

## H-SHAPED STEEL AND METHOD FOR PRODUCING SAME

### TECHNICAL FIELD

**[0001]** This disclosure relates to H-shaped steel widely used as materials of welded steel structures such as marine structures, construction, civil engineering, and bridges, in particular, high-strength H-shaped steel excellent in low-temperature toughness at -40 °C which is used for marine structures in cold climate areas, and a method for producing the same.

### BACKGROUND

**[0002]** Marine structures with which crude oil, natural gas or the like is mined are often operated in cold climate areas and thus H-shaped steel used in the marine structures is required to have excellent low-temperature toughness in its base metal and welded joints. To obtain both high strength and low-temperature toughness, TMCP in which controlled rolling and accelerated cooling are combined, which is widely used for steel plates, is a useful technique for H-shaped steel. However, in producing H-shaped steel, considering formability, heating of a material at high temperature and rolling at high temperature at which deformation resistance is low are necessary and thus the microstructure tends to be coarsened. Further, to refine the microstructure, controlled rolling in an austenite low-temperature range is important but rolling at low temperature has a problem in terms of increased rolling loads and shape stability.

**[0003]** As H-shaped steel having excellent toughness, JP2006-180584A (PTL 1) describes a technique related to a method for producing rolled H-shaped steel in which precipitation embrittlement elements are not added, the amount of solute N is decreased, and accelerated cooling is performed after rolling to thereby ensure the toughness at -40 °C without performing controlled rolling.

Further, WO2013/089156A (PTL 2) proposes a technique in which compositions having ultra low carbon added with Nb and B are used for H-shaped steel excellent in low-temperature toughness used in marine structures and the like. Moreover, JP2016-084524A (PTL 3) and JP2016-156032A (PTL 4) describe a technique of achieving excellent low-temperature toughness at -40 °C by performing air cooling, not adding Nb

which impairs productivity.

#### CITATION LIST

##### Patent Literatures

- [0004]** PTL 1: JP2006-180584A  
PTL 2: WO2013/089156A  
PTL 3: JP2016-084524A  
PTL 4: JP2016-156032A

#### SUMMARY

(Technical Problem)

**[0005]** The technique described in PTL 1 is problematic in terms of achieving both control of material properties and shape stabilization because accelerated cooling is required for the production method.

**[0006]** Further, PTL 2 describes a technique related to H-shaped steel excellent in low-temperature toughness obtained by using compositions added with Nb and B with the C content being 0.040 % or less to achieve Charpy absorbed energy at -40 °C and CTOD properties at -10 °C. However, to substantially reduce C to about 0.020 %, refining time in a steelmaking stage is increased and a relatively large amount of an alloying element needs to be added in order to ensure strength, which increases costs.

**[0007]** On the other hand, PTL 3 and PTL 4 describe a technique in which Nb, which would increase deformation resistance during hot rolling and impair productivity, is not added and the amount of V and N is properly controlled to thereby improve low-temperature toughness at -40 °C and -60 °C. However, since the N content needs to be 0.004 % or more in order to more stably ensure toughness by controlling VN precipitates, there are concerns about cracking during continuous casting and toughness reduction due to the remaining free N.

**[0008]** It could thus be helpful to propose a method for ensuring high strength of YP 355 MPa or more and low-temperature toughness at -40 °C in a flange portion of H-shaped steel without increasing production costs.

(Solution to Problem)

**[0009]** To produce rolled H-shaped steel having high strength and excellent

low-temperature toughness, it is important to apply controlled rolling to hot rolling. In particular, in order to effectively perform controlled rolling in an austenite non-recrystallization temperature range, it is effective to obtain a higher austenite non-recrystallization temperature range through the addition of Nb. To exert the effect of controlled rolling when Nb is not added, rolling in an austenite low temperature range is necessary, and thus rolling loads are increased, rolling time is increased due to temperature control, and dimensional accuracy of H-shaped steel is impaired. Therefore, since Nb is an element which increases deformation resistance but exerts the effect of controlled rolling in a high-temperature range, Nb is a significantly useful element from the viewpoint of material property control. On the other hand, when Nb is added, quench hardenability is increased in a cooling process after hot rolling and untransformed austenite partially transforms to martensite austenite constituent, causing the problem of a deterioration in low-temperature toughness.

**[0010]** Then, the inventors extensively studied methods for ensuring a strength of YP 355 MPa or more and low-temperature toughness at -40 °C in, in particular, a flange portion of H-shaped steel by making full use of the effect of controlled rolling through the addition of a trace amount of Nb. As a result, the inventors found that high strength and low-temperature toughness can be achieved by making full use of the effect of controlled rolling achieved by obtaining a higher austenite non-recrystallization temperature range through the addition of Nb to refine the ferrite grain size by controlled rolling at relatively high temperature, and decreasing the production amount of martensite austenite constituent by optimizing rolling conditions. This disclosure is based on the findings. The primary features of this disclosure are described below.

**[0011]** [1] H-shaped steel comprising: a chemical composition containing (consisting of), in mass%,

C: 0.08 % to 0.16 %,  
Si: 0.05 % to 0.60 %,  
Mn: 0.10 % to 1.80 %,  
Nb: 0.005 % to 0.060 %,  
Ti: 0.0010 % to 0.0200 %,

Al: 0.080 % or less,  
N: 0.0010 % to 0.0060 %,  
P: 0.030 % or less, and

S: 0.030 % or less in a range in which  $C_{eq}$  according to the following formula (1) is 0.44 % or less:

$$C_{eq} = C + Mn / 6 + (Cu + Ni) / 15 + (Cr + Mo + V) / 5 \quad (1),$$

where each element symbol indicates a content of the element and any element not contained is taken as zero, with the balance being Fe and inevitable impurities; and

a microstructure containing ferrite having an average grain size of 15  $\mu m$  or less as a main phase, wherein

the microstructure contains pearlite and/or bainite as a secondary phase and martensite austenite constituent in an amount of 3.0 % or less.

**[0012]** [2] The H-shaped steel according to [1], wherein the chemical composition further contains, in mass%, at least one selected from the group consisting of:

V: 0.050 % or less;  
Cu: 1.0 % or less;  
Ni: 1.0 % or less;  
Cr: 1.0 % or less; and  
Mo: 1.0 % or less.

**[0013]** [3] A method for producing H-shaped steel comprising heating a steel material having the chemical composition according to [1] or [2] at 1150 °C or higher and lower than 1300 °C, and subsequently hot rolling the steel material with a cumulative rolling reduction of 20 % or more when at least a portion corresponding to a flange of the H-shaped steel has a surface temperature of TR °C or lower, the TR calculated by the following formula (2):

$$TR = 174 \log [Nb \times (C + 12 / 14 N)] + 1344 \quad (2).$$

(Advantageous Effect)

**[0014]** According to this disclosure, it is possible to obtain a higher austenite non-recrystallization temperature range through the addition of the suitable amount of Nb and maximize the effect of controlled rolling. As a result, H-shaped steel having a strength of YP 355 MPa or more in its flange portion and excellent low-temperature toughness such that the flange portion has a

Charpy absorbed energy at -40 °C of 50 J or more in terms of toughness can be provided without requiring accelerated cooling after hot rolling, in other words, even with only air cooling after hot rolling.

#### DETAILED DESCRIPTION

**[0015]** The following describes the H-shaped steel of this disclosure in detail. The reasons for limiting the chemical composition of the H-shaped steel of this disclosure are described first. In the following description, “%” regarding compositions denotes “mass%” unless otherwise noted.

**[0016]** C: 0.08 % to 0.16 %

C is an element necessary for improving the strength of steel. To ensure the strength without performing accelerated cooling after hot rolling, the lower limit of the C content is set to 0.08 %. The C content is preferably 0.10 % or more. On the other hand, when the C content is excessively high, the amount of the secondary phase such as pearlite and bainite generated increases, lowering the toughness of the base metal and welding portion, and thus, the upper limit of the C content is set to 0.16 %. The C content is preferably 0.08 % to 0.14 %.

**[0017]** Si: 0.05 % to 0.60 %

Si is effective as a deoxidation element and solid-solution-strengthening element. To obtain the effect, the Si content needs to be at least 0.05 %. On the other hand, a Si content beyond 0.60 % deteriorates the toughness of the base metal and welded portion, and thus, the Si content is set to 0.05 % to 0.60 % and preferably 0.05 % to 0.50 %.

**[0018]** Mn: 0.10 % to 1.80 %

The Mn content needs to be 0.10 % or more to ensure the strength of the base metal. On the other hand, Mn increases cold crack sensitivity if added beyond 1.80 %. Thus, the Mn content is limited to a range of 0.10 % to 1.80 %. From the viewpoint of the toughness of the welded portion, the upper limit of the Mn content is desirably 1.60 %. The Mn content is preferably set to 0.30 % to 1.60 %.

**[0019]** P: 0.030 % or less

A P content exceeding 0.030 % deteriorates the toughness of the welded portion. Thus, the P content is limited to 0.030 % or less. The P

content is preferably 0.020 % or less. Limiting the P content to less than 0.005 % requires high costs. Therefore, from the viewpoint of production costs, the lower limit of the P content is preferably set to 0.005 %.

**[0020]** S: 0.030 % or less

As with P, a S content exceeding 0.030 % deteriorates the toughness of the base metal and welded portion. Thus, the S content is limited to 0.030 % or less and preferably 0.005 % or less. Limiting the S content to less than 0.001 % requires high costs. Therefore, from the viewpoint of production costs, the lower limit of the S content is preferably set to 0.001 %.

**[0021]** Nb: 0.005 % to 0.060 %

Nb is effective for refining of a ferrite microstructure after rolling and cooling by suppressing coarsening of austenite grains during heating of the steel material with forming Nb carbonitrides and is significantly important element to effectively perform controlled rolling at an austenite non-crystallization temperature. Further, Nb is also effective for increasing the strength of steel through precipitation strengthening. To produce the effect and ensure a strength of YP 355 MPa or more, the Nb content needs to be 0.005 % or more. Moreover, when a higher strength of YP 420 MPa or more is required, the Nb content is preferably 0.015 % or more. On the other hand, when Nb is added in an amount of more than 0.060 %, the toughness of the base metal and welded portion is significantly lowered through the generation of martensite austenite constituent. Thus, the upper limit of the Nb content is set to 0.060 %. To further suppress the generation of martensite austenite constituent, the Nb content is preferably set to 0.050 % or less, more preferably 0.040 % or less, and further preferably 0.035 % or less.

**[0022]** Ti: 0.0010 % to 0.0200 %

Ti forms TiN and suppresses coarsening of austenite grains during heating of the steel material, and is thus an element effective for refining the ferrite microstructure after rolling and cooling. Therefore, the Ti content is set to 0.0010 % or more. On the other hand, Ti is also an element for precipitation strengthening and the addition of Ti in an amount of more than 0.0200 % causes precipitation embrittlement. Thus, the upper limit of the Ti content is set to 0.0200 %. The Ti content is preferably set to 0.0050 % to 0.0200 %.

**[0023]** Al: 0.080 % or less

Al is added to steel as a deoxidizer and adding Al beyond 0.080 % does not increase the effect. Thus, the upper limit of the Al content is set to 0.080 %. No lower limitation is placed on the Al content but to sufficiently obtain the deoxidizing effect, the Al content is desirably set to 0.003 % or more. The Al content is preferably 0.015 % to 0.040 %.

**[0024]** N: 0.0010 % to 0.0060 %

N is an element which forms Nb nitrides or Ti nitrides and effective for microstructure refinement. Thus, the N content needs to be 0.0010 % or more. On the other hand, when excessively added N remains as solute N without forming nitrides, the toughness is lowered. Thus, the upper limit of the N content is set to 0.0060 %. The N content is preferably 0.0020 % to 0.0050 %.

**[0025]** The basic compositions are as described above. The balance is Fe and inevitable impurities. In addition to the basic compositions, the chemical composition may optionally further contain at least one selected from the group consisting of V: 0.050 % or less, Cu: 1.0 % or less, Ni: 1.0 % or less, Cr: 1.0 % or less, and Mo: 1.0 % or less.

That is, V is an element for precipitation strengthening, and thus the V content is preferably 0.005 % or more. However, a V content of 0.050 % or more causes precipitation embrittlement, and thus the upper limit of the V content is preferably set to 0.050 %. The V content is more preferably 0.010 % to 0.050 %.

**[0026]** Further, Cu, Ni, Cr, and Mo are elements which contribute to improving strength and from the viewpoint of weldability, these elements may be optionally added within a range not exceeding the upper limit of Ceq described below. Therefore, these elements are preferably added in an amount of 0.01 % or more. On the other hand, a content of each added element beyond 1.0 % leads to lowered toughness and weldability and increased costs. Thus, the content of each added element is preferably set to 1.0 % or less.

**[0027]** Ceq: 0.44 % or less

By increasing Ceq according to the formula (1) described below, the base metal strength can be increased but excessively high Ceq leads to lower

toughness of the base metal and welded portion. Thus, the upper limit of  $C_{eq}$  is set to 0.44 %.  $C_{eq}$  is preferably 0.43 % or less. Note that each element symbol in the formula (1) indicates a content in mass% of the element and any element not contained is taken as zero.

$$C_{eq} = C + Mn / 6 + (Cu + Ni) / 15 + (Cr + Mo + V) / 5 \quad (1)$$

**[0028]** Using a steel material having a chemical composition containing (0.10 to 0.13) % C – 0.3 % Si – 1.5 % Mn with Nb in which the Nb content is varied, hot rolling corresponding to the production of H-shaped steel having a flange thickness of 12 mm to 40 mm was performed and various types of strength and toughness were evaluated and the microstructure was analyzed. Considering the result, the microstructure and production conditions according to this disclosure were limited. The following describes the reasons for limiting the microstructure and production conditions.

**[0029]** [Microstructure]

Average grain size of ferrite: 15  $\mu$ m or less

When a material having the above composition is hot rolled and subsequently air cooled, the microstructure of the material contains ferrite as a main phase and pearlite and/or bainite as a secondary phase. To achieve a desired yield point, YP: 355 MPa or more and a Charpy absorbed energy at -40 °C: 50 J or more, it is important to refine ferrite grains. Specifically, since when the average grain size of ferrite is more than 15  $\mu$ m, the toughness at -40 °C is lowered, it is necessary to set the average grain size of ferrite to 15  $\mu$ m or less.

**[0030]** Fraction of martensite austenite constituent: 3.0 % or less

A part other than ferrite in the microstructure, that is, the secondary phase is made of pearlite and/or bainite. Bainite may partly include martensite austenite constituent. The martensite austenite constituent is a hard phase and serves as the origin of fracture, and thus when the martensite austenite constituent is generated, the toughness at -40 °C is lowered. Therefore, it is necessary to set the area ratio of martensite austenite constituent to 3.0 % or less and preferably 2.5 % or less.

Note that the area ratio of martensite austenite constituent is the ratio of the area of martensite austenite constituent with respect to the whole area of the entire microstructure. Further, ferrite as a main phase is contained in

an area ratio of 70 % or more and preferably 80 % or more. On the other hand, pearlite and/or bainite is preferably contained in an area ratio of 25 % or less. This is because when hard pearlite and/or bainite as a secondary phase is contained in an area ratio of more than 25 %, the base metal toughness is lowered.

**[0031]** [Production conditions]

It is important to heat a steel material having the above chemical composition at 1150 °C or higher and lower than 1300 °C and subsequently hot roll the steel material with a cumulative rolling reduction of 20 % or more when at least a portion corresponding to a flange has a surface temperature of TR °C or lower, the TR calculated by the following formula (2):

$$TR = 174 \log [Nb \times (C + 12 / 14 N)] + 1344 \quad (2).$$

**[0032]** Heating temperature: 1150 °C or higher and lower than 1300 °C

In producing H-shaped steel, it is important to control a shape during hot rolling and it is necessary to heat the steel material to 1150 °C or higher in order to process the steel material in a high temperature range in which deformation resistance is low. Further, to sufficiently dissolve Nb (C, N), it is preferable to heat the steel material at 1200 °C or higher. On the other hand, when the heating temperature is excessively high, TiN precipitates are dissolved to reduce the effect of suppressing coarsening of austenite grains and as a result, the microstructure is coarsened, resulting in lower toughness. Therefore, the heating temperature is set to lower than 1300 °C and preferably 1290 °C or lower.

**[0033]** Hot rolling: a cumulative rolling reduction being 20 % or more when at least a portion corresponding to a flange has a surface temperature of TR °C or lower, the TR calculated by the above formula (2)

The above formula (2) is a result obtained by experimentally determining the austenite non-recrystallization temperature range when Nb is added to the above chemical composition. That is, it is possible to make full use of the controlled rolling effect by performing rolling with a cumulative rolling reduction of 20 % or more at or below a temperature which is calculated by the above formula (2) according to the amount of C, N, and Nb. As a result, a strength of YP 355 MPa or more and the toughness at -40 °C can be stably ensured. As the cumulative rolling reduction is higher, the ferrite

grain size is refined to contribute to improving strength and toughness. Therefore, when a higher strength of YP 420 MPa or more is required, the cumulative rolling reduction is preferably 30 % or more. On the other hand, when an excessive cumulative reduction is applied, the load during rolling is increased and it is difficult to ensure the shape. Therefore, the upper limit of the cumulative rolling reduction is preferably set to 50 %. It is not necessary to define the rolling reduction for temperatures higher than TR °C which is calculated by the above formula (2), and it suffices to define the cumulative rolling reduction for temperatures at or below TR °C in order to ensure a desired strength and toughness.

**[0034]** Note that the surface temperature of at least the portion corresponding to the flange is defined in order to enable controlled rolling while measuring, with a radiation thermometer and the like, and controlling the surface temperature of the flange portion at which material properties are evaluated.

**[0035]** By following the above production conditions, a desired strength and toughness can be ensured through air cooling alone after hot rolling (without accelerated cooling) and, moreover, the shape is stabilized. Further, by performing cooling at a cooling rate as low as that of air cooling, the decomposition of martensite austenite constituent which causes a reduction in toughness is promoted, making it possible to improve the low-temperature toughness.

## EXAMPLES

**[0036]** Steel materials adjusted to the various chemical compositions listed in Table 1 were hot rolled under the conditions listed in Table 2 to produce various types of rolled H-shaped steel having different flange thicknesses. A JIS No. 1A tensile piece was collected in parallel to the rolling direction at a 1/6 position of the flange width from a surface of each obtained H-shaped steel. The tensile piece was subjected to a tensile test to determine the yield point (YP) and tensile strength (TS). Further, a Charpy impact test piece was collected in parallel to the rolling direction at a 1/4 t (t: flange thickness) portion below the surface at the 1/6 position of the flange width to evaluate the absorbed energy at 0 °C, the absorbed energy at -40 °C, and the absorbed energy at -60 °C. Table 2 lists the evaluation results.

**[0037]** Further, a sample for microstructure observation was cut out from the 1/6 position of the flange width. A surface of the sample parallel to the rolling direction and a flange thickness direction was used as an observation plane. The observation plane was polished and etched, and subsequently its microstructure was observed using an optical microscope at x100 to x400 magnification. Then, the microstructures of the main phase and the secondary phase were identified and the ferrite fraction (area ratio) and ferrite grain size (average grain size) were determined by image analysis. Further, the sample for microstructure observation was observed using a scanning electron microscope (SEM) at x1000 magnification to determine the area ratio of martensite austenite constituent (MA fraction) by image analysis. Table 2 also lists these results.

[0038]

Table 1

| Steel No. | Chemical composition (mass %) |      |      |       |       |       |        |       |        |       |      |      |     |      | TR (°C) | Remarks             |
|-----------|-------------------------------|------|------|-------|-------|-------|--------|-------|--------|-------|------|------|-----|------|---------|---------------------|
|           | C                             | Si   | Mn   | P     | S     | Nb    | Ti     | Al    | N      | V     | Cu   | Ni   | Cr  | Mo   | Ceq     |                     |
| A         | 0.12                          | 0.33 | 1.55 | 0.015 | 0.002 | 0.02  | 0.011  | 0.033 | 0.0038 | -     | -    | -    | -   | -    | 0.38    | Example             |
| B         | 0.13                          | 0.3  | 1.51 | 0.012 | 0.002 | 0.018 | 0.013  | 0.03  | 0.0035 | 0.021 | -    | -    | -   | -    | 0.39    | Example             |
| C         | 0.13                          | 0.31 | 1.36 | 0.012 | 0.003 | 0.016 | 0.009  | 0.035 | 0.003  | -     | 0.22 | 0.2  | -   | -    | 0.38    | Example             |
| D         | 0.12                          | 0.34 | 1.49 | 0.011 | 0.003 | 0.025 | 0.007  | 0.04  | 0.0033 | 0.012 | -    | -    | -   | -    | 0.37    | Example             |
| E         | 0.13                          | 0.34 | 1.5  | 0.012 | 0.003 | 0.022 | 0.01   | 0.042 | 0.0032 | 0.013 | -    | -    | -   | -    | 0.4     | Example             |
| F         | 0.12                          | 0.34 | 1.5  | 0.012 | 0.003 | 0.036 | 0.007  | 0.035 | 0.0033 | -     | -    | -    | -   | 0.08 | 0.39    | Example             |
| G         | 0.13                          | 0.3  | 1.51 | 0.012 | 0.002 | 0.01  | 0.013  | 0.03  | 0.0035 | 0.02  | -    | -    | -   | -    | 0.39    | Example             |
| H         | 0.12                          | 0.34 | 1.5  | 0.012 | 0.003 | 0.019 | 0.007  | 0.035 | 0.0033 | -     | -    | -    | -   | 0.1  | 0.39    | Example             |
| I         | 0.13                          | 0.33 | 1.35 | 0.012 | 0.003 | 0.045 | 0.013  | 0.035 | 0.0036 | 0.01  | -    | -    | -   | -    | 0.36    | Example             |
| J         | 0.11                          | 0.26 | 1.59 | 0.018 | 0.002 | 0.034 | 0.015  | 0.039 | 0.0034 | -     | -    | -    | -   | -    | 0.38    | Example             |
| K         | 0.08                          | 0.35 | 1.6  | 0.015 | 0.002 | 0.028 | 0.011  | 0.032 | 0.0038 | 0.015 | 0.25 | 0.25 | -   | -    | 0.38    | Example             |
| L         | 0.12                          | 0.5  | 1.45 | 0.013 | 0.004 | 0.014 | 0.013  | 0.03  | 0.003  | 0.02  | -    | -    | -   | -    | 0.37    | Example             |
| M         | 0.13                          | 0.15 | 1.53 | 0.018 | 0.003 | 0.029 | 0.011  | 0.035 | 0.004  | 0.015 | -    | -    | -   | -    | 0.39    | Example             |
| N         | 0.13                          | 0.15 | 1.65 | 0.02  | 0.003 | 0.029 | 0.011  | 0.035 | 0.004  | 0.015 | -    | -    | -   | -    | 0.41    | Example             |
| O         | 0.15                          | 0.4  | 0.45 | 0.013 | 0.003 | 0.033 | 0.015  | 0.039 | 0.0038 | 0.025 | 0.5  | 0.6  | 0.3 | -    | 0.36    | Example             |
| P         | 0.12                          | 0.4  | 1.3  | 0.013 | 0.003 | 0.049 | 0.015  | 0.039 | 0.0038 | -     | 0.2  | 0.2  | -   | -    | 0.36    | Example             |
| Q         | 0.15                          | 0.32 | 1.15 | 0.017 | 0.002 | 0.006 | 0.015  | 0.039 | 0.0038 | 0.025 | -    | -    | -   | -    | 0.35    | Example             |
| R         | 0.06                          | 0.35 | 1.55 | 0.02  | 0.003 | 0.019 | 0.01   | 0.03  | 0.0031 | -     | -    | -    | -   | -    | 0.32    | Comparative Example |
| S         | 0.12                          | 0.8  | 1.5  | 0.015 | 0.003 | 0.02  | 0.01   | 0.035 | 0.004  | -     | -    | -    | -   | -    | 0.37    | Comparative Example |
| T         | 0.15                          | 0.38 | 0.07 | 0.02  | 0.004 | 0.034 | 0.011  | 0.036 | 0.0037 | 0.029 | -    | -    | -   | -    | 0.17    | Comparative Example |
| U         | 0.18                          | 0.31 | 1.51 | 0.012 | 0.003 | 0.012 | 0.012  | 0.033 | 0.0029 | 0.025 | -    | -    | -   | -    | 0.44    | Comparative Example |
| V         | 0.13                          | 0.33 | 1.35 | 0.012 | 0.003 | 0.075 | 0.013  | 0.035 | 0.0036 | 0.013 | -    | -    | -   | -    | 0.36    | Comparative Example |
| X         | 0.16                          | 0.45 | 1.7  | 0.012 | 0.003 | 0.025 | 0.01   | 0.03  | 0.004  | 0.024 | -    | -    | -   | -    | 0.45    | Comparative Example |
| Y         | 0.11                          | 0.34 | 1.9  | 0.012 | 0.003 | 0.03  | 0.012  | 0.031 | 0.0036 | -     | -    | -    | -   | -    | 0.43    | Comparative Example |
| Z         | 0.1                           | 0.34 | 1.5  | 0.012 | 0.002 | -     | 0.015  | 0.031 | 0.0036 | -     | -    | -    | -   | -    | 0.35    | Comparative Example |
| AA        | 0.11                          | 0.39 | 1.53 | 0.014 | 0.003 | 0.007 | -      | 0.033 | 0.004  | -     | -    | -    | -   | -    | 0.37    | Comparative Example |
| AB        | 0.1                           | 0.24 | 1.49 | 0.01  | 0.004 | 0.004 | 0.01   | 0.025 | 0.0039 | -     | -    | -    | -   | -    | 0.35    | Comparative Example |
| AC        | 0.1                           | 0.1  | 1.34 | 0.01  | 0.005 | 0.02  | 0.019  | 0.033 | 0.0035 | -     | -    | -    | -   | -    | 0.32    | Example             |
| AD        | 0.12                          | 0.32 | 1.45 | 0.015 | 0.003 | 0.023 | 0.007  | 0.033 | 0.0037 | -     | -    | -    | -   | -    | 0.36    | Example             |
| AE        | 0.11                          | 0.3  | 1.53 | 0.014 | 0.004 | 0.012 | 0.0008 | 0.033 | 0.004  | -     | -    | -    | -   | -    | 0.37    | Comparative Example |
| AF        | 0.14                          | 0.26 | 1.47 | 0.018 | 0.005 | 0.01  | 0.025  | 0.033 | 0.0028 | -     | -    | -    | -   | -    | 0.39    | Comparative Example |

[0039]

Table 2

| No. | Steel No. | Heating temperature (°C) | Cumulative rolling reduction at temperature of TR or lower (%) | Flange thickness (mm) | Microstructure |                      |                         |                 | Flange (1/6 width position) |          |           |             |             | Remarks |
|-----|-----------|--------------------------|----------------------------------------------------------------|-----------------------|----------------|----------------------|-------------------------|-----------------|-----------------------------|----------|-----------|-------------|-------------|---------|
|     |           |                          |                                                                |                       | Microstructure | Ferrite fraction (%) | Ferrite grain size (μm) | MA fraction (%) | YP (MPa)                    | TS (MPa) | vE0°C (J) | vE-40°C (J) | vE-60°C (J) |         |
| 1   | A         | 1280                     | 30                                                             | 12                    | F, P           | 85                   | 12                      | 0               | 445                         | 615      | 320       | 230         | 187         | Example |
| 2   | B         | 1250                     | 50                                                             | 12                    | F, P, B        | 83                   | 10                      | 2.5             | 461                         | 638      | 342       | 261         | 214         | Example |
| 3   | B         | 1280                     | 40                                                             | 28                    | F, P, B        | 84                   | 11                      | 2.3             | 453                         | 602      | 298       | 212         | 178         | Example |
| 4   | C         | 1250                     | 50                                                             | 34                    | F, P, B        | 84                   | 14                      | 2.1             | 436                         | 577      | 258       | 205         | 131         | Example |
| 5   | C         | 1280                     | 50                                                             | 19                    | F, P, B        | 85                   | 12                      | 1.2             | 448                         | 587      | 298       | 212         | 183         | Example |
| 6   | D         | 1290                     | 33                                                             | 28                    | F, P, B        | 81                   | 14                      | 2.4             | 436                         | 558      | 254       | 203         | 108         | Example |
| 7   | D         | 1250                     | 33                                                             | 19                    | F, P           | 82                   | 13                      | 0.2             | 436                         | 577      | 288       | 170         | 156         | Example |
| 8   | E         | 1280                     | 50                                                             | 19                    | F, P, B        | 82                   | 13                      | 2.1             | 450                         | 645      | 324       | 267         | 210         | Example |
| 9   | E         | 1280                     | 50                                                             | 28                    | F, P, B        | 80                   | 13                      | 2.3             | 459                         | 611      | 308       | 242         | 219         | Example |
| 10  | F         | 1280                     | 33                                                             | 28                    | F, P           | 82                   | 14                      | 0.3             | 466                         | 603      | 330       | 256         | 204         | Example |
| 11  | G         | 1250                     | 40                                                             | 28                    | F, P, B        | 85                   | 11                      | 1.5             | 423                         | 573      | 324       | 253         | 199         | Example |
| 12  | H         | 1280                     | 33                                                             | 28                    | F, P, B        | 81                   | 12                      | 2.3             | 447                         | 569      | 311       | 271         | 213         | Example |
| 13  | I         | 1280                     | 50                                                             | 40                    | F, P, B        | 81                   | 10                      | 2.4             | 445                         | 584      | 286       | 145         | 101         | Example |
| 14  | J         | 1280                     | 33                                                             | 40                    | F, P, B        | 82                   | 13                      | 2.3             | 431                         | 587      | 316       | 211         | 113         | Example |
| 15  | K         | 1280                     | 50                                                             | 19                    | F, P, B        | 90                   | 13                      | 2.1             | 442                         | 590      | 362       | 242         | 212         | Example |
| 16  | L         | 1250                     | 50                                                             | 28                    | F, P, B        | 81                   | 12                      | 2.9             | 445                         | 568      | 251       | 75          | 64          | Example |
| 17  | M         | 1250                     | 30                                                             | 28                    | F, P, B        | 82                   | 13                      | 1.9             | 433                         | 545      | 333       | 261         | 208         | Example |
| 18  | N         | 1250                     | 50                                                             | 28                    | F, P, B        | 81                   | 12                      | 2.8             | 445                         | 620      | 297       | 199         | 156         | Example |
| 19  | O         | 1280                     | 50                                                             | 28                    | F, P, B        | 83                   | 14                      | 2.1             | 421                         | 598      | 316       | 264         | 210         | Example |
| 20  | P         | 1280                     | 30                                                             | 28                    | F, P, B        | 82                   | 12                      | 2.9             | 438                         | 587      | 239       | 139         | 111         | Example |

F: ferrite, P: pearlite, B: bainite, MA: martensite austenite constituent

Table 2 (cont'd)

| No. | Steel No. | Heating temperature (°C) | Cumulative rolling reduction at temperature of TR or lower (%) | Flange thickness (mm) | Microstructure |                      |                         |                 | Flange (1/6 width position) |          |             |             | Remarks             |
|-----|-----------|--------------------------|----------------------------------------------------------------|-----------------------|----------------|----------------------|-------------------------|-----------------|-----------------------------|----------|-------------|-------------|---------------------|
|     |           |                          |                                                                |                       | Microstructure | Ferrite fraction (%) | Ferrite grain size (µm) | MA fraction (%) | YP (MPa)                    | TS (MPa) | vE-40°C (J) | vE-60°C (J) |                     |
| 21  | Q         | 1280                     | 30                                                             | 12                    | F, P           | 79                   | 15                      | 0               | 435                         | 564      | 258         | 186         | Example             |
| 22  | R         | 1250                     | 10                                                             | 28                    | F, P           | 90                   | 34                      | 0.2             | 314                         | 475      | 265         | 46          | Comparative Example |
| 23  | S         | 1250                     | 50                                                             | 28                    | F, P           | 85                   | 13                      | 0.3             | 368                         | 464      | 150         | 36          | Comparative Example |
| 24  | T         | 1250                     | 50                                                             | 28                    | F, P, B        | 82                   | 15                      | 4.0             | 305                         | 434      | 146         | 33          | Comparative Example |
| 25  | U         | 1250                     | 33                                                             | 40                    | F, P, B        | 78                   | 14                      | 3.5             | 365                         | 563      | 159         | 43          | Comparative Example |
| 26  | V         | 1280                     | 33                                                             | 40                    | F, P, B        | 82                   | 14                      | 6.7             | 453                         | 588      | 145         | 32          | Comparative Example |
| 27  | X         | 1250                     | 33                                                             | 28                    | F, P, B        | 83                   | 14                      | 4.1             | 426                         | 634      | 154         | 39          | Comparative Example |
| 28  | Y         | 1280                     | 33                                                             | 28                    | F, P, B        | 88                   | 11                      | 4.1             | 426                         | 634      | 157         | 37          | Comparative Example |
| 29  | Z         | 1250                     | 25                                                             | 28                    | F, P           | 86                   | 23                      | 0.2             | 334                         | 523      | 225         | 160         | Comparative Example |
| 30  | B         | 1370                     | 33                                                             | 40                    | F, P, B        | 80                   | 36                      | 2.9             | 430                         | 557      | 145         | 40          | Comparative Example |
| 31  | B         | 1280                     | 10                                                             | 40                    | F, P, B        | 80                   | 25                      | 4.3             | 397                         | 545      | 112         | 33          | Comparative Example |
| 32  | E         | 1250                     | 10                                                             | 28                    | F, P, B        | 82                   | 30                      | 3.6             | 462                         | 598      | 125         | 37          | Comparative Example |
| 33  | AA        | 1250                     | 33                                                             | 40                    | F, P, B        | 81                   | 32                      | 1.9             | 421                         | 553      | 157         | 41          | Comparative Example |
| 34  | B         | 1330                     | 50                                                             | 28                    | F, P, B        | 82                   | 25                      | 2.6             | 443                         | 642      | 163         | 45          | Comparative Example |
| 35  | B         | 1320                     | 33                                                             | 28                    | F, P, B        | 83                   | 29                      | 3.5             | 427                         | 633      | 151         | 36          | Comparative Example |
| 36  | B         | 1300                     | 33                                                             | 40                    | F, P, B        | 82                   | 19                      | 3.1             | 455                         | 628      | 216         | 42          | Comparative Example |
| 37  | AC        | 1280                     | 18                                                             | 28                    | F, P, B        | 83                   | 16                      | 2.9             | 441                         | 654      | 198         | 48          | Comparative Example |
| 38  | AD        | 1220                     | 20                                                             | 28                    | F, P, B        | 83                   | 15                      | 2.1             | 386                         | 526      | 224         | 152         | Example             |
| 39  | AD        | 1230                     | 20                                                             | 34                    | F, P, B        | 82                   | 16                      | 2.9             | 351                         | 516      | 247         | 49          | Comparative Example |
| 40  | AB        | 1280                     | 33                                                             | 28                    | F, P, B        | 85                   | 29                      | 2.7             | 395                         | 537      | 157         | 39          | Comparative Example |
| 41  | AE        | 1200                     | 33                                                             | 40                    | F, P, B        | 84                   | 28                      | 2.1             | 344                         | 495      | 201         | 30          | Comparative Example |
| 42  | AF        | 1280                     | 33                                                             | 40                    | F, P, B        | 83                   | 14                      | 2.5             | 452                         | 651      | 103         | 29          | Comparative Example |

F: ferrite, P: pearlite, B: bainite, MA: martensite austenite constituent

**[0040]** Our examples all satisfy a yield point of YP 355 MPa or more, a tensile strength of TS 460 MPa to 690 MPa, and a Charpy absorbed energy at -40 °C of 50 J or more. In contrast, for comparative examples whose composition or production conditions are outside the appropriate ranges, at least one of these properties fail to satisfy the target range.

## CLAIMS

1. H-shaped steel comprising:  
a chemical composition containing, in mass%,  
C: 0.08 % to 0.16 %,  
Si: 0.05 % to 0.60 %,  
Mn: 0.10 % to 1.80 %,  
Nb: 0.005 % to 0.060 %,  
Ti: 0.0010 % to 0.0200 %,  
Al: 0.080 % or less,  
N: 0.0010 % to 0.0060 %,  
P: 0.030 % or less, and  
S: 0.030 % or less in a range in which  $C_{eq}$  according to the following formula (1) is 0.44 % or less:  
$$C_{eq} = C + Mn / 6 + (Cu + Ni) / 15 + (Cr + Mo + V) / 5 \quad (1),$$
  
where each element symbol indicates a content of the element and any element not contained is taken as zero, with the balance being Fe and inevitable impurities; and  
a microstructure containing ferrite having an average grain size of 15  $\mu m$  or less as a main phase, wherein  
the microstructure contains pearlite and/or bainite as a secondary phase and martensite austenite constituent in an amount of 3.0 % or less.
2. The H-shaped steel according to claim 1, wherein the chemical composition further contains, in mass%, at least one selected from the group consisting of:  
V: 0.050 % or less;  
Cu: 1.0 % or less;  
Ni: 1.0 % or less;  
Cr: 1.0 % or less; and  
Mo: 1.0 % or less.
3. A method for producing H-shaped steel comprising:  
heating a steel material having the chemical composition according to

claim 1 or 2 at 1150 °C or higher and lower than 1300 °C, and

subsequently hot rolling the steel material with a cumulative rolling reduction of 20 % or more and 50% or less when at least a portion corresponding to a flange of the H-shaped steel has a surface temperature of TR °C or lower, the TR calculated by the following formula (2):

$$TR = 174 \log [Nb \times (C + 12 / 14 N)] + 1344 \quad (2),$$

followed by air cooling after the hot rolling,

thereby obtaining H-shaped steel comprising a microstructure containing ferrite having an average grain size of 15 μm or less as a main phase, wherein the microstructure contains pearlite and/or bainite as a secondary phase and martensite austenite constituent in an amount of 3.0% or less.