

H-BEAM HAVING PROTRUSIONS, AND MANUFACTURING METHOD FOR SAME

TECHNICAL FIELD

5 [0001] This disclosure relates to an H-beam having protrusions and a manufacturing method for the same, and in particular to an H-beam having protrusions with excellent mechanical properties such as tensile strength and elongation, as well as excellent toughness, which is usable as a substitute for reinforcing bars used as reinforcing materials for large structures such as
10 bridge pier, and to a manufacturing method for the same.

BACKGROUND

[0002] Reinforced concrete using reinforcing bars as reinforcement is widely used in large structures such as bridge pier. Generally, reinforced concrete
15 structures are constructed by installing formwork after assembling reinforcing bars and placing concrete inside the formwork. Here, when overcrowding of reinforcing bars is required for strength, the filling performance of concrete is reduced, which not only deteriorates the construction quality but also prolongs the construction period, which is a major issue. In addition, the
20 number of skilled workers engaged in such construction work is decreasing year by year, and there is a growing need for the development of structural steel that contributes to labor saving and shortening the construction period.

[0003] In response to such demands, various studies have been conducted on H-beams having protrusions, which have greater cross-sectional rigidity than
25 reinforcing bars and can reduce the number of members required in the same structure. Such H-beams having protrusions are provided with protrusions on the outer surfaces of their flanges and are known to have high concrete adhesion performance equivalent to or better than that of reinforcing bars. In addition to mechanical properties such as tensile strength and elongation,
30 H-beams having protrusions, which are used in large structures as a substitute for reinforcing bars, are required to ensure proper toughness in order to guarantee the performance of the structure.

[0004] To satisfy these requirements, for example, JP4045977B (PTL 1) describes an H-beam having protrusions with well-balanced tensile strength
35 and toughness by adjusting the amount of Nb, V, and Ni added in the steel. In addition, JP2006-75883A (PTL 2) describes a technique to set the optimum

cooling stop temperature according to the flange thickness and to adjust the amount of cooling water on the inside and outside of the flanges as appropriate, for the purpose of improving the toughness of the resulting H-beam having protrusions.

5

CITATION LIST

Patent Literature

[0005] PTL 1: JP4045977B

PTL 2: JP2006-75883A

10

SUMMARY

(Technical Problem)

[0006] However, although the H-beams having protrusions described in PTLs 1 and 2 are designed to have both high tensile strength and toughness by adding Nb and V, which form carbonitrides, there is a problem that when rolling materials are manufactured by continuous casting, a defect called continuous casting cracking tends to occur on the surface of the cast steel, resulting in lower manufacturability. It would thus be helpful to provide an H-beam having protrusions, together with a manufacturing method for the same, which can dramatically improve the manufacturability while securing comparable or higher tensile strength compared to conventional H-beams having protrusions.

15

20

(Solution to Problem)

[0007] The present inventors prepared H-beams having protrusions by varying the contents of C, Si, Mn, P, S, Nb, V, Ti, and N, and intensively investigated the tensile properties and toughness. As a result, it was found that the possibility of continuous cast cracking increases when Nb and V are contained in the steel. Furthermore, by optimizing the amount of S, Ti, and N contained in the steel, continuous casting cracking can be stabilized and suppressed even when Nb and V are contained, and excellent toughness can be obtained by promoting intragranular ferrite transformation with TiN as nuclei. [0008] The present disclosure is based on the above findings, and primary features thereof are as follows.

25

30

1. An H-beam having protrusions, comprising: a steel composition containing (consisting of) C: 0.05 mass% to 0.20 mass%, Si: 0.05 mass% to 0.60 mass%, Mn: 1.20 mass% to 1.70 mass%, P: 0.035 mass% or less, S:

35

0.035 mass% or less, Nb: 0.005 mass% to 0.050 mass%, V: 0.005 mass% to 0.050 mass%, Ti: 0.005 mass% to 0.030 mass%, and N: 0.0020 mass% to 0.0100 mass%, within a range satisfying the following Expression (1) with the balance being Fe and inevitable impurities:

5

$$([\%S]/32)/([\%Ti]/48)+4\times([\%N]/14)/([\%Ti]/48) \leq 15.0 \quad (1),$$

where [%S], [%Ti], and [%N] are the contents in mass% of S, Ti, and N in steel; a tensile strength of 490 MPa or more; a yield strength of 355 MPa or more; and an impact absorbed energy at 0 °C, vE₀, of 27 J or more.

10 [0009] 2. The H-beam having protrusions according to the aspect 1, wherein the steel composition further contains at least one selected from the group consisting of Cr: 1.0 mass% or less, Cu: 1.0 mass% or less, Ni: 1.0 mass% or less, Mo: 1.0 mass% or less, Al: 0.10 mass% or less, B: 0.010 mass% or less, Ca: 0.10 mass% or less, Mg: 0.10 mass% or less, and REM: 0.10 mass% or less.

[0010] 3. The H-beam having protrusions according to the aspect 1 or 2, wherein each of the protrusions has a height of 1.5 mm or more.

[0011] 4. A manufacturing method for an H-beam having protrusions by hot rolling a steel material having the steel composition as recited in the aspect 1 or 2, the method comprising: in the hot rolling, performing finish rolling to form protrusions on outer surfaces of flanges of the H-beam; and after the finish rolling, cooling the H-beam at an average cooling rate of 0.1 °C/s to 30 °C/s in a temperature range of from a cooling start temperature of 750 °C or higher to 500 °C.

25 [0012] 5. The manufacturing method for an H-beam having protrusions according to the aspect 4, wherein the finish rolling is performed in a temperature range of 800 °C or higher.

(Advantageous Effect)

30 [0013] The present disclosure makes it possible to stably produce an H-beam having protrusions with excellent toughness, contributing to the realization of rapid construction of large structures and the improvement of the quality of concrete products, which is beneficial to industry.

35

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In the accompanying drawings:

FIG. 1 is a cross-sectional view of an H-beam having protrusions; and
FIGs. 2A-2C each illustrate an H-beam having protrusions; FIG. 2A is a side
view as viewed from the opposing direction of a web, FIG. 2B is a plan view
as viewed from the opposing direction of the outer surfaces of the flanges, and
5 FIG. 2C is a top view of the outer surfaces of the flanges.

DETAILED DESCRIPTION

[0015] The present disclosure will be described in detail below. Firstly, the
reasons for limiting the steel composition to the aforementioned ranges will
10 be explained. The % representations below indicating the steel composition
are in mass% unless stated otherwise.

[0016] C: 0.05 % to 0.20 %

C is an element necessary to ensure the strength of the base metal, and needs
to be contained at least 0.05 %. However, if the C content exceeds 0.20 %, it
15 not only reduces the toughness of the base metal, but also decreases the
weldability. Therefore, in the present disclosure, the C content is 0.05 % to
0.20 %. The C content is preferably 0.10 % or more. The C content is
preferably 0.15 % or less.

[0017] Si: 0.05 % to 0.60 %

Si needs to be contained, as a deoxidizer, at least 0.05 % to ensure the strength
of the base metal. However, if the Si content exceeds 0.60 %, weldability
deteriorates due to the high binding power of Si with oxygen, in addition to a
decrease in toughness. Therefore, in the present disclosure, the Si content is
0.05 % to 0.60 %. The Si content is preferably 0.20 % or more. The Si
25 content is preferably 0.40 % or less.

[0018] Mn: 1.20 % to 1.70 %

Mn, like Si, is a relatively inexpensive element that is important for
increasing strength since it has the effect of increasing the strength of steel.
However, if the Mn content is less than 1.20 %, the addition effect is small.
30 On the other hand, if the Mn content exceeds 1.70 %, the upper bainite
transformation is accelerated and the toughness is reduced, which is not
desirable. Therefore, in the present disclosure, the Mn content is 1.20 % to
1.70 %. The Mn content is preferably 1.40 % or more. The Mn content is
preferably 1.60 % or less.

35 [0019] P: 0.035 % or less

If the P content exceeds 0.035 %, the ductility of the steel deteriorates.

Therefore, in the present disclosure, the P content in the steel is 0.035 % or less. It is preferably 0.020 % or less. On the other hand, since a lower P content is preferable, the lower limit of the P content is not particularly limited, and may be 0 %. However, P is usually inevitably contained in steel as an impurity, and reducing the P content to an excessively low level increases the refining time and cost. Therefore, the P content is preferably 0.005 % or more.

[0020] S: 0.035 % or less

When S is contained in steel, it exists in the steel mainly in the form of A type inclusions. When the S content exceeds 0.035 %, the amount of these inclusions increases significantly, and at the same time, coarse inclusions are formed, which greatly reduces the toughness of the steel. Therefore, in the present disclosure, the S content in the steel is 0.035 % or less. It is preferably 0.020 % or less. On the other hand, since a lower S content is preferable, the lower limit of the S content is not particularly limited, and may be 0 %. Since S is usually inevitably contained in steel as an impurity, and reducing the S content to an excessively low level increases the refining time and cost. Therefore, the S content is preferably 0.002 % or more.

[0021] Nb: 0.005 % to 0.050 %

Nb is an element that has the effect of improving tensile strength and yield point by precipitating as carbonitrides. To obtain this effect, the Nb content needs to be 0.005 % or more. On the other hand, if the Nb content exceeds 0.050 %, precipitation embrittlement is accelerated and upper bainite transformation is promoted, which makes continuous casting cracking more likely to occur and also reduces toughness. Therefore, in the present disclosure, the Nb content is 0.005 % to 0.050 %. The Nb content is preferably 0.010 % or more. The Nb content is preferably 0.030 % or less.

[0022] V: 0.005 % to 0.050 %

V is an element that has the effect of improving tensile strength and yield point by precipitating as carbonitrides. To obtain this effect, the V content needs to be 0.005 % or more. On the other hand, if the V content exceeds 0.050 %, precipitation embrittlement is accelerated, making continuous casting cracking more likely to occur. Therefore, in the present disclosure, the V content is 0.005 % to 0.050 %. The V content is preferably 0.010 % or more. The V content is preferably 0.030 % or less.

[0023] Ti: 0.005 % to 0.030 %

Ti is a useful element that is effective in preventing surface cracking during bending and bending back in continuous casting, and is thus actively added in the range of 0.005 % or more. Ti is also effective in improving toughness by forming TiN in the steel to refine austenite grains, and by promoting intragranular ferrite transformation with TiN as nuclei to refine the microstructure. On the other hand, a Ti content exceeding 0.030 % is undesirable because it causes coarse TiN and reduces the toughness of the steel. Therefore, in the present disclosure, the Ti content is 0.005 % to 0.030 %. The Ti content is preferably 0.010 % or more. The Ti content is preferably 0.020 % or less.

[0024] N: 0.0020 % to 0.0100 %

N is a useful element that forms carbonitrides in steel and improves the strength of the steel, and the N content needs to be 0.0020 % or more. However, if the N content exceeds 0.0100 %, the carbonitrides formed become coarse and reduce the toughness of the steel. N content beyond 0.0100 % also causes surface cracking in the cast steel and deteriorate the quality of the cast steel, which is not desirable. Therefore, in the present disclosure, the N content is 0.0020 % to 0.0100 %. The N content is preferably 0.0030 % or more. The N content is preferably 0.0070 % or less.

[0025] In the present disclosure, it is not enough to simply satisfy the above ranges for each element. For S, Ti, and N, when [%S], [%Ti], and [%N] are the contents in mass% of S, Ti, and N in the steel, respectively, it is important to satisfy the relationship of:

$$([\% S] / 32) / ([\% Ti] / 48) + 4 \times ([\% N] / 14) / ([\% Ti] / 48) \leq 15.0 \quad (1).$$

[0026] The present inventors investigated the cause of cracking in steel during continuous casting and found that the cause of cracking was the precipitation of coarse MnS and V and Nb carbonitrides into ferrite generated at austenite grain boundaries during continuous casting. Accordingly, in order to suppress such precipitation of MnS and V- and Nb-based carbonitrides into ferrite, the inventors investigated the effect of adjusting the contents of S, Ti, and N in the steel, and found that the precipitation of MnS and V- and Nb-based carbides into intergranular ferrite could be suppressed, thereby preventing cracking during continuous casting. In other words, by keeping the value calculated on the left side of Expression (1) above, which is

a parameter based on the contents of S, Ti, and N, not to exceed 15.0, S can be precipitated as Ti carbon sulfide and N as TiN, the precipitation of coarse MnS and V- and Nb-based carbonitrides into ferrite generated in austenite grain boundaries during continuous casting can be suppressed, and continuous casting cracking can be stably controlled. It is more preferable that the right side of Expression (1) be 10.0 or less, i.e., it is more preferable to satisfy:

$$([\%S]/32)/([\%Ti]/48)+4\times([\%N]/14)/([\%Ti]/48) \leq 10.0 \quad (1)'$$

[0027] In the steel composition of an H-beam having protrusions used in the present disclosure, the balance other than the above components is Fe and inevitable impurities.

Furthermore, in addition to the above components, the H-beam having protrusions disclosed herein may further contain at least one selected from the group consisting of Cr: 1.0 % or less, Cu: 1.0 % or less, Ni: 1.0 % or less, Mo: 1.0 % or less, Al: 0.10 % or less, B: 0.010 % or less, Ca: 0.10 % or less, Mg: 0.10 % or less, and REM: 0.10 % or less, for the purpose of improving strength, ductility, toughness, and welded portion characteristics.

The reasons for limitations on the contents of these elements.

[0028] Cr: 1.0 % or less

Cr is an element capable of further increasing the strength of the steel by solid solution strengthening. However, if the Cr content exceeds 1.0 %, upper bainite transformation is promoted and toughness is reduced, which is not desirable. Therefore, when the steel composition contains Cr, the Cr content is 1.0 % or less. It is more preferably 0.005 % or more. It is more preferably 0.5 % or less.

[0029] Cu: 1.0 % or less

Cu is an element capable of further increasing the strength of the steel by solid solution strengthening. However, if the Cu content exceeds 1.0 %, Cu cracking easily occurs. Therefore, when the steel composition contains Cu, the Cu content is 1.0 % or less. It is more preferably 0.005 % or more. It is more preferably 0.5 % or less.

[0030] Ni: 1.0 % or less

Ni is an element capable of increasing the strength of the steel without deteriorating the ductility. In addition, since Cu cracking can be suppressed by combined addition with Cu, when the steel composition contains Cu, it is

desirable to contain Ni as well. However, if the Ni content exceeds 1.0 %, the hardenability of the steel tends to increase more and the toughness tends to decrease. Therefore, when the steel composition contains Ni, the Ni content is 1.0 % or less. It is more preferably 0.005 % or more. It is more preferably 0.5 % or less.

[0031] Mo: 1.0 % or less

Mo is an element capable of further increasing the strength of the steel by solid solution strengthening. However, if the Mo content exceeds 1.0 %, a large amount of upper bainite tends to be formed in the steel, and the toughness tends to decrease. Therefore, when the steel composition contains Mo, the Mo content is 1.0 % or less. It is more preferably 0.005 % or more. It is more preferably 0.5 % or less.

[0032] Al: 0.10 % or less

Al is an element that can be added as a deoxidizer. However, when the Al content exceeds 0.10 %, a large amount of oxide-based inclusions is formed in the steel due to the high bonding strength between Al and oxygen. As a result, the ductility of the steel is decreased. Therefore, when the steel composition contains Al, the Al content is preferably 0.10 % or less. On the other hand, the lower limit of the Al content is not particularly limited, yet for deoxidation, it is preferably 0.001 % or more. It is more preferably 0.001 % or more. It is more preferably 0.03 % or less.

[0033] B: 0.010 % or less

B is an element that segregates at grain boundaries in steel and has an effect of improving grain boundary strength. It is also an effective element for improving toughness by forming composite precipitates with TiN, which is a nucleation site for intragrain ferrite, and by refining the microstructure. On the other hand, when the B content exceeds 0.010 %, toughness is reduced by grain boundary precipitation of coarse carbonitrides. Therefore, when the steel composition contains B, the B content is 0.010 % or less. It is more preferably 0.001 % or more. It is more preferably 0.003 % or less.

[0034] Ca: 0.10 % or less

Ca has the effect of transforming the oxides and sulfides in sulfide-based inclusions into those that are more stable at high temperatures, and granulating the sulfide-based inclusions. The effect of Ca on the morphology control of inclusions can improve the toughness and ductility of the steel. However, if the Ca content exceeds 0.10 %, the cleanliness

decreases, and the toughness tends to be lowered. Therefore, when the steel composition contains Ca, the Ca content is 0.10 % or less. It is more preferably 0.0010 % or more. It is more preferably 0.0050 % or less.

[0035] Mg: 0.10 % or less

5 Mg has the effect of transforming the oxides and sulfides in sulfide-based inclusions into those that are more stable at high temperatures, and granulating the sulfide-based inclusions. The effect of Mg on the morphology control of inclusions can improve the toughness and ductility of the steel. However, if the Mg content exceeds 0.10 %, the cleanliness
10 decreases, and the toughness tends to be lowered. Therefore, when the steel composition contains Mg, the Mg content is 0.10 % or less. It is more preferably 0.0010 % or more. It is more preferably 0.0050 % or less.

[0036] REM: 0.10 % or less

Rare earth metals (REM) have the effect of transforming the oxides and
15 sulfides in sulfide-based inclusions into those that are more stable at high temperatures, and granulating the sulfide-based inclusions. The effect of REM on the morphology control of inclusions can improve the toughness and ductility of the steel. However, if the REM content exceeds 0.10 %, the cleanliness decreases, and the toughness tends to be lowered. Therefore, if
20 the steel composition contains REM, the REM content is 0.10 % or less. It is more preferably 0.0010 % or more. It is more preferably 0.0050 % or less.

The balance other than the above elements is Fe and inevitable impurities.

[0037] An H-beam having protrusions according to the present disclosure will be described in detail. Specifically, as illustrated in FIG. 1, the H-beam
25 having protrusions disclosed herein is formed from a pair of flanges 2 connected by a web 3, as is the case with general H-beams. The H-beam having protrusions is provided with protrusions 4 on the outer surface of each flange 2. The protrusions 4 are provided to impart concrete adhesion performance. In an H-beam having protrusions 1 in which protrusions 4 are
30 provided for this purpose, the portion where the protrusions 4 are provided is the outer surface of each flange 2 as illustrated in FIG. 2A. In the embodiment illustrated, protrusions 4 are formed on the entire outer surface of each flange 2 in an array in the longitudinal direction of the flange 2, in the form of ridges extending in the width direction of the flange 2 in the
35 cross-sectional shape illustrated in FIG. 2B, which is an enlarged view of the region enclosed by the square in FIG. 2A.

[0038] The shape, dimensions, and number of protrusions can be set freely according to the specifications required for the H-beam having protrusions. Therefore, although not limited to the embodiments illustrated in the figures, for example, the height h of each protrusion 4 is preferably 1.5 mm or more in consideration of concrete adhesion performance. On the other hand, the upper limit of the height h is preferably 6 mm from the viewpoint of preventing roller fracture. Preferably, the distance d between the protrusions 4 satisfies the relationship of $h/d \geq 0.05$ with the height h , considering the concrete adhesion performance.

[0039] Next, a manufacturing method for an H-beam having protrusions will be described. There are no restrictions on the smelting methods for steel (slab or beam blank), and any of the conventional methods are suitable. The hot-rolling conditions for forming into an H-beam are also not restricted, and hot rolling can be done according to a conventional method. The protrusions can be formed by using rolls that have grooves formed on the surface of the rolls corresponding to the protrusions to be formed as the rolls that apply pressure to the region where the protrusions are to be formed (the outer surface of each flange) during finish rolling in the hot rolling. After the finish rolling, it is necessary to perform cooling so as to satisfy the conditions below.

[0040] Cooling start temperature at the flange: 750 °C or higher

In the present disclosure, the cooling start temperature at the flange is 750 °C or higher in order to prevent a drop in production efficiency by starting cooling of the steel material immediately after the finish rolling. On the other hand, if the cooling start temperature at the flange is lower than Ar_3 temperature, it is difficult to obtain sufficient strength. Therefore, it is preferable to set the cooling start temperature at the flange to Ar_3 temperature or higher. The Ar_3 transformation temperature can be simply expressed in relation to the steel composition using, for example:

$$Ar_3 = 910 - 310 \times [\%C] + 25 \times ([\%Si] + 2 \times [\%Al]) - 80 \times [M_{neq}] \quad (2),$$

where $[M_{neq}]$ is a value calculated by:

$$[M_{neq}] = [\%Mn] + [\%Cr] + [\%Cu] + [\%Mo] + [\%Ni]/2 + 10 \times ([\%Nb] - 0.02) \quad (3).$$

In Expressions (2) and (3), [%M] indicates the content in mass% of element M in the steel. In calculating Ar_3 in Expressions (2) and (3), the content of element M that is not actively contained is calculated using the content (analytical value) of element M that is contained as an inevitable impurity.

5 [0041] Average cooling rate in a temperature range from the cooling start temperature to 500 °C: 0.1 °C/s to 30 °C/s

If the average cooling rate in a temperature range from the cooling start temperature to 500 °C is lower than 0.1 °C/s, it is difficult to ensure a predetermined tensile property and toughness. Therefore, the cooling rate is
10 0.1 °C/s or higher. On the other hand, if the cooling rate increases beyond 30 °C/s, the formation of bainite or martensite will cause adverse effects such as reduced toughness and excessive increase in tensile strength. Therefore, the average cooling rate in a temperature range from the cooling start temperature to 500 °C is in the range of 0.1 °C/s to 30 °C/s. A preferred average cooling
15 rate is in the range of 0.5 °C/s to 10 °C/s.

[0042] By adjusting the composition in the above-described ranges and performing rolling and cooling according to the above-described conditions, excellent mechanical performance can be obtained for an H-beam having protrusions, with a tensile strength of 490 MPa or more, a yield strength of
20 355 MPa or more, and an impact absorbed energy at 0 °C, vE_0 , of 27 J or more. There is no need to specify an upper limit for any of these properties, yet for practical purposes, tensile strength is up to about 640 MPa, yield strength is up to about 475 MPa, and impact absorbed energy at 0 °C, vE_0 , is up to about 350 J.

25 [0043] The H-beam having protrusions according to the present disclosure is not particularly limited in terms of its flange thickness. The protrusions on the outer surface of each flange are formed using rollers with grooves in the finish rolling process. In other words, in order to provide the desired protrusion height, it is necessary to increase the rolling reduction ratio at each
30 flange as much as possible. Accordingly, an H-beam having protrusions with a thicker flange requires a higher rolling reduction ratio. As described below, by controlling the rolling temperature within the appropriate range, the present disclosure can provide a sufficient protrusion height even in thick-walled H-beams with flange thicknesses of 16 mm or more, where the
35 efficiency of provision of a sufficient protrusion height is said to be reduced.

[0044] In the finish rolling, in which forming to form protrusions is

performed during hot rolling, it is preferable to set the finish rolling temperature at 800 °C or higher from the perspective of forming protrusions with a sufficient protrusion height. If the finish rolling temperature is lower than 800 °C, it is difficult to stably form protrusions with a sufficient height.

5 On the other hand, although the upper limit of the finish rolling temperature is not particularly limited, if this temperature exceeds 1050°C, the austenite grain size becomes coarse, and the toughness tends to decrease. Therefore, the finish rolling temperature is preferably 1050 °C or lower.

10 EXAMPLES

[0045] The structure, function, and effect of the present disclosure will be described in more detail below with reference to examples. However, the present disclosure is not restricted by any means to these examples, which may be changed appropriately within the range conforming to the purpose of

15 the disclosure, all of such changes being included within the technical scope of the disclosure.

[0046] Steel materials with the compositions listed in Table 1 were made into beam blanks with a cross-section of 400 mm x 560 mm x 8,000 mm in length using a continuous casting machine, and the presence of cracks on the surface

20 was investigated. That is, the surface of each beam blank was observed in the longitudinal direction and examined for the presence of cracks with a length of 10 mm or more. The number of surface cracks per 1 m² was determined and evaluated using the following indices: "A" no cracks, "B" 1 to 4 cracks/m², "C" 5 or more cracks/m². Those rated either A or B were

25 considered to have passed the test. Table 1 lists the results of the determination of surface cracking. Steel samples whose steel composition satisfied the Expression (1) above were rated either A or B for the presence of surface cracks.

[0047] Of these beam blanks, those rated A or B for the presence of surface

30 cracks were heated at 1250 °C for 2 hours, and then hot rolled and cooled under the conditions listed in Table 2 to prepare H-beams having protrusions 1 with a cross-sectional shape as illustrated in FIG. 1 which has, specifically, a web 3 and a pair of flanges 2 located at both ends of the web. In this case, each H-beam having protrusions was prepared with the cross-sectional

35 dimensions (web height × flange width × web thickness × flange thickness) adjusted to one of the following: 320 mm × 323 mm × 25 mm × 25 mm or 350

mm × 333 mm × 35 mm × 40 mm. In finish rolling, as rolling rolls to press down the outer surfaces of flanges, rolling rolls with grooves corresponding to the shape of the protrusions to be formed on the outer surfaces of the flanges were used, and protrusions 6 extending in the width direction of the flanges 2 were formed on the outer surfaces of the flanges, as illustrated in FIG. 2. In this case, the finish rolling rolls to press down the outer surfaces of the flanges are provided with grooves that can form protrusions with a protrusion width w of 15 mm and a protrusion height h of 1.5 mm or more. The cooling rate ($^{\circ}\text{C/s}$) after the finish rolling was calculated by measuring the temperature of the outer surfaces of the flanges with a radiation thermometer, and converting and the temperature change between the start and stop of cooling per unit time (second).

[0048]

Table 1

Steel No.	Chemical composition (mass%)*1																	Expression (1) *,*2	Surface cracking	Remarks	
	C	Si	Mn	P	S	Nb	V	Ti	N	Cr	Cu	Ni	Mo	Al	B	Ca	Mg				REM
1	0.10	0.30	1.55	0.009	0.005	0.020	0.020	0.007	0.0046	-	-	-	-	-	-	-	-	-	10.1	B	Conforming steel
2	0.19	0.07	1.21	0.015	0.008	0.048	0.007	0.018	0.0039	-	-	-	-	-	-	-	-	-	3.6	A	
3	0.09	0.36	1.67	0.016	0.006	0.018	0.025	0.020	0.0051	-	-	-	-	-	-	-	-	-	3.9	A	
4	0.16	0.19	1.39	0.012	0.010	0.025	0.016	0.015	0.0060	-	-	-	-	-	-	-	-	-	6.5	A	
5	0.13	0.34	1.48	0.016	0.006	0.024	0.018	0.013	0.0045	-	-	-	-	-	-	-	-	-	5.4	A	
6	0.14	0.20	1.35	0.010	0.034	0.016	0.025	0.011	0.0022	-	-	-	-	-	-	-	-	-	7.4	A	
7	0.17	0.42	1.42	0.018	0.011	0.031	0.039	0.017	0.0050	-	-	-	-	-	-	-	-	-	5.0	A	
8	0.12	0.39	1.56	0.011	0.008	0.015	0.021	0.015	0.0056	-	-	0.11	-	-	-	-	-	-	5.9	A	
9	0.14	0.35	1.50	0.021	0.005	0.009	0.043	0.009	0.0034	-	-	-	-	-	-	-	-	-	6.0	A	
10	0.15	0.16	1.64	0.035	0.024	0.009	0.034	0.006	0.0038	-	-	-	-	-	-	-	-	-	14.7	B	
11	0.13	0.34	1.58	0.014	0.006	0.017	0.027	0.012	0.0040	-	-	-	-	0.03	-	-	-	-	5.3	A	
12	0.05	0.58	1.69	0.020	0.009	0.006	0.049	0.028	0.0091	-	-	-	0.16	-	-	-	-	-	4.9	A	
13	0.12	0.30	1.47	0.013	0.007	0.011	0.026	0.021	0.0045	0.43	-	-	-	-	-	-	-	-	3.4	A	
14	0.11	0.33	1.60	0.008	0.015	0.008	0.013	0.016	0.0052	-	0.28	0.15	-	-	-	-	-	-	5.9	A	
15	0.16	0.48	1.39	0.012	0.009	0.040	0.028	0.008	0.0071	-	-	-	-	-	0.0026	-	-	-	13.9	B	
16	0.15	0.18	1.35	0.017	0.006	0.023	0.025	0.018	0.0055	-	-	-	-	-	-	0.0032	-	-	4.7	A	
17	0.13	0.32	1.62	0.015	0.005	0.016	0.032	0.010	0.0046	-	-	-	-	-	-	-	0.0045	-	7.1	A	
18	0.14	0.40	1.40	0.022	0.007	0.038	0.041	0.011	0.0095	-	-	-	-	-	-	-	-	0.0071	12.8	B	
19	0.04	0.26	1.30	0.015	0.008	0.015	0.018	0.015	0.0045	-	-	-	-	-	-	-	-	-	4.9	A	
20	0.22	0.51	1.64	0.018	0.010	0.029	0.034	0.006	0.0050	-	-	-	-	-	-	-	-	-	13.9	B	
21	0.13	0.03	1.22	0.013	0.006	0.009	0.020	0.019	0.0029	-	-	-	-	-	-	-	-	-	2.6	A	
22	0.15	0.61	1.61	0.012	0.009	0.027	0.019	0.010	0.0034	-	-	-	-	-	-	-	-	-	6.0	A	
23	0.08	0.15	1.19	0.010	0.007	0.016	0.007	0.012	0.0040	-	-	-	-	-	-	-	-	-	5.4	A	
24	0.18	0.39	1.73	0.016	0.005	0.032	0.030	0.016	0.0038	-	-	-	-	-	-	-	-	-	3.7	A	
25	0.14	0.31	1.50	0.037	0.020	0.020	0.027	0.021	0.0046	-	-	-	-	-	-	-	-	-	4.4	A	
26	0.12	0.35	1.56	0.024	0.036	0.021	0.026	0.006	0.0055	-	-	-	-	-	-	-	-	-	21.6	C	
27	0.13	0.24	1.42	0.026	0.016	0.004	0.010	0.012	0.0041	-	-	-	-	-	-	-	-	-	6.7	A	
28	0.17	0.41	1.64	0.015	0.023	0.052	0.035	0.008	0.0073	-	-	-	-	-	-	-	-	-	16.8	C	
29	0.15	0.30	1.38	0.018	0.006	0.010	0.003	0.016	0.0032	-	-	-	-	-	-	-	-	-	3.3	A	
30	0.18	0.45	1.52	0.017	0.022	0.029	0.051	0.007	0.0074	-	-	-	-	-	-	-	-	-	19.2	C	
31	0.11	0.37	1.55	0.011	0.008	0.024	0.024	0.004	0.0058	-	-	-	-	-	-	-	-	-	22.9	C	
32	0.10	0.19	1.64	0.019	0.010	0.045	0.029	0.032	0.0089	-	-	-	-	-	-	-	-	-	4.3	A	
33	0.08	0.28	1.68	0.022	0.006	0.027	0.030	0.018	0.0017	-	-	-	-	-	-	-	-	-	1.8	A	
34	0.14	0.34	1.50	0.015	0.018	0.033	0.025	0.009	0.0104	-	-	-	-	-	-	-	-	-	18.8	C	
35	0.19	0.28	1.56	0.009	0.027	0.036	0.022	0.005	0.0066	-	-	-	-	-	-	-	-	-	32.0	C	
36	0.13	0.31	1.43	0.012	0.010	0.020	0.013	0.007	0.0066	-	-	-	-	-	-	-	-	-	15	C	

*1: Underlined if outside the scope of the disclosure.

*2: $([\%]/32)/([\%Ti]/48)+4 \times ([\%N]/14)/([\%Ti]/48)$

*3: Surface cracking rating: "A" no cracks, "B" 1 to 4 cracks/m², and "C" 5 or more cracks/m².

[0049] The obtained H-beams with protrusions were subjected to protrusion height evaluation, tensile tests, and toughness tests. The following describes the details of the evaluation and test results.

[0050] <Protrusion Height Evaluation>

5 For the obtained H-beams having protrusions, the protrusion height h on the outer surface of each flange as illustrated in FIG. 2B was measured. This value h was measured at three points in the rolling direction of each H-beam having protrusions after the finish rolling: the lead end, the center, and the tail end, and the results were averaged to give an average value, which was used
10 as h . The lower limit of the performance requirement for the protrusion height was set at 1.5 mm, and the range from this value and above was defined as the suitable range for the protrusion height h . In addition, the manufacturing conditions under which H-beams having protrusions were obtained with a protrusion height h not lower than this value can be evaluated
15 as particularly favorable conditions from the viewpoint of ease of protrusion formation.

[0051] <Tensile Test>

A JIS 1A test piece (full-thickness flange specimen) specified in JIS Z2201 was taken from a flange 1/6B portion indicated by reference numeral 5 in
20 FIG. 1 (60 mm long in the flange widthwise direction across 1/6B), such that the tensile direction would be parallel to the longitudinal direction of the flanges of the H-beam, and a tensile test was conducted in accordance with JIS Z2241 to measure the yield strength (yield stress YS or 0.2 % proof stress) and the tensile strength.

25 [0052] <Toughness Test>

A 2-mm V-notch Charpy impact test specimen as specified in JIS Z2202 was taken from the flange 1/6B portion 5 as illustrated in FIG. 1, centered at $1/4t$ from the back of the flange (t is the flange thickness), and a Charpy impact test was conducted according to JIS Z2242 to measure the absorbed energy at
30 0 °C.

[0053] The investigation results are listed in Table 2. The test results (Test Nos. 1 to 19 and 31 in Table 2) for those H-beams having protrusions fabricated by using conforming steels that satisfied the conditions for the steel composition according to the present disclosure and the manufacturing
35 method within the scope of the present disclosure (where the average cooling rate at the outer surface of each flange was within the scope of the present

disclosure) all satisfy the desired properties (tensile strength: 490 MPa or more, yield strength: 355 MPa or more, and impact absorbed energy at 0°C, vE_0 : 27 J or more). Although Test No. 33 satisfied the desired properties for tensile strength, yield strength, and impact absorbed energy at 0 °C, the
5 protrusion height was 1.4 mm, which was below the suitable range (1.5 mm or more) because the finish rolling temperature was below the suitable lower limit of 800 °C.

[0054] On the other hand, in the comparative examples (Test Nos. 20-30 and 32-34 in Table 2) where the steel compositions of the H-beams did not satisfy
10 the conditions disclosed herein or the manufacturing method within the scope of the present disclosure was not applied, any of the values of tensile strength, yield strength, and toughness did not satisfy the required properties.

[0055]

Table 2

Test No.	Steel sample No.	Flange thickness [mm] *2	Hot rolling conditions *1			Protrusion height [mm]	Mechanical properties *1			Remarks
			Finish rolling temp. [°C]	Cooling start temp. at the flange [°C]	Average cooling rate [°C/s]		Tensile strength [MPa]	Yield strength [MPa]	Impact absorbed energy vE ₀ [J]	
1	1	25	924	885	27.6	2.5	602	420	185	Example
2	2	25	905	873	7.4	2.3	583	405	89	
3	3	25	943	905	11.7	2.6	559	390	251	
4	4	25	886	842	0.8	2.2	562	388	172	
5	5	25	902	860	0.6	2.3	555	376	158	
6	6	25	924	892	7.7	2.4	560	372	223	
7	7	25	896	851	7.8	2.3	600	405	103	
8	8	25	868	822	6.2	2.2	531	377	234	
9	9	25	971	930	10.6	2.8	557	380	248	
10	10	25	910	864	0.8	2.4	542	371	256	
11	11	25	908	865	0.9	2.3	546	380	208	
12	12	25	917	879	19.3	2.2	498	356	312	
13	13	25	955	912	7.1	2.7	528	360	211	
14	14	25	843	835	0.5	2.2	506	358	229	
15	15	25	900	857	0.5	2.4	594	415	96	
16	16	25	894	862	8.3	2.2	569	391	143	
17	17	25	829	764	7.5	2.2	573	399	198	
18	18	25	902	871	6.8	2.3	585	406	85	
19	5	40	910	868	0.6	2.3	546	364	124	Comparative Example
20	19	25	925	897	0.8	2.6	446	306	289	
21	20	25	954	919	15.3	2.4	685	502	13	
22	21	25	878	836	0.5	2.5	476	321	234	
23	22	25	906	865	11.9	2.1	634	423	24	
24	23	25	923	882	0.7	2.4	468	335	195	
25	24	25	915	879	12.6	2.2	649	459	18	
26	25	25	931	900	7.8	2.5	558	394	15	
27	27	25	948	904	8.6	2.6	496	350	253	
28	29	25	967	927	9.5	2.7	503	353	230	
29	32	25	880	846	7.0	2.2	580	399	10	Example
30	33	25	903	873	0.7	2.3	490	340	126	
31	2	25	792	771	8.1	1.4	594	406	78	Comparative Example
32	12	25	910	745	7.5	2.1	475	339	91	
33	5	25	905	860	0.08	2.3	501	348	45	
34	5	25	918	879	32.1	2.4	596	420	24	

*1: Underlined if outside the scope of the disclosure.

*2: Cross-sectional dimensions: either 320 mm × 323 mm × 25 mm or 350 mm × 333 mm × 35 mm × 40 mm.

REFERENCE SIGNS LIST

5	[0056]	1	H-beam having protrusions (rolled H-beam)
		2	Flange
		3	Web
		4	Protrusion
		5	Flange 1/6B portion (sampling position)

CLAIMS

1. An H-beam having protrusions, comprising:

5 a steel composition containing C: 0.05 mass% to 0.20 mass%, Si: 0.05 mass% to 0.60 mass%, Mn: 1.20 mass% to 1.70 mass%, P: 0.035 mass% or less, S: 0.035 mass% or less, Nb: 0.005 mass% to 0.050 mass%, V: 0.005 mass% to 0.050 mass%, Ti: 0.005 mass% to 0.030 mass%, and N: 0.0020 mass% to 0.0100 mass%, within a range satisfying the following Expression (1) with the balance being Fe and inevitable impurities:

10

$$([\%S]/32)/([\%Ti]/48)+4\times([\%N]/14)/([\%Ti]/48) \leq 15.0 \quad (1),$$

where [%S], [%Ti], and [%N] are the contents in mass% of S, Ti, and N in steel;

15

a tensile strength of 490 MPa or more;
a yield strength of 355 MPa or more; and
an impact absorbed energy at 0 °C, vE₀, of 27 J or more.

2. The H-beam having protrusions according to claim 1, wherein

20

the steel composition further contains at least one selected from the group consisting of Cr: 1.0 mass% or less, Cu: 1.0 mass% or less, Ni: 1.0 mass% or less, Mo: 1.0 mass% or less, Al: 0.10 mass% or less, B: 0.010 mass% or less, Ca: 0.10 mass% or less, Mg: 0.10 mass% or less, and REM: 0.10 mass% or less.

25

3. The H-beam having protrusions according to claim 1 or 2, wherein each of the protrusions has a height of 1.5 mm or more.

4. A manufacturing method for an H-beam having protrusions by

30

hot rolling a steel material having the steel composition as recited in claim 1 or 2, the method comprising:

in the hot rolling, performing finish rolling to form protrusions on outer surfaces of flanges of the H-beam; and

35

after the finish rolling, cooling the H-beam at an average cooling rate of 0.1 °C/s to 30 °C/s in a temperature range of from a cooling start temperature of 750 °C or higher to 500 °C.

5. The manufacturing method for an H-beam having protrusions according to claim 4, wherein the finish rolling is performed in a temperature range of 800 °C or higher.