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(54) **METHOD FOR MANUFACTURING SEAMLESS STEEL PIPE**

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PROCEDE DE FABRICATION D'UN TUBE EN ACIER SANS SOUDURE

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- **PATENT ABSTRACTS OF JAPAN vol. 015, no. 289 (C-0852), 23 July 1991 (1991-07-23) & JP 03 104819 A (KAWASAKI STEEL CORP), 1 May 1991 (1991-05-01)**

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Description

[0001] The present invention relates to a production method for seamless steel pipe, and particularly, it relates to a method for improving the properties of inner surface and internal of thickness for seamless steel pipes made of materials difficult for processing, such as stainless steel.

[0002] Mannesmann-type process has been widely used for the production of seamless steel pipe heretofore. The method for producing seamless steel pipe in accordance with the Mannesmann-type method comprises first preparing a hollow pipe from a rolled raw material (round billet) heated to a predetermined temperature through a pierce-rolling step using a piercing machine. In general, as shown in Fig. 11, a piercing machine comprises two rolls and a plug supported at the front end of a bar. The round billet is forced forward to the axial direction with rotating itself by the rotation of the roll. Tensile stress and compression stress generate alternately on the central portion of the round billet as to establish a state to easily generate a hole. Thus, by setting a plug at this state, a hole generates at the central portion of the round billet to produce a hollow pipe. The pipe wall is further rolled between the roll and plug to finally yield a hollow pipe. Thereafter, the hollow pipe is successively expanded and thinned by an elongating mill such as an elongator, a plug mill, or a mandrel mill, and, after it is re-heated if necessary, the outer diameter of the pipe is reduced to provide the seamless steel pipe of desired size by using a reducing mill such as a stretch reducer, a sizer, etc.

[0003] In general, there are two types of production methods for round billets for use the raw material for seamless steel pipes. One is a direct method for continuously casting a round billet, and the other is a method comprising producing a round billet by hot rolling from continuously cast slab (simply referred to hereinafter as "slab").

[0004] As described above, hollow pipe is produced by piercing the center part of the cross section of the round billet using a plug in the piercing process. In this case, defects sometime generate on the inner surface of the hollow pipe, and the reason for this is thought to be as follows. In case the round billet for use is produced by continuous casting, as shown in Fig. 2, the center part of the cross section of the round billet approximately corresponds to the final position of solidification of continuous casting. Accordingly, porosities, cavities, and a portion at which the solute components such as S, P, Mn, etc. (referred to hereinafter as "center segregation zone") segregate, are present in the vicinity of the central portion of the cross section. The hatched portion in the figure represents the center segregation zone, porosities, and cavities. In this case, porosity refers to an aggregation of small gas pores, and cavity refers to cavities other than porosities. It is believed that defects initiated from the porosities, cavities, and center segregation zone generate on the inner surface of the hollow pipe during piercing. These become the inner surface defects of the seamless steel pipe. Fig. 3 is the enlarged view of the inner surface defects of the seamless steel pipe shown in Fig. 2. Further, as shown in Fig. 4, in case round billet is produced by hot rolling a continuously cast slab, the final solidified position is located in the vicinity of the center portion of the plate thickness direction of the continuously cast slab. Accordingly, porosities, cavities, and center segregation zone are present in the vicinity of the central portion of the cross section of the round billet. It is believed that defects initiated from the porosities, cavities, and center segregation zone generate on the inner surface of the hollow pipe during piercing. These become the inner surface defects of the seamless steel pipe. Fig. 5 is the enlarged view of the inner surface defects of the seamless steel pipe shown in Fig. 4. In particular, there is a problem that the frequency of generation is high for a material difficult for proceesing, such as stainless steel.

[0005] In the light of such circumstances, for instance, in document JP 80 52 555 regarding continuous casting of the round billet, there is proposed a production method for a seamless steel pipe free from inner surface flaws, comprising piercing after heating it to the rolling temperature, a round billet obtained by displacing the final solidification position of the billet from the billet center by 1 to 3 % of the slab diameter, and then producing a hollow pipe by piercing while setting the center of the round billet as the rolling center.

[0006] However, although it is possible to prevent inner surface flaws from generating by the technology disclosed in JP 80 52 555, there remains a problem that double sheet-like defects tend to generate in the inside of the build-up portion of the steel pipe.

[0007] The position displaced from the billet center by 1 to 3 % of the billet diameter is known to be the position subject to vigorous shear strength by the plug on piercing. Thus, if center segregation zone, porosities, and cavities present in such a high concentration at such a position, not only it becomes impossible to cohere porosities and cavities by compression, but also fractures generate due to the concentration of strain on the highly concentrated center segregation zone. It is believed that double sheet-like defects generate in this manner as shown in Fig. 6.

[0008] An object of the present invention is to overcome the aforementioned problems of the prior art technology, and to propose a production method of a seamless steel pipe showing excellent inner pipe surface (referred to hereinafter as "inner surface") properties and inner properties for build-up steel pipes (referred to hereinafter as "inside thick wall properties").

[0009] In order to accomplish the problems above, the present inventors have extensively studied on the relation between the position of center segregation zone of the rolled raw material and the generation of double sheet-like defects. As a result, the present inventors have found that, by setting the center segregation zone partition ratio W to 20 % or higher, the inner plane properties and inside thick wall properties can be improved, wherein W is defined by the following equation (1):

$$W\ (\%) = (\Delta w/D) \times 100 \qquad \text{---}\ (1)$$

(Where, W: center segregation zone partition ratio (%), Δw: the separation width of the center segregation zone at the center of thickness direction of round billet (mm), and D: total thickness of round billet (outer diameter) (mm)).

[0010] Furthermore, the present inventors have studied on a less inexpensive, more effective, and more stable production method of a slab produced by continuous casting suitable for producing a round billet having a center segregation zone partition ratio W defined by the equation (1) above of 20 % or higher.

[0011] As a method for displacing the final solidification position from the center of a slab produced by continuous casting, proposed is a method disclosed in document JP 21 82 347, which comprises differing the quantity of secondary cooling water for the central portion within the same plane of the width direction of the slab from that in the peripheral portion. However, in accordance with the study of the present inventors, it has been found difficult to stably produce a slab capable of producing a round billet having a center segregation zone partition ratio W of 20 % or higher by simply differing the quantity of secondary cooling water for the central portion from that in the peripheral portion.

[0012] The present inventors have found that, by performing casting of the steel melt inside the tundish while setting the superheating degree (=temperature of steel melt - liquidus temperature of steel) within a predetermined range, and by adjusting the secondary cooling water ratio until complete solidification within a predetermined range while setting the quantity of the secondary cooling water at the central portion in the width direction of the slab larger than that at the peripheral portion in the width direction of the slab during casting, it is possible to stably cast a slab capable of producing a round billet having a center segregation zone partition ratio W of 20 % or higher.

[0013] Thus, the present invention has been completed based on the aforementioned findings by adding further studies thereto. More specifically, in a production method for seamless steel pipe comprising producing a round billet by hot rolling a continuously cast slab, producing a hollow raw pipe by heating the round billet to a predetermined temperature and pierce-rolling, and obtaining a steel pipe of predetermined size by stretch rolling or further draw rolling the resulting hollow raw pipe, the present invention is a production method for seamless steel pipe having excellent inner plane and inside thick wall properties, characterized by that a round billet having a center segregation zone partition ratio W (%) of 20 % or higher is used, wherein W is defined by the following equation (1):

$$W\ (\%) = (\Delta w/D) \times 100 \qquad \text{---}\ (1)$$

(Where, W: center segregation zone partition ratio (%), Δw: the separation width of the center segregation zone at the center of thickness direction of round billet (mm), and D: total thickness of round billet (outer diameter) (mm)).

[0014] Further preferably in the present invention, the continuously cast slab above is cast by using a steel melt while setting the superheating degree of the steel melt inside the tundish in a range of 25 to 65°C, and, while setting the quantity of the secondary cooling water at the central portion in the width direction of the slab larger than that at the peripheral portion in the width direction of the slab, by adjusting the secondary cooling water ratio until complete solidification within a range of from 1.2 to 2.0 1/kg-steel. In this case, secondary cooling water ratio refers to the ratio of the total amount of cooling water per unit time at the secondary cooling zone (l/min) with respect to the amount cast per unit time (kg-steel/min).

Fig. 1 shows schematically drawn production process of a seamless steel pipe according to the present invention. At the same time, Fig. 1 is an explanatory diagram schematically showing the positions of the porosities, cavities, center segregation zone, and the relation among the center of piercing position and the inner surface defect positions.

Fig. 2 is an explanatory diagram schematically showing, in a conventional case using round billet as the raw material, the relation among the positions of the porosities, cavities, center segregation zone, and the center of piercing position, and the relation among the inner surface defect positions.

Fig. 3 is an enlarged diagram of the inner surface defect of a seamless steel pipe shown in Fig. 2.

Fig. 4 is an explanatory diagram schematically showing, in a conventional case using slab as the raw material, the relation among the positions of the porosities, cavities, center segregation zone, and the center of piercing position, and the relation among the inner surface defect positions.

Fig. 5 is an enlarged diagram of the inner surface defect of a seamless steel pipe shown in Fig. 4.

Fig. 6 is an explanatory diagram schematically showing for a conventional case, the relation among the positions of the porosities, cavities, center segregation zone, and the center of piercing position, and the relation among the inner surface defect positions.

Fig. 7 is an explanatory diagram provided for the explanation of the definition of center segregation zone partition ratio W.

Fig. 8 is a graph showing the influence of equiaxed crystal ratio on the morphology of the center segregation zone.

Fig. 9 is a schematic diagram showing the classification in morphology of the center segregation zone.

Fig. 10 is an explanatory diagram showing the pattern of the quantity of secondary cooling water used in the Examples.

Fig. 11 is a schematic diagram showing the process for producing a hollow pipe from a round billet using a piercing mill.

[0015] In Fig. 1 is shown the outline of the production process of a seamless steel pipe according to the present invention. In the present invention, slab is made from a steel melt having the desired composition by continuous casting method. A round billet is obtained from the continuously cast slab by hot rolling to use the raw material for seamless steel pipe.

[0016] The continuously cast slab for use in the present invention comprises a center segregation zone separated at the center part in the width direction of the slab. More specifically, a region (ΔB), in which porosities and cavities are extinguished by pressure welding and in which center segregation zone is reduced or extinguished, is provided at the central part in the width direction of the slab for about 10 % of the width B. In this manner, the center segregation zone partition ratio W (%) of the round billet, which is the rolling raw material, can be set to 20 % or higher. The degradation of inner plane properties and of inside thick wall properties, which is attributed to a large misplacement of the porosities, cavities, and the center segregation zone from the center of piercing position in the cross section of the round billet, can be prevented from occurring.

[0017] The method for establishing the region in the central part of the slab in the width direction, which is free from porosities and cavities, and from which center segregation zone is reduced or extinguished, is described below. For instance, by applying forge draft to the central part in the width direction in the vicinity of the final solidification position of the slab taken out from the continuously casting mold, porosities and cavities can be prevented from generating, and the non-solidified solution containing concentrated alloy elements can be discharged.

[0018] The steel melt injected into the casting mold solidifies from the surface layer in contact with the casting mold plane as heat is drawn out from the casting mold plane, and is drawn out continuously from the casting mold while forming a solidified shell. After drawn out from the casting mold, the steel melt is further cooled by secondary cooling using water spray and the like, such that the solidified shell may be further developed by sequential solidification. In order to reduce or extinguish the center segregation zone while preventing porosities and cavities from generating, it is preferred that 1 to 10% of press forging is applied to the portion in the vicinity of the final solidification position, more specifically, at a position containing 1 to 5% of non-solidified melt. In the present invention, porosities and cavities disappear by pressure welding accounting for 10% or more of the width at central part in the width direction of the slab, and at the same time, there is formed a region in which the center segregation zone is reduced or extinguished.

[0019] In case the region above accounts for less than 10% of the width of the slab, shear deformation functions during pierce-rolling, and double-sheet-like defects tend to generate attributed to the porosities and cavities that are present in the center segregation zone, or to the center segregation zone, etc. The wider the region, the more preferable; however, a wider region requires a wider forging region. Accordingly, the load of press forging increases as to make the apparatus unfeasibly gigantic. Hence, the upper limit of this region is about 50% of the width.

[0020] As a method for establishing the region free from porosities and cavities and from which center segregation zone is reduced or extinguished in the central part of the width direction of the slab, the following method is more preferably employed in the place of forge drafting (press forging) as below.

[0021] Slab is continuously cast by using a steel melt the superheating degree thereof inside the tundish is set in a range of 25 to 65°C, and, while setting the quantity of the secondary cooling water at the central portion in the width direction of the slab is set larger than that at the peripheral portion in the width direction of the slab during continuos casting, the secondary cooling water ratio until complete solidification is adjusted within a range of from 1.2 to 2.0 l/kg-steel.

[0022] In order to separate the center segregation zone at the center of the width direction of the slab, and to establish the region from which the center segregation zone is reduced or extinguished in the central part of the width direction of the slab, the amount of equiaxed crystals is preferably decreased by developing columnar crystals during continuous casting.

[0023] The relation between the shape of the center segregation zone of the continuously cast slab and the content ratio of equiaxed crystals is given in Fig. 8. The details of the shapes (types) present in the center segregation zone are shown in Fig. 9. Referring to Fig. 9, B represents the slab width, T represents the slab thickness, and ΔB represents the separation width of the center segregation zone. Fig. 8 shows that, as the content ratio of equiaxed crystal decreases, the shape of the center segregation zone generating on the continuously cast slab tends to shift from the common c type shape shown in Fig. 9 to the intermediate shape b type, and to the a type in which the center segregation zone is separated at the center of the width direction of the slab. The a type, in which the center segregation zone is separated at the center of the width direction of the slab, is most preferred as the raw material for seamless steel pipe.

[0024] The accurate mechanism for changing into such a shape in which the center segregation zone is separated at the center of the width direction of the slab due to the decrease of the content ratio of equiaxed crystal is not yet to be clarified, but the present inventors presume as follows.

[0025] In general, the solidified structure of a slab produced by continuous casting changes from columnar crystals in the surface layer to equiaxed crystals in the inside. The constitution ratio of the columnar crystals to the equiaxed crystals differs depending on the forging conditions. The columnar crystals continuously grow from the surface of the cast slab towards the inside, but the equiaxed crystals grow by nucleation and flotation inside the non-solidified residual metal melt. Accordingly, the static pressure of the steel melt of the non-solidified metal that functions on the slab during solidification at continuous casting is supported only by the outer shell (solidified shell) of the columnar crystals continuously growing inward from the surface, and the equiaxed crystals that are solidifying and floating have no function on the static pressure of steel melt.

[0026] That is, a thicker shell can be obtained by increasing the content ratio of columnar crystals instead of increasing the content ratio of equiaxed crystals, and hence, the expansion, i.e., the so-called bulging phenomenon occurring due to the static pressure of steel melt during solidification, which is a cause of generating and growing center segregation zone specific to continuous casting slab, can be suppressed. Accordingly, the transportation of solute-enriched steel melt among crystals due to the fluidization of steel melt residue can be suppressed, and the accumulation of enriched steel melt can also be prevented from occurring. This results in decreased generation of center segregation zone. In addition, in case the content ratio of columnar crystals is high, the volume of the residual steel melt that is present among the easily movable crystal grains also decreases at the portion of final solidification. Thus, even in case bulging phenomenon should take place, the accumulation of enriched steel melt decreases as to result in a thin finally solidified center segregation zone. The transportation of solute enriched steel melt generates not only by bulging, but also by contraction with solidification and by heat shrinkage of the solidified shell; however, in this case again, for similar reasons, the thickness of the center segregation zone and the solute segregation concentration increase.

[0027] Furthermore, in case of columnar crystals, the solidification proceeds unidirectionally. Thus, the growth rate of the columnar crystals can be increased by applying intense cooling from the surface of the slab. In contrast to above, equiaxed crystals show isotropic solidification. Hence, intense cooling from the surface of the slab hardly has effect on increasing the thickness of the outer shell. Thus, in case forced cooling is applied to the center part in the width direction of the slab under the conditions as such containing columnar crystals at high ratio, the corresponding central part of thickness solidifies more rapidly as compared with other portions.

[0028] From the reasons above, in case the content of equiaxed crystals is low, the separation of center segregation zone is believed to be accelerated by applying forced cooling in the vicinity of the central part in the width direction of the slab.

[0029] Concerning the casting conditions for suppressing the generation of equiaxed crystals, it is preferred to use a steel melt the superheating degree thereof inside the tundish is set in a range of 25 to 65°C. In case the superheating degree of the steel melt is lower than 25°C, equiaxed crystals tend to generate; in case the superheating degree becomes so high as to exceed 65°C, the rate of solidification decreases as to accelerate the delay in the position of final solidification due to lowered rate of solidification. This results in an increased formation of center segregation zone. Accordingly, the superheating degree of steel melt is preferably set in a range of 25 to 65°C.

[0030] Furthermore, continuous casting installations sometimes are equipped with an electromagnetic stirring apparatus for use in electromagnetic stirring of the steel melt inside the casting mold. Application of electromagnetic stirring inside a casting mold has excellent effects as such that it accelerates the dissolution of mold powder and induces homogeneous development of the solidified shell, thereby reducing micro segregation zones on the surface layer of the slab and preventing the defect generation, such as surface crack, from occurring. On the other hand, however, although not so affecting as the electromagnetic stirring in the secondary cooling zone, it is known to have a tendency of increasing equiaxed crystals. Accordingly, electromagnetic stirring in the casting mold is preferably not used, or used only under conditions as such that it does not considerably increase the content ratio of equiaxed crystals.

[0031] Further, in the secondary cooling zone, the secondary cooling water ratio until complete solidification is set within a range of from 1.2 to 2.0 l/kg-steel. In case the secondary cooling water ratio is less than 1.2 1/kg-steel, the cooling ability becomes too low for separating the center segregation zone, or the bulging of the solidified shell becomes too large as to accelerate the formation of the center segregation zone. On the other hand, in case the secondary cooling water ratio is greater than 2.0 l/kg-steel, surface cracks occur on the slab or porosities increase at the final solidification position as to cause fear of generating lamination on making pipes. Furthermore, the shapes of the slab become non-uniform as to increase cases of processing the slabs before rolling round billets. In view of such facts, the secondary cooling water ratio until complete solidification is set within a range of from 1.2 to 2.0 l/kg-steel. Furthermore, in the present invention, the quantity of the secondary cooling water in the secondary cooling zone is preferably set as such that it may be larger at the central portion in the width direction of the slab as compared with that at the peripheral portion in the width direction of the slab. By thus setting the quantity of the secondary cooling water larger at the central portion in the width direction of the slab as compared with that at the peripheral portion in the width direction of the slab, the growth rate of the solidified shell at the central portion in the width direction of the slab increases as to accelerate the growth of columnar crystals. Thus, it facilitates the separation in the center segregation zone. Furthermore, the quantity of the secondary cooling water at the central portion in the width direction of the slab is set as such that, in the entire range of the casting direction of the secondary casting zone, the average in the slab width direction is preferably 1.3 to 3 times larger than the quantity of the secondary cooling water in the peripheral portion in the width direction of the slab. Further, in the entire region of secondary cooling zone, the quantity of the secondary cooling water need not always be larger at the central portion in the slab width direction as compared with that in the peripheral portion in the slab width direction, but it may be the same at the upstream side of the secondary cooling zone. As the average value for the slab width direction in the entire region of casting direction in the secondary cooling zone, the quantity may be larger for the central portion in the slab width direction as compared with that for the peripheral portion in the slab width direction.

[0032] In this case, the term "central portion of width" refers to the larger one of the portion taken for 0.1 x (length of slab width) on both sides from the center in the width direction and the portion taken for (slab thickness) /2 on both sides from the center in the width direction. The term "peripheral portion in the width direction" refers to the portion remaining after removing the central portion in the width direction and the edge portions in the width direction from the length of slab width. The edge portion in the width direction refer to the larger one of the portion taken for 100 mm from the corner to the center in the direction of slab width and the portion corresponding to an area corresponding to the length of the slab thickness taken from the corner to the center in the direction of slab width.

[0033] In order to more effectively separate the center segregation zone, the thickness ratio of the equiaxed crystals in the thickness direction at the center part in the width direction of the slab is preferably controlled to 20 % or less. Since the electromagnetic stirring in the secondary cooling zone tends to hinder the development and growth of columnar crystals, it is particularly preferred in the present invention not to apply electromagnetic stirring in the secondary cooling tone.

[0034] In accordance with the method for controlling the casting conditions in the proper range described above, a region free from porosities and cavities, in which center segregation zone is reduced or extinguished, can be formed at the central part in the width direction of the slab accounting for 20 % or more without applying pressure forging. Furthermore, this method is effective in that it needs no economical load for installing and maintaining a pressure forging equipment.

[0035] The slab above having established the region in the central part of the slab in the width direction, which is freed from porosities and cavities by pressure welding, and from which center segregation zone is reduced or extinguished, is then hot rolled to obtain a round billet of desired dimension.

[0036] By applying the method above, there can be obtained a round billet having a center segregation zone partition ratio W (%) of 20 % or higher, wherein W is defined by the following equation (1):

$$W\ (\%) = (\Delta w/D) \times 100 \qquad \text{--- (1)}$$

Where, W: center segregation zone partition ratio (%), Δw: the separation width of the center segregation zone at the center of thickness direction of round billet (mm), and D: total thickness of round billet (outer diameter) (mm). The definition of the width of center segregation zone at the center of thickness direction of round billet, Δw, is given in Fig. 7.

[0037] By controlling the center segregation zone partition ratio W (%) to 20 % or higher, the region containing porosities, cavities, and center segregation zones can be removed from the inner plane on pierce rolling, so as to prevent inner defects from generating, and to improve the inner plane properties. Furthermore, the shear deformation in the region containing porosities, cavities, and center segregation zones on pierce rolling can be reduced, such that double-sheet fractures can be prevented from generating, and that the inside properties can be improved.

[0038] In case W is less than 20%, the positions at which porosities, cavities, and center segregation zones are present correspond to the region at which large shear deformations generate, and leave fear of generating inner defects and causing double-sheet fractures inside the thick walls of the steel pipe.

[0039] Based on the aforementioned facts, the center segregation zone partition ratio W was restricted to 20% or higher, preferably, in a range of from 20 to 60%. In case W is 60% or higher, there occurs fear of generating surface crack or lamination on making pipes due to the increase in porosity at the position of final solidification. Furthermore, the shapes of slab become non-uniform as to increase cases of processing the slabs before rolling round billets. Accordingly, an upper limit was set for W.

[0040] The round billet having the center segregation zone partition ratio W above is then heated to a predetermined temperature and pierce rolled to obtain a hollow pipe. Preferably, the heating temperature is set in a range of from 1200 to 1300°C. In case the temperature is lower than 1200°C, deformation resistance increases as to make rolling difficult. On the other hand, if the temperature exceeds 1300°C, there occurs problems as such that hot workability decreases due to the presence of δ ferrites or grain boundary melting, or that the amount of generated oxidation scales increases.

The conditions of piercing are not particularly limited, and there is no problem on employing the conditions generally known in the art.

[0041] Subsequently, the hollow pipe above is re-heated if necessary, and is expanded to a desired dimension by reducing the thickness using an elongating mill such as a mandrel mill, plug mill, and the like. The conditions of elongating need not be particularly limited in the present invention, and there is no problem on employing the conditions generally known in the art.

[0042] After applying elongating, the seamless steel pipe is re-heated if necessary, and is subjected to reducing. Reducing is performed by using a reducing mill such as a hot stretch reducer, sizer, and the like, so that the outer diameter may be reduced to provide the steel pipe product of the predetermined dimension. The conditions of reducing are such of an ordinary pass schedule, and there is no need of limiting it particularly.

Examples

[0043] (Example 1) The steel melt shown in Table 1 was melt in a converter, and after applying vacuum refining, slabs having a thickness of 260 mm and a width of 750 mm were cast by continuous casting process at a casting rate of 1.05 m/min. In the continuous casting, pressure forging at a draft of 0 to 5 % was applied over a length of 100 to 300 mm in the central part along the direction of width of the slab at a position in the vicinity of the final solidification point, more specifically, at a position whose non-solidified matter accounts for 2%.

[0044] The slab thus obtained was then cut, and the cross section was polished and etched, such that it may be subjected to macroscopic structure observation. Thus was confirmed the presence or absence of a region free of porosities and cavities, and in which the center segregation zone is reduced or extinguished (center segregation zone partition region), and measurements were made on the width of the separation region of the center segregation zone, ΔB (the separation width of the center segregation zone). Etching was performed by using 36% hydrochloric acid saturated with ferric chloride.

[0045] The slab thus obtained was heated to 1200°C, and then rolled into a 140 to 260 mmϕ round billet by hot rolling. The cross section of the resulting round billet was polished and etched for microscopic structure observation. Thus, porosities, cavities, and the position of center segregation zone were confirmed and the center segregation zone partition ratio W was calculated.

[0046] The round billet thus obtained was heated to 1250°C, and was piercing by using a piercer to obtain a hollow pipe. Subsequently, elongating was performed by using a mandrel mill to obtain a steel pipe 172 mm in outer diameter and 8 mm in wall thickness, and a seamless steel pipe (steel pipe product) 88.9 mmϕ in outer diameter and 6.5 mm in wall thickness was obtained by using a hot stretch reducer (reducing mill).

[0047] The properties of the inner surface, outer surface and the inside of the thick wall portion of the steel pipe product thus obtained were investigated on defects visually, with ultrasonic flaw detection and magnetic powder flaw detection. The properties of the inner and outer surface as well as the inside wall properties were evaluated by counts of inner and outer surface flaws and double-sheet fractures per 100-m length of the steel pipe product (where, evaluation is shown by the ratio with respect to a conventional case taken as 100).

[0048] The results are given in Table 2.

[0049] The examples according to the present invention show, even in case of materials difficult for processing, that the flaws on inner surface walls can be prevented from generating, and that further generation of defects in the inside of the wall portion of steel pipes, such as two-sheet fractures, can be prevented from occurring. Thus, the inner surface properties and inside wall properties are extremely improved as compared with conventional examples. Furthermore, in the comparative examples falling out of the range of the present invention, the generation of inner surface flaws and fractures inside the thick wall portion is observed.

[0050] (Example 2) The steel melt of steel composition A shown in Table 1 was molten in a converter, and after further applying vacuum refining thereto, slabs having a thickness of 260 mm and a width of 750 mm were cast by continuous casting process at a casting rate of 1.05 m/min.

[0051] Vertical bending-type continuous casting machine was used. The continuous casting machine had a machine length of 25.6 m and a secondary cooling length of 20 m from the meniscus. Continuous casting was carried out under conditions shown in Table 3.

[0052] Concerning continuous casting, superheating degree and secondary cooling water ratio were changed as shown in Table 3, and the quantity of secondary cooling water was varied in the direction of slab width. The variation in the quantity of secondary cooling water was set in two patterns as shown in Fig. 10; pattern 1 comprises setting higher in the central part in the slab width (part shown by Wc) as compared with that in the peripheral part in the slab width direction (part shown by We), and pattern 2 comprises setting constant in the width direction. In the pattern 1 of the quantity of secondary cooling water, intense cooling is applied to the central part in the slab width direction (the region (Wc) extended by 0.13B on both sides of the center of width; where B represents the slab width in millimeter) by increasing the quantity of secondary cooling water by a times as compared with that in the peripheral part in the slab width direction.

In the pattern 1 of the quantity of secondary cooling water, secondary cooling was applied by setting α = 1 and We = 100 mm for the range from meniscus to 4.0 m, and α = 2 and We = 200 mm for the range from 4.0 m to 20 m. Average value for the quantity of secondary cooling water is given in Table 3.

[0053] The slab thus obtained was cut, and the cross section perpendicular to the casting direction was polished and etched, such that it may be subjected to macroscopic structure observation. Thus was confirmed the presence or absence of a region free of porosities and cavities, and in which the center segregation zone is reduced or extinguished (center segregation zone partition region), and measurements were made on the width of the separation region of the center segregation zone, ΔB (the separation width of the center segregation zone) .

[0054] The shape of the center segregation zone was classified according to the patterns (a, b, c) shown in Fig. 9. Further, from the macroscopic structure observation, measurements on the content ratio of equiaxed crystals in the thickness direction at the central part of the slab width.

[0055] The slab thus obtained was rolled into a 190-mm diameter round billet by hot rolling. The cross section of the resulting round billet was polished and etched for macroscopic structure observation. Thus, porosities, cavities, and the position of center segregation zone were confirmed, and the center segregation zone partition ratio W was calculated.

[0056] The round billet thus obtained was heated to 1250°C, and was piercing by using a piercer to obtain a hollow pipe. Subsequently, elongating was performed by using a mandrel mill to obtain a steel pipe 172 mm in outer diameter and 8 mm in wall thickness, and a seamless steel pipe (steel pipe product) 88.9 mmϕ in outer diameter and 6.5 mm in wall thickness was obtained by using a hot stretch reducer (reducing mill).

[0057] Concerning the inner plane properties of the steel pipe product thus obtained, ultrasonic flaw detection was employed to investigate the defects. The inner plane property was evaluated by the inner plane defect ratio (counts of defects per 100 m length of steel pipe product). The results are given in Table 3.

[0058] The examples according to the present invention all show decrease in inner plane defects of the seamless steel pipe as to show improved inner plane properties. On the other hand, it can be understood that inner plane defects occur frequently on the comparative examples falling out of the range according to the present invention.

[0059] According to the present invention, the flaws on inner walls can be prevented from generating, and further generation of defects in the inside of the wall portion of steel pipes such as two-sheet fracture can be prevented from occurring, improvement of yield and productivity of seamless steel pipes can be enhanced and remarkable effects can be produced in industry.

Table 1

Steel No.	Chemical composition (mass %)							
	C	Si	Mn	S	P	Cr	Mo	Others
A	0.20	0.25	0.47	0.002	0.018	12.9	-	
B	0.10	0.39	0.42	0.002	0.017	8.7	0.98	V:0.19, Nb:0.08

Table 2

Steel Pipe No.	Steel Type No.	Continuous casting of slab		Slab – Rolling to round billet		Product size	Evaluation of properties(*)			Note (**)
		Slab thickness ts / mm	Center segregation zone separation width ΔB/B ×100%	Billet diameter after rolling D / mmϕ	Segregation zone separation ratio Δw/D ×100%	Outer diameter × wall thickness mmϕ × mm	Inner plane	Wall Inside	Outer plane	
1	A	260	0	190	0	88.9 × 7.2	100	100	100	Conventional Example 1
2	A	260	13	190	16	88.9 × 7.2	92	125	95	Comparative Example
3	A	260	22	190	25	88.9 × 7.2	57	99	101	Present Invention
4	A	260	45	140	49	40.0 × 7.0	55	101	98	Present Invention
5	B	260	27	190	30	88.9 × 7.2	60	98	102	Present Invention
6	B	260	0	190	0	88.9 × 7.2	100	100	100	Conventional Example 2

(*) Relative ratio with respect to Conventional Example 1 taken as 100

Table 3

Steel Pipe No.	Steel Type No.	Continuous casting of Slab										Slab – Round billet rolling		Product size	Evaluation of properties	Note
		Superheating of steel melt	Electro-magnetic stirring	Secondary cooling zone				Slab thickness T	Equiaxed crystals content ratio	Shape of center segregation zone	Separation width of the center segregation zone	Billet diameter after rolling	Segregation zone separation ratio	Outer diameter × wall thickness	Inner plane defect ratio	
				Pattern	Secondary cooling water ratio	Water quantity ratio in width direction (average)										
						Periphery Wo	Central Wc									
		°C		(*)	l/kg			mm	%		ΔB mm	D mmϕ	Δw/D ×100%	mmϕ × mm	counts/ 100m	
1	A	14	Yes	2	1.2	1.0	1.0	260	55	c	0	190	0	88.9 × 6.5	8.2	Comp.
2		20	Yes	2	1.2	1.0	1.0	260	30	c	0	190	0	88.9 × 6.5	4.5	Comp.
3		25	Yes	2	1.2	1.0	1.0	260	25	c	0	190	0	88.9 × 6.5	4.2	Comp.
4		46	Yes	2	1.2	1.0	1.0	260	31	c	0	190	0	88.9 × 6.5	6.7	Comp.
5		68	Yes	2	1.2	1.0	1.0	260	32	c	0	190	0	88.9 × 6.5	9.4	Comp.
6		70	Yes	2	1.2	1.0	1.0	260	29	c	0	190	0	88.9 × 6.5	10.2	Comp.
7		70	Yes	2	1.3	1.0	1.0	260	24	c	0	190	0	88.9 × 6.5	9.3	Comp.
8		14	No	1	1.2	1.0	1.2	260	40	c	0	190	0	88.9 × 6.5	3.0	Comp.
9		20	No	1	1.3	1.0	1.4	260	30	b	0	190	0	88.9 × 6.5	3.9	Comp.
10		25	No	1	1.5	1.0	1.3	260	15	a	190	190	26	88.9 × 6.5	0	Ex.
11		35	No	1	1.5	1.0	1.5	260	20	a	210	190	29	88.9 × 6.5	0	Ex.
12		46	No	1	1.2	1.0	2.0	260	15	b	55	190	8	88.9 × 6.5	2.4	Comp.
13		46	No	1	1.7	1.0	2.0	260	5	a	170	190	21	88.9 × 6.5	0	Ex.
14		50	No	1	1.5	1.0	2.0	260	9	a	145	190	20	88.9 × 6.5	0	Ex.
15		70	Yes	1	1.8	1.0	2.8	260	5	b	0	190	0	88.9 × 6.5	3.2	Comp.
16		60	No	1	1.8	1.0	2.8	260	3	a	200	190	31	88.9 × 6.5	0	Ex.

(*) See Fig. 8

Claims

1. A production method for seamless steel pipe comprising producing a round billet by hot rolling a continuously cast slab, producing a hollow pipe by heating the round billet to a predetermined temperature and piercing, and obtaining a steel pipe of predetermined size by elongating or further reducing the resulting hollow pipe,
characterized in that
the continuously cast slab is cast such that it comprises a center segregation zone separated at the center part in the width direction of the slab of dimensions such the hot rolled round billet has a center segregation zone partition ratio W (%) of 20 % or higher, wherein W is defined by the following equation (1):

$$W (\%) = (DELTA\ w / D) \times 100$$

(where DELTA w: separation width of the center segregation zone at the center of thickness direction of round billet (mm), and D: total thickness of round billet (outer diameter) (mm)).

2. The production method for seamless steel pipe as claimed in claim 1, **characterized in that** the continuously cast slab is cast by using a steel melt while setting the superheating degree of the steel melt inside the tundish in a range of 25 to 65°C, and, while setting the quantity of the secondary cooling water at the central portion in the width direction of the slab larger than that at the peripheral portion in the width direction of the slab, by adjusting the secondary cooling water ratio until complete solidification within a range of from 1.2 to 2.0 l/kg-steel.

3. The production method for seamless steel pipe as claimed in claim 1, **characterized in that** the continuously cast slab is cast by using a steel melt while setting the superheating degree of the steel melt inside the tundish in a range of 25 to 65°C, and, while setting the quantity of the average secondary cooling water at the central portion in the width direction within the entire area of the casting direction of the secondary cooling zone 1.3 to 3.0 times as large as that at the peripheral portion in the width direction of the slab, by adjusting the secondary cooling water ratio until complete solidification within a range of from 1.2 to 2.0 l/kg-steel.

4. The production method for seamless steel pipe as claimed in claim 1, **characterized in that** the thickness ratio of the equiaxed crystal ratio in the thickness direction at the width center part of the continuously cast slab accounts for 20 % or less.

Patentansprüche

1. Verfahren zur Herstellung eines nahtlosen Stahlrohres, das das Herstellen eines runden Walzblocks durch Warmwalzen einer kontinuierlichen Gußplatte, Herstellen eines hohlen Rohres durch Erwärmen des runden Walzblocks auf eine vorbestimmte Temperatur und Durchstoßen, und Erhalten eines Stahlrohres von vorbestimmter Größe durch Verlängern oder weiteres Reduzieren des sich ergebenden hohlen Rohres aufweist,
dadurch gekennzeichnet, dass
die kontinuierliche Gußplatte derart gegossen ist, dass eine zentrale Absonderungszone getrennt in dem zentralen Teil in der Richtung der Breite der Gußplatte von Abmessungen derart vorgesehen ist, dass der warm- gewalzte runde Walzblock ein Aufteilungsverhältnis W (%) der mittleren Absonderungszone von 20% oder höher hat, wobei W durch die folgende Gleichung (1) definiert ist:

$$W (\%) = (DELTA\ w/D) \times 100$$

Wo DELTA w: Trennbreite der mittleren Absonderungszone in der Mitte in der Richtung der Dicke des runden Walzblockes (mm) ist, und D: Gesamtdicke des runden Walzblocks (Außendurchmesser) (mm)).

2. Verfahren zur Herstellung eines nahtlosen Stahlrohres nach Anspruch 1, **dadurch gekennzeichnet, dass** die kontinuierliche Gußplatte unter Verwendung einer Stahlschmelze gegossen wird, während der Überhitzungsgrad der Stahlschmelze innerhalb der Gießwanne in einem Bereich von 25 bis 65° C festgelegt ist, und, während die

Menge des sekundären Kühlwassers an dem zentralen Abschnitt in der Richtung der Breite der Gußplatte größer als diejenige an dem peripheren Abschnitt in der Richtung der Breite der Gußplatte ist, durch Einstellen des sekundären Kühlwasserverhältnisses bis zum vollständigen Festwerden innerhalb eines Bereiches von 1,2 bis 2,0 l/kg - Stahl.

3. Verfahren zur Herstellung eines nahtlosen Stahlrohres nach Anspruch 1, **dadurch gekennzeichnet, dass** die kontinuierliche Gußplatte unter Verwendung einer Stahlschmelze gegossen wird, während der Überhitzungsgrad der Stahlschmelze innerhalb der Gießwanne in einem Bereich von 25 bis 65° C festgelegt ist, und, während die Menge des durchschnittlichen sekundären Kühlwassers an dem zentralen Abschnitt in der Richtung der Breite innerhalb des gesamten Bereichs der Gießrichtung der sekundären Kühlzone 1,3 bis 3,0 mal so groß wie die des peripheren Abschnittes in der Richtung der Breite der Gußplatte ist, durch Einstellen des sekundären Kühlwasserverhältnisses bis zum vollständigen Festwerden innerhalb eines Bereiches von 1,2 bis 2,0 l/kg - Stahl.

4. Verfahren zur Herstellung eines nahtlosen Stahlrohres nach Anspruch 1, **dadurch gekennzeichnet, dass** das Verhältnis der Dicke des gleichachsigen Kristallverhältnisses in der Richtung der Dicke an dem Breiten- Mittelteil der kontinuierliche Gußplatte 20 % oder weniger beträgt.

Revendications

1. Procédé de production d'un tube d'acier sans soudure comprenant les étapes consistant à produire un bloc rond en laminant à chaud une brame coulée en continu, produire un tube creux en chauffant le bloc rond à une température prédéterminée et en perçant, et obtenir un tube d'acier d'une taille prédéterminée en allongeant ou en réduisant davantage le tube creux résultant,
caractérisé en ce que
la brame coulée en continu est coulée de telle sorte qu'elle comprend une zone de ségrégation centrale, séparée au niveau de la partie centrale dans le sens de la largeur de la brame, de dimensions telles que le bloc rond laminé à chaud présente un rapport de partage de zone de ségrégation centrale W (%) de 20 % ou plus, où W est défini par l'équation (1) suivante :

$$W(\%) = (\text{DELTA } w/D) \times 100$$

(où DELTA w : largeur de séparation de la zone de ségrégation centrale au centre dans le sens de l'épaisseur du bloc rond (mm) et D : épaisseur totale du bloc rond (diamètre externe) (mm)).

2. Procédé de production d'un tube d'acier sans soudure selon la revendication 1, **caractérisé en ce que** la brame coulée en continu est coulée en utilisant une coulée d'acier tout en fixant le degré de surchauffage de la coulée d'acier à l'intérieur du bain de coulée dans une plage de 25 à 65 °C, et, tout en fixant la quantité de l'eau de refroidissement secondaire au niveau de la portion centrale dans le sens de la largeur de la brame plus grande qu'au niveau de la portion périphérique dans le sens de la largeur de la brame, en ajustant le rapport d'eau de refroidissement secondaire jusqu'à solidification complète dans une plage allant de 1,2 à 2,0 1/kg d'acier.

3. Procédé de production d'un tube d'acier sans soudure selon la revendication 1, **caractérisé en ce que** la brame coulée en continu est coulée en utilisant une coulée d'acier tout en fixant le degré de surchauffage de la coulée d'acier à l'intérieur du bain de coulée dans une plage de 25 à 65 °C, et, tout en fixant la quantité de l'eau de refroidissement secondaire moyenne au niveau de la portion centrale dans le sens de la largeur dans la zone entière de la direction de coulée de la zone de refroidissement secondaire 1,3 à 3,0 fois celle au niveau de la portion périphérique dans le sens de la largeur de la brame, en ajustant le rapport d'eau de refroidissement secondaire jusqu'à solidification complète dans une plage allant de 1,2 à 2,0 l/kg d'acier.

4. Procédé de production d'un tube d'acier sans soudure selon la revendication 1, **caractérisé en ce que** le rapport d'épaisseur du rapport de cristaux équiaxes dans le sens de l'épaisseur au niveau de la partie centrale de la largeur de la brame coulée en continu représente 20 % ou moins.

FIG. 1

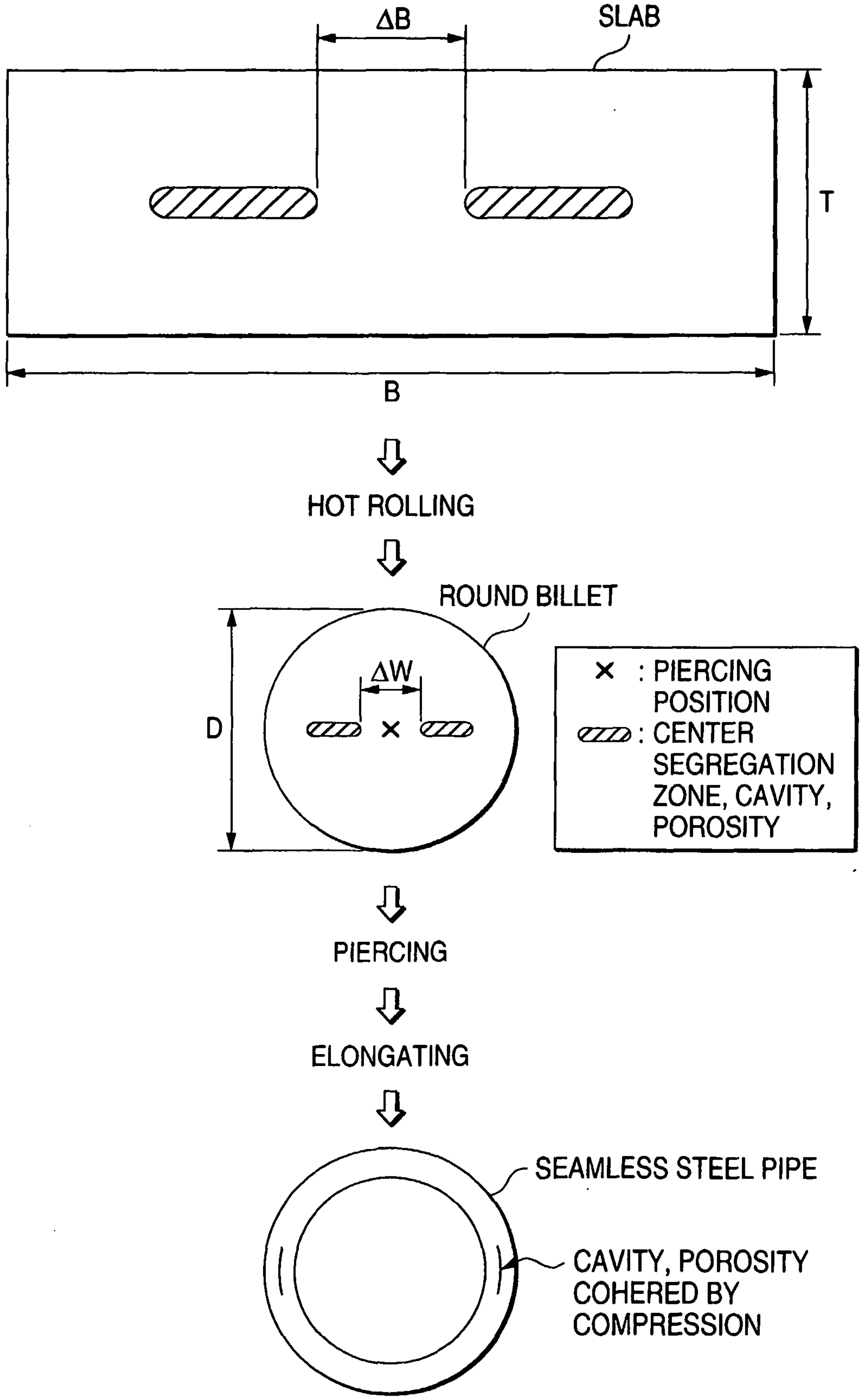

ΔB
SLAB
T
B
HOT ROLLING
ROUND BILLET
ΔW
D
× : PIERCING POSITION
: CENTER SEGREGATION ZONE, CAVITY, POROSITY
PIERCING
ELONGATING
SEAMLESS STEEL PIPE
CAVITY, POROSITY COHERED BY COMPRESSION

FIG. 2

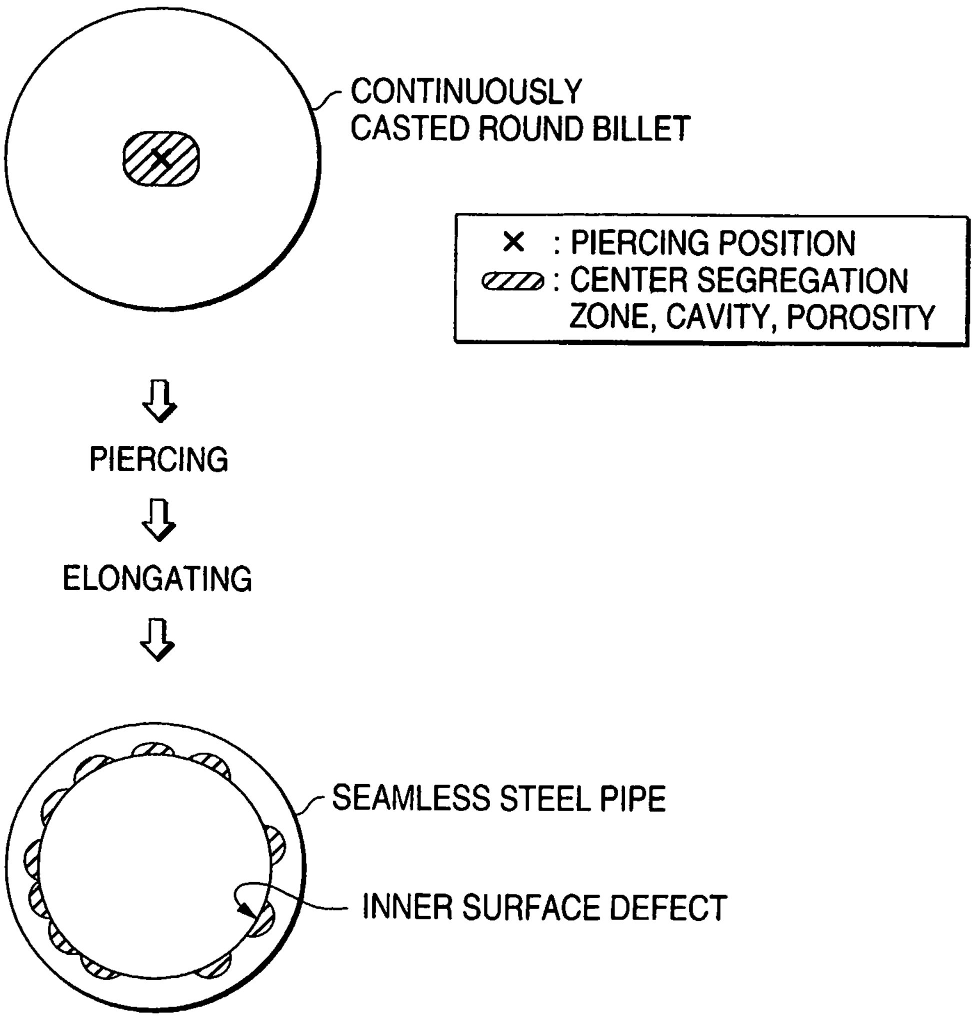

CONTINUOUSLY
CASTED ROUND BILLET
× : PIERCING POSITION
: CENTER SEGREGATION
ZONE, CAVITY, POROSITY
PIERCING
ELONGATING
SEAMLESS STEEL PIPE
INNER SURFACE DEFECT

FIG. 3

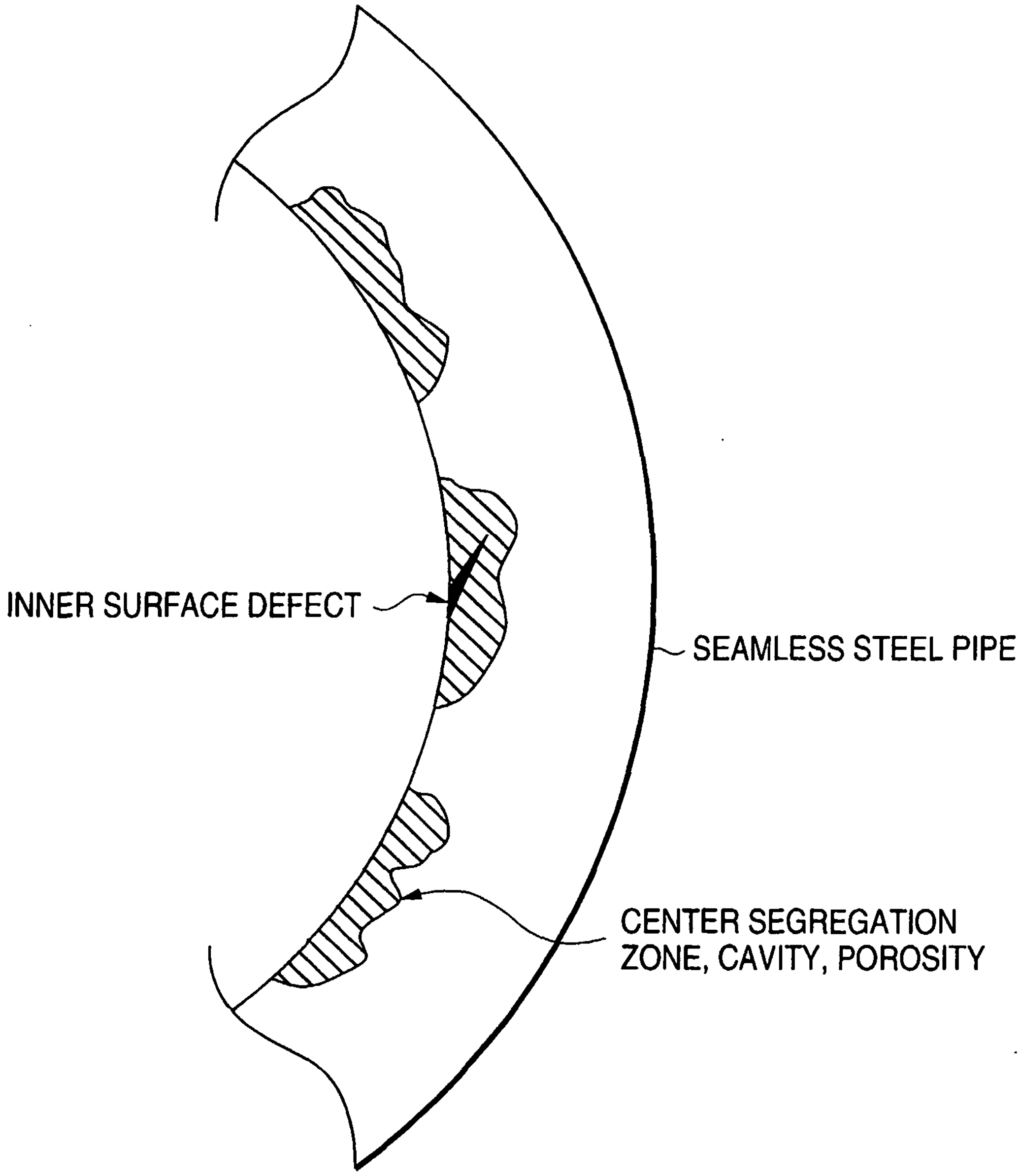

INNER SURFACE DEFECT
SEAMLESS STEEL PIPE
CENTER SEGREGATION ZONE, CAVITY, POROSITY

FIG. 4

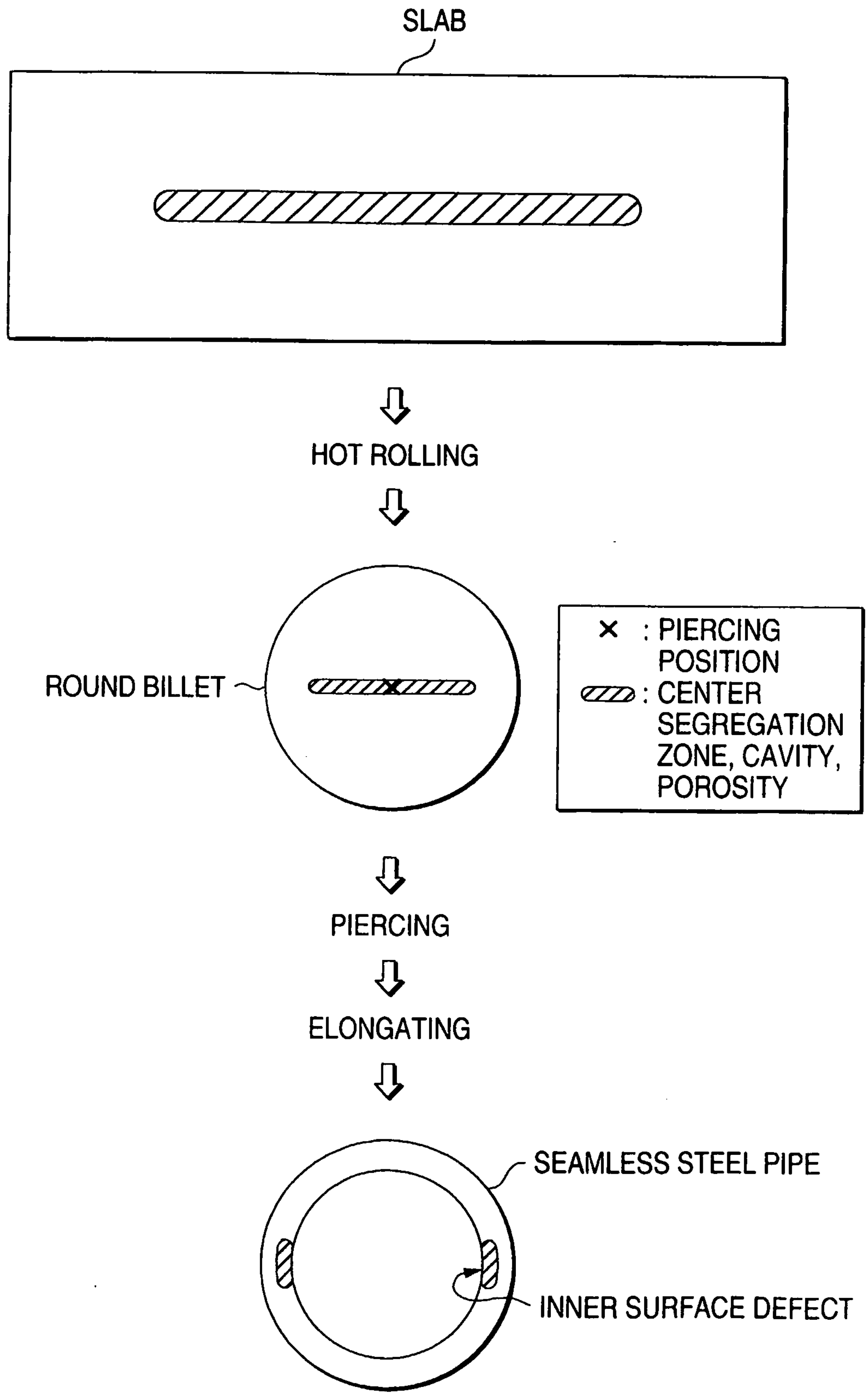

SLAB
HOT ROLLING
ROUND BILLET
× : PIERCING POSITION
: CENTER SEGREGATION ZONE, CAVITY, POROSITY
PIERCING
ELONGATING
SEAMLESS STEEL PIPE
INNER SURFACE DEFECT

FIG. 5

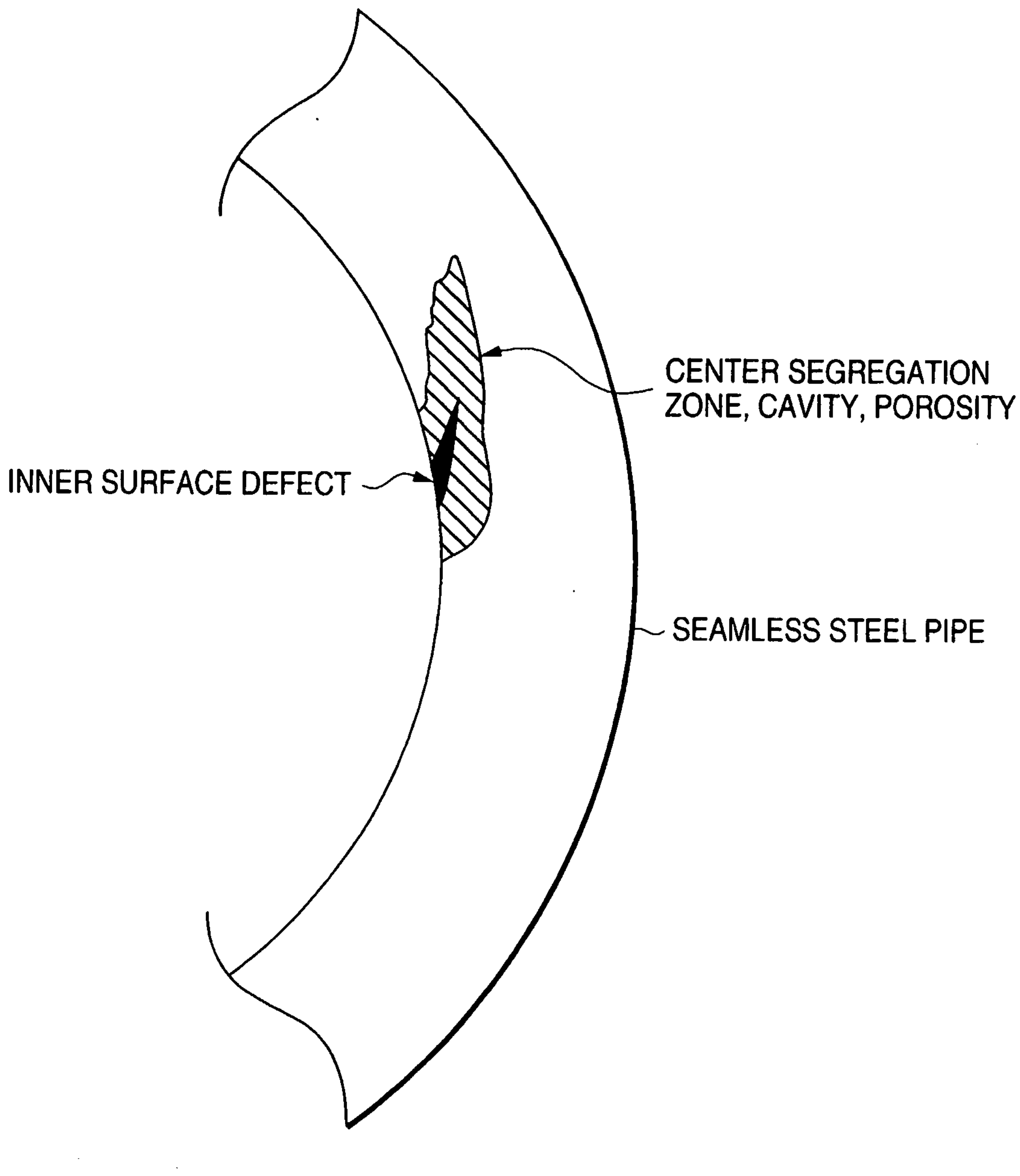

CENTER SEGREGATION
ZONE, CAVITY, POROSITY
INNER SURFACE DEFECT
SEAMLESS STEEL PIPE

FIG. 6

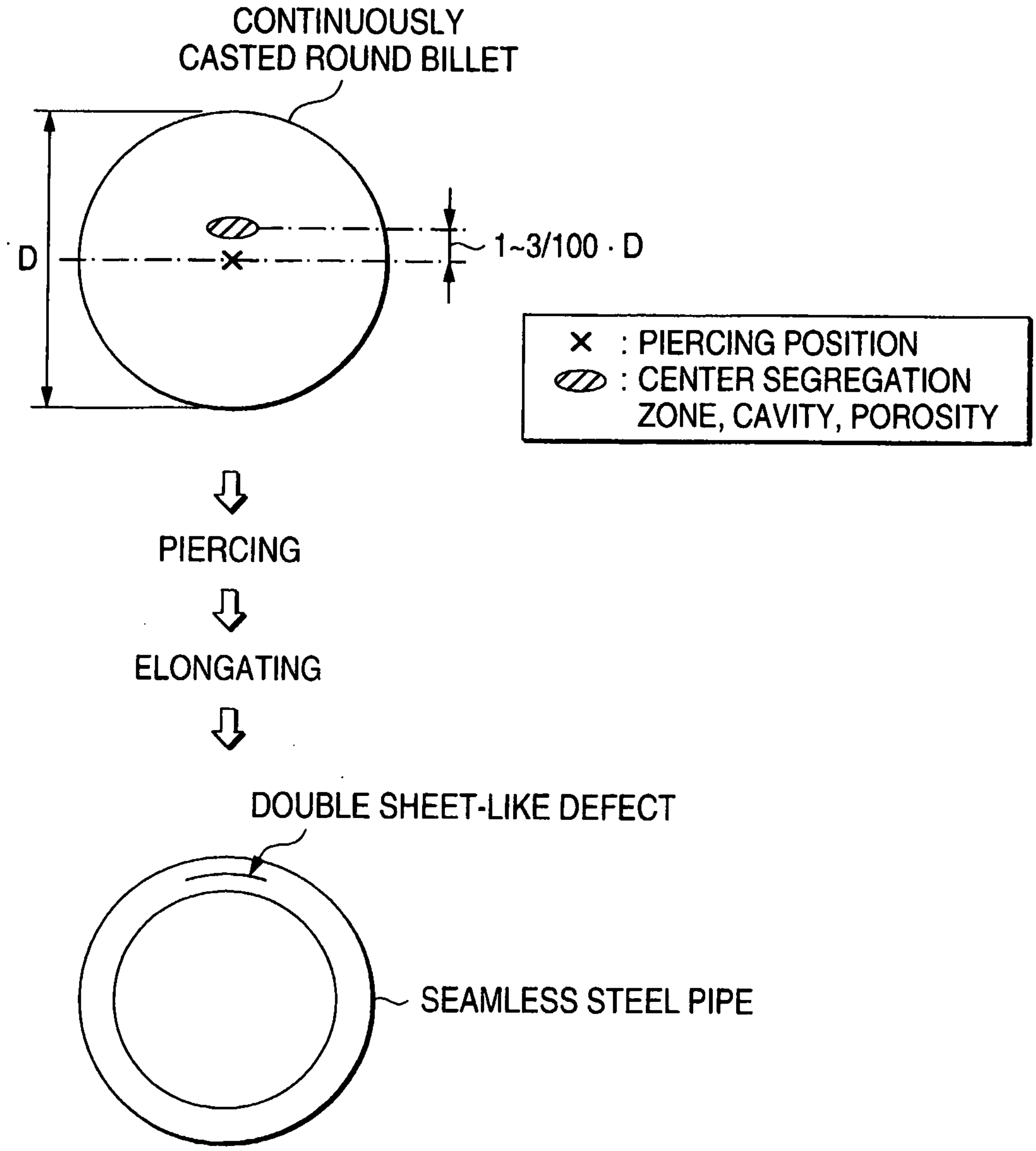

CONTINUOUSLY
CASTED ROUND BILLET
D
1~3/100 · D
× : PIERCING POSITION
: CENTER SEGREGATION
ZONE, CAVITY, POROSITY
PIERCING
ELONGATING
DOUBLE SHEET-LIKE DEFECT
SEAMLESS STEEL PIPE

FIG. 7

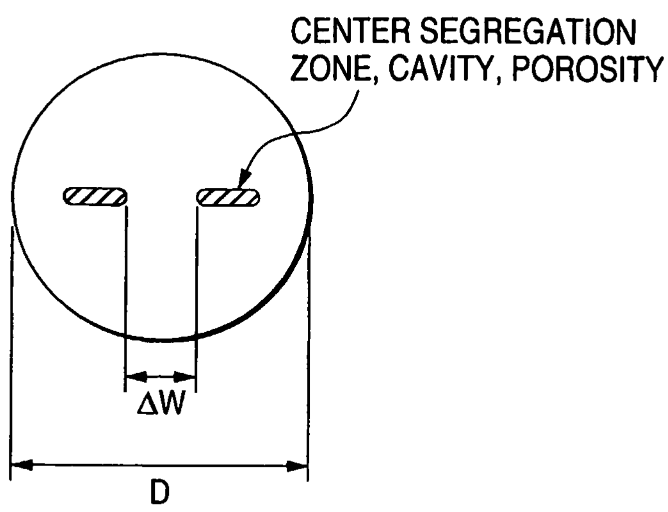

CENTER SEGREGATION
ZONE, CAVITY, POROSITY
ΔW
D

FIG. 8

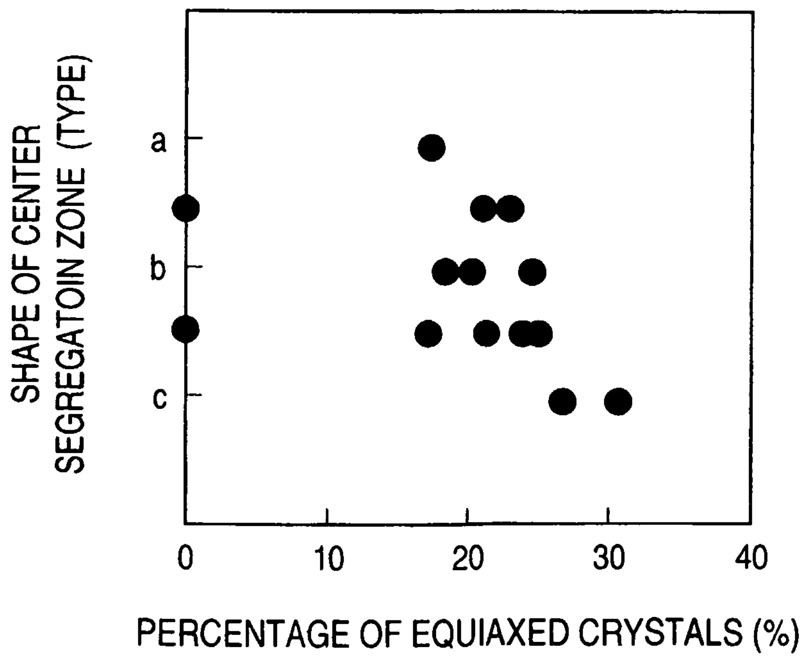

SHAPE OF CENTER
SEGREGATOIN ZONE (TYPE)
a
b
c
0
10
20
30
40
PERCENTAGE OF EQUIAXED CRYSTALS (%)

FIG. 9

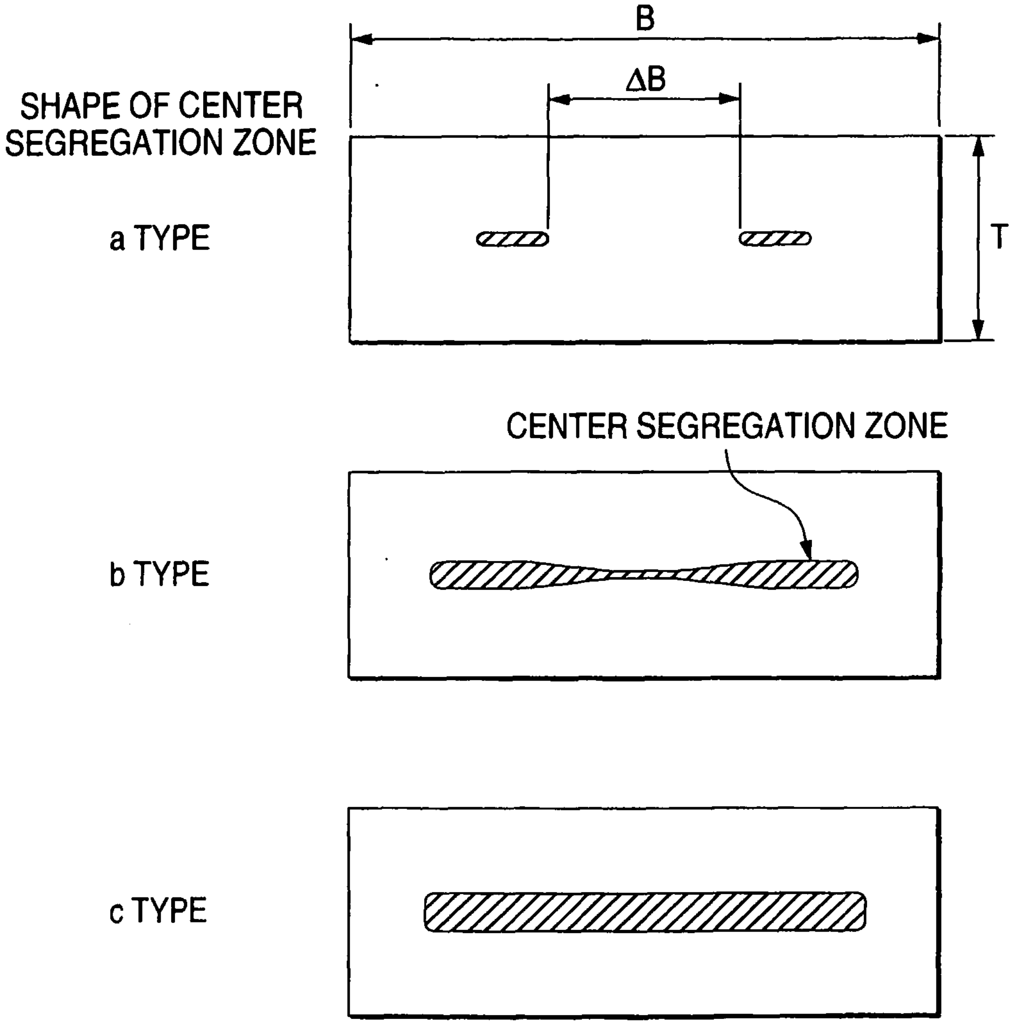

B
ΔB
SHAPE OF CENTER
SEGREGATION ZONE
a TYPE
T
CENTER SEGREGATION ZONE
b TYPE
c TYPE

FIG. 10

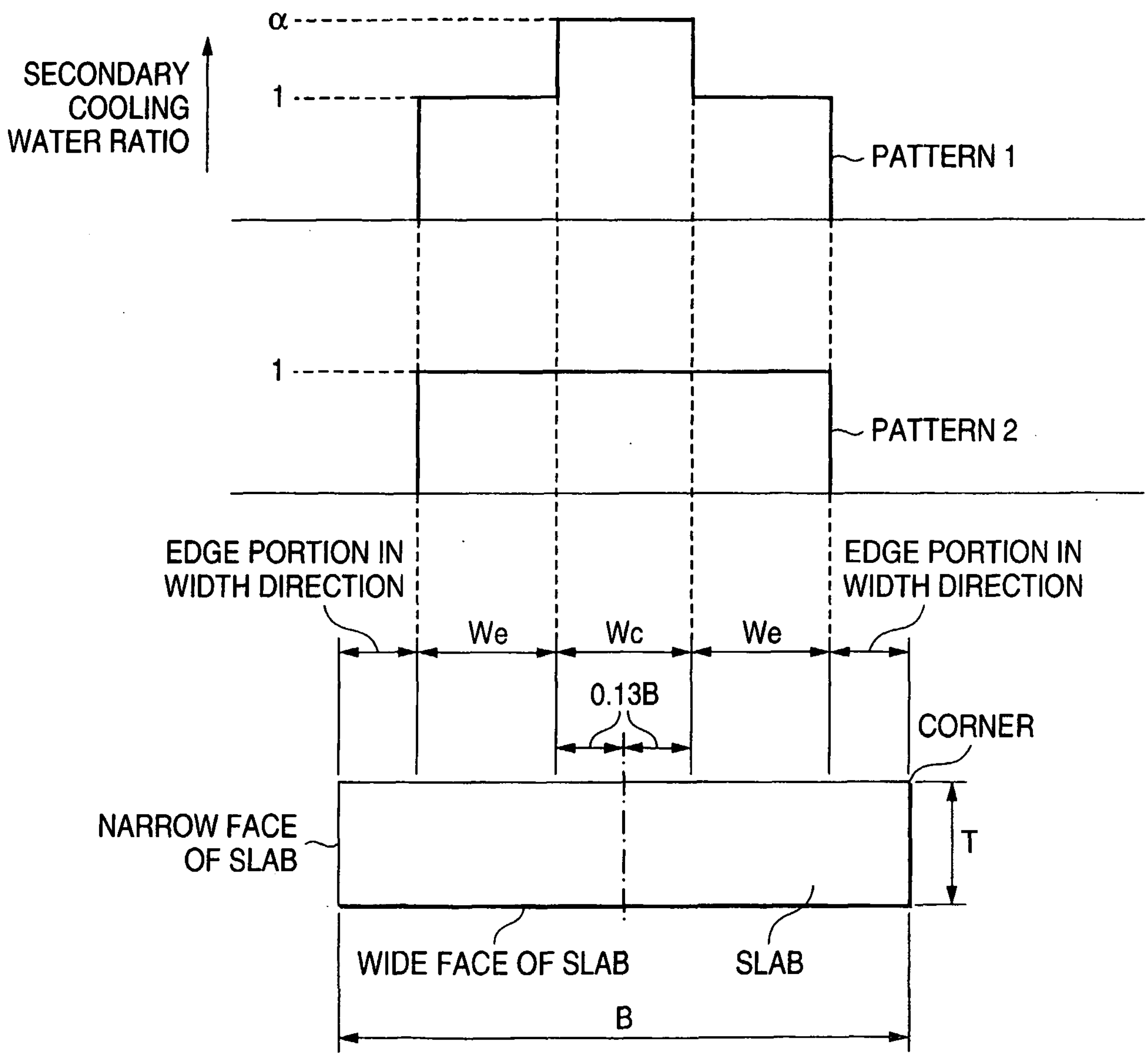
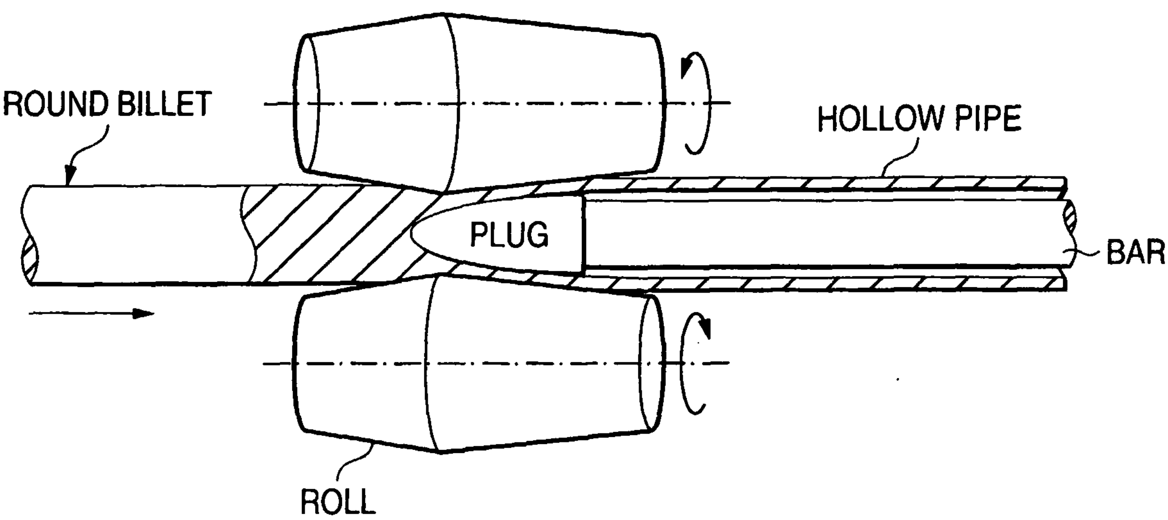

α
SECONDARY COOLING WATER RATIO
1
PATTERN 1
1
PATTERN 2
EDGE PORTION IN WIDTH DIRECTION
EDGE PORTION IN WIDTH DIRECTION
We
Wc
We
0.13B
CORNER
NARROW FACE OF SLAB
T
WIDE FACE OF SLAB
SLAB
B

FIG. 11



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Patent documents cited in the description

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- JP 2182347 A **[0011]**