In the hot rolling, the rough rolling is performed by the split method illustrated in FIG. 1(b).

**[0082]** In a steelmaking step (an upstream side of a heating furnace in FIG. 4), chemical components of molten steel are adjusted, and then casting is performed, thereby obtaining a rectangular steel billet (which is also referred to as so-called “slab”). The casting is preferably continuous casting from a viewpoint of productivity. Further, a thickness of the steel billet is preferably set to 200 mm or more from a viewpoint of productivity, and is preferably 350 mm or less when taking a reduction in the segregation, homogeneity of a heating temperature in the hot rolling, and the like into consideration.

**[0083]** Next, the steel billet is heated by using the heating furnace, and the hot rolling is performed. Subsequently, the rough rolling based on the split method illustrated in FIG. 1(b) is performed by using a rough rolling mill. After that, the intermediate rolling is performed by using an intermediate universal rolling mill (an intermediate rolling mill) and water coolers. Subsequently, the finish rolling is performed by using a finish rolling mill, and the hot rolling is terminated. At this time, it is also possible to cool the H-shaped steel by water at a timing according to need. Hereinafter, conditions and the like in the respective steps will be described.

**[0084]** (Heating temperature of steel billet: 1100 to 1350° C.) The heating temperature of the steel billet is set to 1100 to 1350° C.

**[0085]** If the heating temperature is low, a deformation resistance becomes high, so that the heating temperature of the steel billet is set to 1100° C. or more for securing a shaping property in the hot rolling. On the other hand, if the heating temperature of the steel billet exceeds 1350° C., there is a chance that an oxide on a surface of the steel billet being a material is smelted to damage an inside of the heating furnace. In order to cause sufficient solid-solution of the element such as Nb which forms a precipitate, a lower limit of the heating temperature of the steel billet is preferably set to 1150° C. or more. In particular, when a sheet thickness of a product is small, a cumulative reduction ratio becomes large, so that the heating temperature of the steel billet is preferably set to 1200° C. or more. In order to make a structure finer, it is preferable to set an upper limit of the heating temperature of the steel billet to 1300° C. or less.

**[0086]** (Definition of split length H in rough rolling step)

**[0087]** In the rough rolling based on the split method, it is possible to set a split length H obtained by a caliber having a predetermined caliber tip angle (a tip angle of projection of an inner periphery of the caliber) in FIG. 5 so that a thickness T of the steel billet having the rectangular cross section and a flange width F of the rolled H-shaped steel formed by the finish rolling step satisfy the following expression (1) together with the split length H.

$$H \geq 0.5F - 0.5T \quad (1)$$

**[0088]** As indicated in the above expression (1), a lower limit of the split length H is set to satisfy 0.5F-0.5T or more with respect to the thickness T of the steel billet having the rectangular cross section and the flange width F of the rolled H-shaped steel formed by the finish rolling step. This is for

suppressing a reduction amount in a caliber with an obtuse angle by which the aggregation of the central segregation portion is likely to occur, by performing the rolling and shaping based on the split method until when the flange width after the rough rolling becomes about the same as a flange width of a product. Although an upper limit of the split length H is not particularly provided, it is desirably  $0.8F-0.5T$  or less, since if the split length H exceeds  $0.8F-0.5T$ , excessive edging rolling becomes required when performing the intermediate rolling, which deteriorates the productivity.

**[0089]** (Tip Angle of Projection in Caliber when Creating Split)

**[0090]** The caliber tip angle (the tip angle of the projection of the inner periphery of the caliber) illustrated in FIG. 1(b) and FIG. 5 is only required to be set to an angle which is acute enough to create a split, and an upper limit thereof may be set to  $40^\circ$ , for example. This is because if the caliber tip angle exceeds  $40^\circ$ , the central segregation portion of the slab is not dispersed in the flanges, and is aggregated in the fillet portions, similarly to the edging rolling illustrated in FIG. 1(a). By setting the caliber tip angle to  $40^\circ$  or less, the central segregation portion is dispersed without being aggregated in the flanges when performing the rolling with the split-creating caliber as illustrated in the split method in FIG. 1(b), and it becomes possible to suppress the reduction in the toughness at the fillet portions.

**[0091]** Although a lower limit of the caliber tip angle is not particularly provided, it is preferably  $25^\circ$  or more, since if the caliber tip angle is less than  $25^\circ$ , there is a possibility that rolls are broken when performing the rolling.

**[0092]** Note that at this time, it is possible that the central segregation portion of the slab is not divided into right and left flanges in an I-posture as illustrated in FIG. 1(b), but is dispersed in either the left flange or the right flange.

**[0093]** When rolled H-shaped steel having a flange width of 150 mm or more, for example, is manufactured by the split method illustrated in FIG. 1(b), a central segregation portion is dispersed in a flange portion, and remains in a region 15 mm or more apart from a vicinity of a center of the flange width toward one end face or both end faces in the flange width direction and within 2 mm from a flange surface layer in the thickness direction (in the flange thickness direction from a flange face positioned on a side opposite to that of a web), in the flange. When the rolled H-shaped steel is manufactured by the split method illustrated in FIG. 1(b), the central segregation portion dispersed in the flange portion remains in the region along the predetermined length. The central segregation portion dispersed in the vicinity of the surface layer can be made to appear by the identification using the nital etchant described above.

**[0094]** A top 5% average concentration of Mn in the central segregation portion dispersed in the vicinity of the surface layer is set to (CMn-surface), and a segregation degree at this position (CMn-surface)/(CMn) is desirably not less than 1.1 nor more than 1.6. In the split method, the segregation degree at the flange surface layer tends to be higher when compared to the edging method. If the segregation degree is 1.1 or more, there is a merit such that a crack on the surface can be visually checked, and it becomes easy to perform the inspection, and further, it also becomes possible to trace a plurality of products to be manufactured as respective individuals, based on the crack on the surface. On the other hand, if the segregation degree exceeds 1.6, a

large number of cracks are likely to occur on the flange surface, so that the segregation degree is desirably not less than 1.1 nor more than 1.6. Note that the way of determining the top 5% average concentration regarding

**[0095]** (CMn-surface) is according to the way of determining the top 5% average concentration regarding (CMn-max) described above. Specifically, the ways of determining the numeric values are basically the same in which only the positions of collecting the samples are different.

**[0096]** (Intermediate Rolling Step)

**[0097]** In the intermediate rolling step in the hot rolling, it is possible to perform controlled rolling by using an intermediate universal rolling mill. The controlled rolling is a manufacturing method of controlling a rolling temperature and a reduction ratio. In the intermediate rolling in the hot rolling, it is preferable to perform interpass water-cooled rolling of one pass or more. In the interpass water-cooled rolling, the water cooling is performed between rolling passes, to thereby perform rolling while providing a temperature difference between a surface layer portion and an inner portion of the flange. The interpass water-cooled rolling is a manufacturing method in which, for example, a flange surface temperature is lowered to  $700^\circ\text{C}$ . or less through the water cooling performed between the rolling passes, and then rolling is performed in a recuperation process.

**[0098]** When the interpass water-cooled rolling is performed, it is preferable to perform water cooling between the rolling passes by using water coolers provided in front of and behind the intermediate universal rolling mill, and it is preferable that spray cooling of flange lateral surfaces with the use of the water cooler, and reverse rolling are repeatedly conducted. In the interpass water-cooled rolling, even if a reduction ratio is small, it is possible to introduce a working strain into an inside of the sheet in the thickness direction. Further, by reducing the rolling temperature in a short period of time by the water cooling, the productivity is also improved.

**[0099]** Note that after the termination of the hot rolling as the intermediate rolling step and the finish rolling step, it is possible to directly perform accelerated cooling on inner surfaces and outer surfaces of the flanges by using the water cooler provided on an outlet side of the finish rolling mill. This makes it possible to uniformize a cooling rate at the inner and outer surfaces of the flanges, and improve a material and an accuracy of form. By the cooling water jetted to the inner surfaces of the flanges, an upper surface side of the web after the rough rolling step is cooled. In order to suppress warpage of the web, it is also possible to perform cooling from a lower surface of the web.

**[0100]** In the rolled H-shaped steel manufactured by the manufacturing method of the H-shaped steel according to the present embodiment described above, it is possible to complete the rolling and shaping by dispersing the central segregation portion which exists in the slab before being subjected to the rolling and shaping, without making the central segregation portion aggregate in the fillet portions. Concretely, the rolled H-shaped steel is manufactured in which  $\Delta T_{rs}$  is  $40^\circ\text{C}$ . or less in the flanges after performing the rolling and shaping, and the segregation degree thereof becomes 1.6 or less (refer to FIG. 2).

**[0101]** In such rolled H-shaped steel, it is possible to avoid exertion of an adverse effect on the toughness and the embrittlement characteristic which is caused by the aggre-

gation of the central segregation portion in the fillet portions of the flanges. Specifically, it is possible to realize the manufacture of the H-shaped steel product excellent in the toughness and the embrittlement characteristic. Further, the central segregation portion dispersed in the flange remains in the region 15 mm or more apart from the center of the flange width toward one end face or both end faces in the flange width direction and within 2 mm in the flange thickness direction from the face positioned on the side opposite to that of the web, in the flange, but, the central segregation portion is not aggregated, so that it can be estimated that there is no influence almost at all with respect to the toughness and the embrittlement characteristic. Besides, although various examinations, experiments, and so on have been conventionally required to examine the state of the inside of the flange, in the H-shaped steel product according to the present embodiment, it is possible to visually check the flange face positioned on the side opposite to that of the web.

**[0102]** One example of the embodiment of the present invention has been explained above, but, the present invention is not limited to the illustrated embodiment. It should be understood that various changes and modifications can be adopted within the scope of the spirit as set forth in claims, and those should also be covered by the technical scope of the present invention.

#### EXAMPLES

**[0103]** As examples of the present invention, samples were collected from rolled H-shaped steels each manufac-

tured by satisfying the chemical composition and the manufacturing condition described in the above-described embodiment, and the samples were subjected to a chemical analysis. Meanwhile, as comparative examples, samples were collected from rolled H-shaped steels each of which did not satisfy either the chemical composition or the manufacturing condition described in the above-described embodiment, and the samples were subjected to a similar chemical analysis. Hereinafter, detailed comparison between the examples and the comparative examples will be described.

#### EXAMPLES

**[0104]** First, as Nos. 1 to 13, and 28 of examples, steels having chemical compositions (unit: mass %) shown in Table 1 were smelted, and steel billets each having a thickness of 250 to 300 mm were manufactured through continuous casting. The steels were smelted in a converter, subjected to primary deoxidation, components were adjusted by adding an alloy thereto, and according to need, vacuum degassing treatment was conducted. Further, the obtained steel billets were subjected to hot rolling under manufacturing conditions shown in Table 2. In the hot rolling, rough rolling was performed, and subsequently, by using an intermediate universal rolling mill and water coolers provided in front of and behind the intermediate universal rolling mill, spray cooling of flange lateral surfaces, reverse rolling, and water cooling after the rolling were conducted according to need.

TABLE 1

EXAMPLE No.	C	Si	Mn	P	S	Cu	Ni	Cr	V	Mo	Nb	Ti	Al	REM	Ca	N
1	0.01	0.34	0.60	0.045	0.009	0.01	0.00	0.00	0.00	0.000	0.00	0.01	0.02	0.000	0.0000	0.0043
2	0.23	0.44	0.66	0.015	0.026	0.01	0.02	0.01	0.00	0.000	0.00	0.01	0.05	0.000	0.0000	0.0030
3	0.14	0.06	2.09	0.047	0.030	0.02	0.02	0.00	0.00	0.000	0.00	0.02	0.05	0.000	0.0000	0.0033
4	0.14	0.48	1.49	0.023	0.019	0.00	0.01	0.01	0.00	0.000	0.00	0.01	0.03	0.000	0.0000	0.0051
5	0.14	0.09	0.46	0.006	0.030	0.02	0.01	0.01	0.00	0.000	0.00	0.02	0.03	0.000	0.0000	0.0026
6	0.18	0.49	2.46	0.028	0.038	0.00	0.02	0.01	0.07	0.000	0.00	0.01	0.04	0.000	0.0020	0.0037
7	0.20	0.40	1.24	0.042	0.049	0.02	0.01	0.01	0.00	0.000	0.00	0.03	0.01	0.000	0.0000	0.0028
8	0.07	0.09	1.74	0.023	0.043	0.00	0.00	0.00	0.00	0.120	0.00	0.01	0.03	0.000	0.0000	0.0019
9	0.07	0.11	2.24	0.019	0.020	0.01	0.02	0.00	0.00	0.000	0.03	0.02	0.03	0.000	0.0020	0.0034
10	0.15	0.40	1.90	0.006	0.024	0.01	0.01	0.01	0.00	0.000	0.00	0.01	0.02	0.000	0.0000	0.0055
11	0.14	0.06	2.15	0.049	0.040	0.02	0.00	0.01	0.00	0.000	0.00	0.04	0.04	0.000	0.0000	0.0064
12	0.16	0.30	2.20	0.036	0.044	0.00	0.01	0.00	0.02	0.000	0.00	0.00	0.00	0.000	0.0020	0.0091
13	0.15	0.40	2.31	0.044	0.014	0.00	0.01	0.01	0.01	0.000	0.00	0.02	0.04	0.000	0.0020	0.0151
28	0.21	0.12	1.80	0.011	0.005	0.01	0.01	0.01	0.00	0.000	0.00	0.02	0.04	0.007	0.0000	0.0051

TABLE 2

EXAMPLE No.	HEATING TEMPERATURE (° C.)	CALIBER TIP ANGLE (°)	SPLIT LENGTH (mm)	SLAB THICKNESS (mm)	FLANGE WIDTH OF PRODUCT (mm)	0.5F-0.5T
1	1350	40	150	250	500	125
2	1350	40	100	250	400	75
3	1300	30	280	250	700	225
4	1300	30	100	300	400	50
5	1250	40	200	300	500	100
6	1250	40	200	300	600	150
7	1200	40	300	300	700	200
8	1200	40	120	300	500	100

TABLE 2-continued

EXAMPLE No.	HEATING TEMPERATURE (° C.)	CALIBER TIP ANGLE (°)	SPLIT LENGTH (mm)	SLAB THICKNESS (mm)	FLANGE WIDTH OF PRODUCT (mm)	0.5F-0.5T
9	1100	25	160	300	600	150
10	1100	25	210	300	700	200
11	1100	40	170	300	600	150
12	1200	40	250	250	500	125
13	1200	40	300	250	600	175
28	1250	40	200	250	500	125

**[0105]** Further, from respective positions of the most embrittled portion and F/6-t/4 (refer to FIG. 3), test pieces in which a rolling direction was set to a longitudinal direction were collected to measure the mechanical properties. As the mechanical properties, the yield point (YP), the tensile strength (TS), and  $vTrs$  were measured. A tensile test was conducted based on JIS Z 2241 (2011 edition), and a Charpy impact test was conducted based on JIS Z 2242 (2005 edition). Further, samples were collected from the respective positions of the most embrittled portion and F/6-t/4, and regarding a region within a square of 10 mm (in a longitudinal direction)×10 mm (in a flange thickness direction) where the central segregation portion was aggregated, (CMn-max) was measured and calculated through the EPMA, and (CMn) was measured and calculated through the method described in JIS G0404 (2014 edition).

**[0106]** Further, the central segregation remained within 2 mm from a surface layer 15 mm or more apart from a center of the flange width toward at least one end face in the flange width direction, and as the Mn concentration of the surface layer portion, (CMn-surface) was measured and calculated through the EPMA regarding a region including no central segregation parallel to the flange thickness direction and positioned at 10 mm below the flange surface layer in the thickness direction (refer to FIG. 3).

**[0107]** The measurement and calculation results are shown in Table 3 below.

**[0108]** Note that regarding target values of the respective properties of the H-shaped steel which should be manufactured, the yield point (YP) or the 0.2% yield strength at room temperature is 335 MPa or more, the tensile strength (TS) at room temperature is 450 MPa or more, and  $\Delta vTrs$  is 40° C. or less.

**[0109]** As shown in Table 3, in each of Nos. 1 to 13, and 28 of the examples, the strength at room temperature is within the target range, and  $\Delta vTrs$  satisfies the target value of 40° C. or less. Further, in each of the examples, the segregation degree of Mn was 1.6 or less. The segregation degree of Mn is desirably 1.5 or less, and more desirably 1.4 or less.

#### COMPARATIVE EXAMPLES

**[0110]** As Nos. 14 to 27 of comparative examples, steels having chemical compositions shown in Table 4 were smelted, and steel billets each having a thickness of 250 to 300 mm were manufactured through a method similar to that of the above-described examples. Subsequently, the obtained steel billets were subjected to hot rolling under manufacturing conditions shown in Table 5.

**[0111]** Note that in the following Table 4 and Table 5, an underlined portion indicates that the chemical composition and the manufacturing condition according to the present invention described in the above-described embodiment are not satisfied.

TABLE 3

EXAMPLE No.	F/6-t/4			MOST EMBRITTLED PORTION				SURFACE LAYER PORTION		
	YP(YS) (MPa)	TS (MPa)	$vTrs$ (° C.)	$C_{Mn}$ (mass %)	$vTrs$ (° C.)	$C_{Mn-max}$ (mass %)	SEGREGATION DEGREE	$\Delta vTrs$ (° C.)	$C_{Mn-surface}$ (mass %)	SEGREGATION DEGREE
1	422	688	-8	0.59	27	0.88	1.49	35	0.68	1.16
2	351	452	-17	0.66	8	0.81	1.22	25	0.74	1.12
3	468	588	-18	2.08	6	2.34	1.12	24	2.34	1.12
4	363	555	-6	1.49	19	1.70	1.14	25	1.68	1.13
5	435	691	-19	0.44	11	0.61	1.38	30	0.49	1.10
6	460	664	0	2.44	30	3.21	1.32	30	3.06	1.26
7	346	591	-5	1.22	18	1.36	1.12	23	1.34	1.10
8	393	586	-11	1.72	21	2.55	1.48	32	1.99	1.15
9	448	599	-19	2.26	17	3.02	1.34	36	2.80	1.24
10	404	610	-17	1.91	19	2.91	1.53	36	2.70	1.41
11	496	543	-8	2.16	16	2.70	1.25	24	2.68	1.24
12	421	574	-7	2.21	26	3.10	1.40	33	2.69	1.22
13	441	591	-12	2.29	19	3.01	1.31	31	2.91	1.27
28	410	551	-8	1.81	24	2.61	1.44	32	2.51	1.39

TABLE 4

COMPARATIVE EXAMPLE No.	C	Si	Mn	P	S	Cu	Ni	Cr	V	Mo	Nb	Ti	Al	REM	Ca	N
14	<u>0.00</u>	0.26	1.24	0.005	0.050	0.02	0.02	0.00	0.00	0.000	0.00	0.02	0.04	0.000	0.0000	0.0032
15	<u>0.26</u>	0.30	1.18	0.005	0.020	0.00	0.01	0.00	0.00	0.000	0.00	0.01	0.03	0.000	0.0000	0.0046
16	0.14	0.03	1.75	0.003	0.034	0.02	0.02	0.01	0.00	0.000	0.00	0.01	0.04	0.000	0.0000	0.0031
17	0.18	<u>0.52</u>	0.52	0.005	0.014	0.01	0.00	0.00	0.00	0.000	0.00	0.02	0.04	0.000	0.0000	0.0018
18	0.04	0.49	<u>0.31</u>	0.016	0.040	0.01	0.01	0.01	0.00	0.000	0.00	0.01	0.04	0.000	0.0000	0.0040
19	0.16	0.07	<u>2.59</u>	0.035	0.046	0.00	0.00	0.01	0.00	0.000	0.00	0.01	0.03	0.000	0.0000	0.0054
20	0.13	0.33	1.15	<u>0.057</u>	0.006	0.01	0.02	0.01	0.00	0.000	0.00	0.01	0.04	0.000	0.0000	0.0061
21	0.08	0.19	2.01	<u>0.049</u>	<u>0.059</u>	0.00	0.01	0.00	0.00	0.000	0.00	0.01	0.03	0.000	0.0000	0.0032
22	0.21	0.49	1.35	0.020	0.020	0.01	0.01	0.01	0.00	0.000	0.00	0.01	0.01	0.000	0.0000	0.0048
23	0.04	0.39	1.58	0.035	0.012	0.00	0.01	0.02	0.00	0.000	0.00	0.03	0.01	0.000	0.0000	0.0037
24	0.14	0.07	0.96	0.022	0.015	0.02	0.02	0.01	0.00	0.000	0.00	0.01	0.01	0.000	0.0000	0.0029
25	0.17	0.25	2.06	0.004	0.050	0.00	0.02	0.00	0.00	0.000	<u>0.10</u>	0.01	0.05	0.000	0.0000	0.0046
26	0.16	0.17	1.20	0.034	0.027	0.01	0.02	0.01	0.00	<u>0.410</u>	0.00	0.01	0.05	0.000	0.0000	0.0050
27	0.23	0.33	1.46	0.022	0.027	0.01	0.01	0.01	0.00	0.000	0.00	0.01	0.02	<u>0.020</u>	0.0000	0.0065

TABLE 5

COMPARATIVE EXAMPLE No.	HEATING TEMPERATURE (° C.)	CALIBER TIP ANGLE (°)	SPLIT LENGTH (mm)	SLAB THICKNESS (mm)	FLANGE WIDTH OF PRODUCT (mm)	0.5F-0.5T
14	1350	40	100	300	400	50
15	1350	40	100	250	300	25
16	1300	40	100	300	400	50
17	1300	25	250	300	700	200
18	1300	40	250	300	700	200
19	1300	40	200	250	600	175
20	1250	30	200	250	600	175
21	1250	30	200	250	600	175
22	1200	<u>45</u>	200	250	500	125
23	1100	40	<u>120</u>	250	500	125
24	1300	40	<u>140</u>	300	600	150
25	1300	40	170	300	600	150
26	1300	40	250	300	700	200
27	1300	40	250	300	700	200

[0112] Further, from the most embrittled portion and the position of F/6-t/4 (refer to FIG. 3), test pieces in which a rolling direction was set to a longitudinal direction were collected to measure the mechanical properties, similarly to the above-described examples. As the mechanical properties, the yield point (YP), the tensile strength (TS), and vTrs were measured. Further, samples were collected from the respective positions of the most embrittled portion, the surface layer portion, and F/6-t/4, and (CMn-max) and

(CMn-surface) were measured and calculated through the EPMA, and (CMn) was measured and calculated through the method described in JIS G0404 (2014 edition), similarly to the above-described examples.

[0113] The measurement and calculation results are shown in Table 6 below. Note that in Table 6 below, an underlined portion indicates a value which is out of the target value of each property of the H-shaped steel which should be manufactured.

TABLE 6

COMPARATIVE EXAMPLE No.	F/6-t/4			MOST EMBRITTLLED PORTION			SURFACE LAYER PORTION			
	YP(YS) (MPa)	TS (MPa)	vTrs (° C.)	C <sub>Mn</sub> (mass %)	vTrs (° C.)	C <sub>Mn-max</sub> (mass %)	SEGREGATION DEGREE	ΔvTrs (° C.)	C <sub>Mn-surface</sub> (mass %)	SEGREGATION DEGREE
14	<u>299</u>	414	-18	1.24	8	1.92	1.55	26	1.91	1.55
15	406	519	<u>16</u>	1.18	<u>56</u>	1.78	1.50	<u>40</u>	1.57	1.33
16	<u>312</u>	<u>425</u>	-19	1.74	14	2.73	1.57	33	2.36	1.36
17	365	520	<u>11</u>	0.50	<u>56</u>	0.79	1.57	<u>45</u>	0.58	1.16
18	337	<u>410</u>	-11	0.32	21	0.47	1.45	32	0.42	1.32
19	420	508	<u>12</u>	2.61	<u>67</u>	<u>4.29</u>	<u>1.64</u>	<u>55</u>	3.68	1.41
20	434	562	<u>14</u>	1.14	<u>61</u>	1.50	1.31	<u>47</u>	1.31	1.15
21	395	480	<u>11</u>	2.01	<u>53</u>	3.05	1.51	<u>42</u>	2.50	1.24
22	408	471	-12	1.36	<u>37</u>	<u>2.21</u>	<u>1.63</u>	<u>49</u>	1.94	1.43
23	389	653	-2	1.56	<u>42</u>	<u>2.67</u>	<u>1.71</u>	<u>44</u>	2.52	1.61
24	472	548	-16	0.96	<u>32</u>	<u>1.67</u>	<u>1.73</u>	<u>48</u>	1.49	1.55
25	464	672	-9	2.06	<u>37</u>	2.64	1.28	<u>46</u>	2.41	1.17

TABLE 6-continued

COMPARATIVE EXAMPLE No.	YP(YS) (MPa)	TS (MPa)	F/6-t/4				MOST EMBRITTLED PORTION			SURFACE LAYER PORTION	
			vTrs (° C.)	C <sub>Mn</sub> (mass %)	vTrs (° C.)	C <sub>Mn-max</sub> (mass %)	SEGREGATION DEGREE	∠vTrs (° C.)	C <sub>Mn-surface</sub> (mass %)	SEGREGATION DEGREE	
26	496	663	-15	1.19	<u>28</u>	1.89	1.59	<u>43</u>	1.31	1.10	
27	346	511	-1	1.48	<u>48</u>	1.95	1.32	<u>49</u>	1.80	1.22	

[0114] As shown in Table 6, in Nos. 14, 16, and 18, the amounts of C, Mn, and Si are small, and thus the strength is insufficient. In No. 15 in which the C amount is large, and in No. 17 in which the Si amount is large, vTrs at F/6-t/4 is 0° C. or more due to the increase and coarsening of the hard phase, and the toughness is reduced also at the most embrittled portion. In No. 19 in which the Mn amount is large, vTrs at F/6-t/4 is 0° C. or more, the central segregation degree deteriorates at the most embrittled portion, and the toughness deteriorates due to MnS and MA. In No. 20 in which the P amount is large, and in No. 21 in which the S amount is large, the toughness is lowered. In No. 22, the caliber tip angle in the rough rolling exceeds 40°, and the central segregation portion of the slab is aggregated without being dispersed, resulting in that the toughness of the most embrittled portion is lowered. In Nos. 23 and 24, since the split length is insufficient, the central segregation portion of the slab is aggregated without being dispersed, resulting in that the toughness of the most embrittled portion is lowered. In No. 25 in which the Nb amount is large, in No. 26 in which the Mo amount is large, and in No. 27 in which the REM amount is large, the toughness of the most embrittled portion is lowered.

INDUSTRIAL APPLICABILITY

[0115] The present invention is applicable to rolled H-shaped steel manufactured by performing hot rolling on a steel billet, and a manufacturing method thereof.

1-4. (canceled)

5. Rolled H-shaped steel, comprising a chemical composition composed of:

- in mass %,
  - C: 0.01 to 0.25%;
  - Si: 0.05% to 0.50%;
  - Mn: 0.40 to 2.50%;
  - P: 0.050% or less;
  - S: 0.050% or less;
  - N: 0.020% or less;
  - Cu: 0.70% or less;
  - Ni: 0.70% or less;
  - Cr: 0.50% or less;
  - V: 0.12% or less;
  - Mo: 0.30% or less;
  - Nb: 0.08% or less;
  - Ti: 0.05% or less;
  - Al: 0.07% or less;
  - REM: 0.010% or less;
  - Ca: 0.0050% or less; and

the balance: Fe and inevitable impurities, wherein:

a top 5% average value of Mn concentrations in a most embrittled portion in a flange is 1.6 times or less an Mn concentration at a position of 1/6 in a flange width direction from an end face in the flange width direction

and 1/4 in a flange thickness direction from a face of a flange positioned on a side opposite to that of a web; and

a top 5% average value of Mn concentrations in a central segregation portion dispersed in a region along 15 mm or more from a center of the flange width toward one end face or both end faces in the flange width direction and within 2 mm from a flange surface layer in the thickness direction is not less than 1.1 times nor more than 1.6 times the Mn concentration at the position of 1/6 in the flange width direction from the end face in the flange width direction and 1/4 in the flange thickness direction from the face of the flange positioned on the side opposite to that of the web.

6. A manufacturing method of rolled H-shaped steel being a manufacturing method of manufacturing the rolled H-shaped steel according to claim 5, comprising heating a steel billet having a rectangular cross section to 1100 to 1350° C., and sequentially performing a rough rolling step, an intermediate rolling step, and a finish rolling step, wherein:

to a rolling mill which performs the rough rolling step, a plurality of calibers of three or more to shape a material to be rolled are provided;

at least one of the plurality of calibers is a split-creating caliber provided to a pair of upper and lower rolls and formed with projections which create splits vertically with respect to a width direction of the material to be rolled; and

in a subsequent stage of the split-creating caliber, a shaping caliber which sequentially bends divided parts formed by the split-creating caliber is provided.

7. The manufacturing method of the rolled H-shaped steel according to claim 6, wherein

a tip angle of the projections formed in the split-creating caliber is 40° or less.

8. The manufacturing method of the rolled H-shaped steel according to claim 6, wherein a length H of the split created by the projection, a thickness T of the steel billet having the rectangular cross section, and a width F of a flange of the rolled H-shaped steel formed by the finish rolling step satisfy the following expression (1),

$$H \geq 0.5F - 0.5T \tag{1}$$

9. The manufacturing method of the rolled H-shaped steel according to claim 7, wherein

a length H of the split created by the projection, a thickness T of the steel billet having the rectangular cross section, and a width F of a flange of the rolled H-shaped steel formed by the finish rolling step satisfy the following expression (1),

$$H \geq 0.5F - 0.5T \tag{1}$$

\* \* \* \* \*