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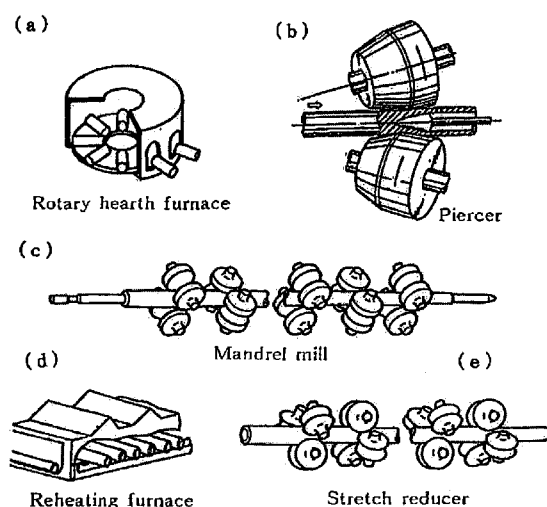
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(54) **Title:** CONTROLLED ROLLING METHOD OF SEAMLESS STEEL TUBE EXCELLENT IN STRENGTH AND LOW-TEMPERATURE TOUGHNESS

FIG. 1

(57) **Abstract:** The present invention provides a controlled rolling method of a seamless steel tube excellent in strength and low-temperature toughness to be applied to a process of making a seamless steel tube, and this controlled rolling method comprises performing piercing-rolling in the recrystallization region of the γ phase (approximately 950°C or more); performing elongation rolling and reducing rolling within the non-recrystallization region of the γ phase (950°C to Ar3 transformation point) in the elongation rolling step and in the reducing rolling step; and performing controlled cooling or quenching immediately after the reducing rolling. If a sizer is used in the reducing rolling step, the rolling in the ($\alpha + \gamma$) dual phase temperature region (Ar3 transformation point to Ar1 transformation point) is carried out in the reducing rolling step. The present controlled rolling method can solve problems of significant increase in hot deformation resistance and significant deterioration of hot deformability (hot workability) due to low-temperature rolling, and can produce a seamless steel tube excellent in strength and low-temperature toughness, along with use of a controlled cooling method.



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DESCRIPTION

TITLE OF INVENTION

CONTROLLED ROLLING METHOD OF SEAMLESS STEEL TUBE
EXCELLENT IN STRENGTH AND LOW-TEMPERATURE TOUGHNESS

TECHNICAL FIELD

[0001]

The present invention relates to a controlled rolling method of a seamless steel tube excellent in strength and low-temperature toughness, which is applied in a process of making a seamless steel tube.

BACKGROUND ART

[0002]

Examples of a process of making a seamless steel tube include a Mannesmann-plug mill process, a Mannesmann-mandrel mill process, Mannesmann-assel mill and a Mannesmann-push-bench mill process, and others.

[0003]

In these processes of making a seamless steel tube, a solid billet (round steel bar) heated at a predetermined temperature in a heating furnace is pierced and formed into a hollow piece in a hollow bar shape through a piercing-rolling mill of an inclined rolling process, and this hollow piece is formed into a hollow shell mostly by reducing a wall thickness thereof by using an elongation rolling mill such as a rotary elongator and a plug mill, a mandrel mill, an assel mill or a push-bench mill. Subsequently, the resultant hollow shell is formed into a seamless steel tube in a predetermined size mostly by reducing an outer diameter thereof by using a reducing rolling mill such as a sizer or a stretch-reducer.

[0004]

Hereinafter, explanations will be provided on the Mannesmann-mandrel mill process as an example of the above mentioned producing process, but the other producing processes exert the same actions in the production of a seamless steel tube.

[0005]

FIGS. 1 are drawings of explaining configurations of apparatuses used in the Mannesmann-mandrel mill process, and (a) illustrates a rotary hearth type heating furnace, (b) illustrates a rotary piercing mill (inclined cross roll piercing mill) (c) illustrates a mandrel mill (elongation rolling mill), (d) illustrates a reheating furnace, and (e) illustrates a stretch reducer (reducing rolling mill), respectively.

[0006]

As a rotary piercing mill illustrated in FIG. 1(b), a Mannesmann-piercing mill in which inclined barrel type rolls are driven was commonly used at the beginning, but in recent years, a so-called inclined cross piercing mill (cone piercing mill) has been widely used, in which cone-type rolls disposed in an inclined and crossed manner are driven.

[0007]

The mandrel mill illustrated in FIG. 1(c) used to comprise 8 stands, but in recent years, a mandrel mill having fewer stands including four or five stands has been increasingly used. As a notable aspect in the mandrel mill, a full float mandrel mill was commonly used at the beginning, in which a mandrel bar is inserted into the inside of a hollow shell and this hollow shell along with the inserted mandrel bar is continuously rolled by grooved caliber rolls, which is an innovation of a mandrel bar operating process; but recently, a retained mandrel mill (restrained mandrel mill) has been more widely used as a mandrel mill ensuring high efficiency and high quality.

[0008]

In this retained mandrel mill, there are a full retract process, in which a mandrel bar is retained and restrained by a mandrel bar retainer (not illustrated) from mandrel's rear side (entrance side of the rolling mill) until completion of the rolling, and the mandrel bar is retracted simultaneously with the completion of the rolling, and a semi-float process in which a mandrel bar is released simultaneously with the completion of the rolling.

[0009]

In the production of a medium-diameter seamless steel tube, a full retract process is commonly employed, and in the production of a small-diameter seamless steel tube, a semi-float process is commonly employed. In the former full retract process, an extractor is disposed on a delivery side of a mandrel mill, and a hollow

shell is pulled out by the mandrel mill during the rolling operation. If a temperature of metal of the shell on the delivery side of the mandrel mill is sufficiently high, the hollow shell can be pulled out by a sizing mill (sizer) instead of an extractor, so that this hollow shell can be subjected to a reducing rolling into a final target size, which can dispense with a reheating furnace.

[0010]

In a reducing rolling mill illustrated in FIG. 1(e), a sizer is used in the production of a medium-diameter seamless steel tube, and a stretch reducer is used in the production of a small-diameter seamless steel tube. As a sizer, a sinking sizer or a reducer whose rate of the number of revolutions of rolls in each stand is invariable was used at the beginning, but in recent years, a triple-roll type sizer or stretch reducer whose respective stands are independently driven has been widely used.

[0011]

The above mentioned triple-roll type stretch reducer includes 24 to 28 stands at maximum, and these independently driven stands can have tension force as much as 85% of deformation resistance at maximum to act between these stands, which enables not only outer diameter reduction but also wall thickness adjustment in a considerably wide range.

[0012]

To the contrary, a triple-roll type sizer includes 8 to 12 stands at maximum, and has fewer stands than those of a stretch reducer, so that large tension force cannot be expected between these stands. In addition, a triple-roll type sizer attains outer diameter reduction per stand which is much smaller than that of a stretch reducer.

[0013]

In such a process of making a seamless steel tube, a so-called inline thermo-mechanical treatment process, in which potential heat generated in hot working is effectively utilized after the hot rolling so as to perform quenching and then tempering, is sometimes employed (see Patent Literatures 1 to 3), but there is no disclosure of applying the controlled rolling method to a process of making a seamless steel tube.

[0014]

The fundamental principle of a controlled rolling method will be described as follows. The controlled rolling technology has been developed as a production technique for source material of a UOE large-diameter welded steel pipe. Source material of a UOE large-diameter welded steel tube is produced through a reverse rolling process by using a thick plate rolling mill. Such a thick plate rolling technique has been remarkably progressed in order to satisfy demands for high strength, improvement of low temperature toughness and less alloy elements of a line pipe.

[0015]

Normally, strengthening mechanism of steel includes solid-solution strengthening, precipitation strengthening, precipitation hardening, fine grain strengthening and transformation strengthening and others. Among these, the solid-solution strengthening involves increase in alloy elements, which conflicts with the demand for less alloy elements. The precipitation strengthening and the precipitation hardening accompany embrittlement, which hinders high toughness. Hence, the grain refinement is the only method for coping with both of strength and toughness, and it could be said that the progress of material in the rolling technology is attributable to the efforts of the technical development for attaining grain refinement.

[0016]

The controlled rolling method is a rolling technique for attaining grain refinement only through the rolling process by appropriately controlling processing heat history such as chemical compositions, heating temperature, rolling temperature and rolling reduction rate, and has been widely employed in the production of source materials for a high-strength and high-toughness line pipe.

[0017]

The controlled rolling method can be considered in three phases of the metallurgical mechanism. Specifically, the controlled rolling method can be categorized into three phases as follows.

[Phase 1] rolling in the recrystallization temperature region of the γ phase at a relatively higher temperature (950°C or more).

[Phase 2] rolling in the non-recrystallization temperature region of the γ phase at a lower temperature (950°C or less, Ar3 transformation point or more).

[Phase 3] rolling in the ($\gamma + \alpha$) dual phase region at a further lower temperature (Ar3 transformation point or less, Ar1 transformation point or more).

[0018]

FIG. 2 is a diagram of iron - carbon equilibrium.

FIG. 3 is a drawing of explaining three phases of the metallurgical mechanism in the controlled rolling step, and representing the change of microstructure in respective rolling temperature regions in the above mentioned three phases. The source of FIG. 3 is cited from " 'Today and future of manufacturing technologies of steel tube and pipe, 112th, 113th Nishiyama memorial Seminars,' The Iron and Steel Institute of Japan", and it should be noted that this drawing had been a metallurgical conceptual diagram before the controlled rolling method was developed, so that this drawing does not reflect a current metallurgical conceptual diagram after the controlled rolling method was developed.

[0019]

The γ grains that coarsened due to heating get refined through repetitive rolling-recrystallization in the recrystallization temperature region. If the γ grains are rolled in the low temperature region where the γ grains are unlikely to be recrystallized, the γ grains are elongated without being recrystallized, so as to form deformation zones and annealing twins inside the grains. At the time of the γ -to- α transformation, the deformation bands and the annealing twins along with the γ grain boundary contribute as formation sites of α transformation nuclei, which results in refinement of α grains.

[0020]

If the γ grains were rolled in the ($\gamma + \alpha$) dual phase region at the Ar3 point or less in addition to the above rolling in the non-recrystallization region, the untransformed γ grains become further more elongated so as to form deformation bands inside the grains. At the same time, the transformed α grains are also subjected to the rolling so that subgrains are formed in the grains, which results in further refinement of the α grains.

[0021]

Demands for heavy wall thickness, high strength and high toughness at low temperature in line pipes have encouraged development and progress of the controlled rolling technology, such as low temperature heating, increase in total rolling reduction rate in the non-recrystallization region and enhancement of the ($\gamma + \alpha$) dual phase region rolling in slabs. The advantageous metallurgical effects of low-temperature heating enhance refinement of the γ grains at the time of heating, and consequently the α grains after rolling also become refined, thereby enhancing the toughness.

[0022]

Intensified dual phase region rolling realizes increase in strength thanks to the grain refinement effects, but at the same time, promotes strong rolling texture, and generates separations in Charpy and DWTT fracture surfaces, which results in decrease in fracture transition temperature. Hence, in high-grade line pipes, the dual phase region rolling has been utilized as far as the toughness in accordance with the toughness requirement is not impaired, but gradually phased out as the controlled cooling technology is developed.

[0023]

Controlled rolled bainitic steel (acicular ferrite steel) has been developed for the purpose of grain refinement through controlled rolling and increase in strength by transformation strengthening. Increase in amount of bainite significantly enhances the strength, which is advantageous to high-strength steel of X 70 or more. The amount of bainite increases along with increase in amount of Mn, and at the same time the A_{r3} point becomes lower, thereby refining the α grains and enhancing the strength and the toughness. Slight addition of B into Nb and TiC contributes to generation of bainite, thereby attaining high strength without deteriorating toughness.

[0024]

As mentioned above, the developments of the controlled rolling technique and the micro alloying technique enable the production of source materials in high grade, and further stringent demands for high strength, high toughness, heavy wall thickness and less alloy elements require new developments of technologies, and such demands have brought about an accelerated cooling technique after a rolling process, that is, the controlled cooling technique.

CITATION LIST

PATENT LITERATURE

[0025]

Patent Literature 1: Japanese Patent Application Publication No. 06-240357

Patent Literature 2: Japanese Patent Application Publication No. 11-302785

Patent Literature 3: Japanese Patent Application Publication No. 2001-240913

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0026]

As mentioned above, the controlled rolling method is a thermo-mechanical treatment method developed in a rolling step of a thick plate which is source material of UOE large-diameter welded steel pipe, and the achievement thereof significantly depends on the fact that a thick plate rolling mill applies reverse rolling. Therefore, the above technique cannot be applied directly to a hot strip mill that applies one-way rolling.

[0027]

If the above technique is applied to the process of making a seamless steel tube, drastic modifications will be required in current commercial operations. Problems concerning this issue will be described as follows.

[0028]

(1) In order to produce a seamless steel tube excellent in strength and low-temperature toughness through the controlled rolling, the low-temperature rolling in the non-recrystallization region of the γ phase should be carried out at least in the elongation rolling step. When the low-temperature rolling in the non-recrystallization region of the γ phase is carried out in the reducing rolling step, the non-recrystallized γ grains cannot be elongated and extended because while the outer-diameter rolling reduction is carried out, the wall-thickness reduction is not carried out in this reducing rolling step. Even in the case of performing the low-temperature rolling in the non-recrystallization temperature region of the γ phase in the reducing rolling step, the elongation rolling process entails the low-temperature rolling in the non-recrystallization temperature region of the γ phase.

[0029]

Now, the Ar₃ transformation point varies according to the C content of a shell material, as illustrated in FIG. 2: approximately 850°C for a low-carbon steel of 0.10%C; 800°C for a medium-carbon steel of 0.30%C; and 770°C for a medium-carbon steel of 0.50%C. The non-recrystallization region of the γ phase falls within the temperature range from 100°C to 180°C at most, which is extremely narrow temperature range. Hence, it is not easy to maintain the rolling temperature in the elongation rolling step within this narrow temperature range.

[0030]

The rolling of a seamless steel tube is one way rolling, and its rolling speed is high, and its cooling speed is further higher than the rolling speed since the metal of shell is cooled on both inner and outer surfaces, accordingly it is further more difficult to control the rolling temperature of the seamless steel tube than the case of the thick plate rolling.

[0031]

(2) It should be noted that the low-temperature rolling in the non-recrystallization temperature region of the γ phase involves significant increase in hot deformation resistance.

FIG. 4 is a drawing of showing the respective relations between the rolling temperature and the deformation resistance: (a) in low-carbon killed steel; (b) in 0.5%Mo steel; and (c) in 1.0%Cr steel. This source is cited from the literature " 'Rolling Theory and Its Application', The Iron and Steel Institute of Japan".

[0032]

As shown in FIG. 4, the deformation resistance varies based on the chemical compositions and the strain rate of source material, and in the comparison of the rolling temperature between 1200°C and 900°C, the temperature decrease by 300°C causes triple increase in deformation resistance.

[0033]

Significant increase in rolling load, rolling torque and power required in the rolling causes not only a safety problem to a rolling mill but also serious problems to commercial operations. The thick plate rolling process applies reverse rolling so that it can easily cope with such problems simply by increasing the number of passes,

but the process of making a seamless steel tube cannot easily cope with these problems. Particularly, it is quite difficult to cope with excessive load in a piercing-rolling mill and in the subsequent elongation rolling mill.

[0034]

(3) The most problematic issue in the low-temperature rolling in the non-recrystallization temperature region of the γ phase is that hot deformability of steel material becomes deteriorated significantly.

FIG. 5 is a drawing of illustrating influence of rolling temperature on hot deformation of medium carbon steel. In this drawing, the hot deformability is represented by the number of torsion at fracture in a torsion test, and the source of this is cited from "'Rolling Theory and Its Application', The Iron and Steel Institute of Japan".

[0035]

As illustrated in FIG. 5, in the comparison of the rolling temperature between 1200°C and 900°C, decrease in temperature by 300°C causes the decrease of hot deformability to one-third. If the hot deformability is deteriorated to this extent, the significant generation of inner surface defects becomes unavoidable in the piercing-rolling step, and lamination (embedded flaw inside the wall thickness) also occurs, there is no quality as an end product any more.

[0036]

Even if the decrease of temperature might be 150°C in the piercing-roll, it is extremely difficult to produce a seamless steel tube without generating inner surface defects. Once inner surface defects are generated in the piercing-rolling step, these defects will develop more in the following elongation rolling step and in the reducing rolling process, so that these defects can never disappear.

[0037]

The present invention has been made in light of the above mentioned problems from (1) to (3), and has an object to provide a specific controlled rolling method in a process of making a seamless steel tube, so as to produce a seamless steel tube excellent in strength and low-temperature toughness, along with use of a controlled cooling process.

[0038]

As mentioned at the beginning, the present invention relates to the controlled rolling technology of a seamless steel tube, and the controlled cooling technique is an associated technique following completion of the controlled rolling step. The present invention, however, does not have an object to provide new findings in the controlled cooling process, but intends to realize the controlled rolling technology in producing a seamless steel tube.

SOLUTION TO PROBLEM

[0039]

In order to solve the above described problems, the present inventers have focused attention on that, when performing controlled rolling in a process of making a seamless steel tube, it is preferable to perform thin-wall piercing at high reduction rate by using an inclined cross piercing mill through the diameter-expansion piercing method, and it is effective to perform piercing at a higher temperature within the recrystallization region of the γ phase in the piercing-rolling step, to cope with significant increase in rolling load and significant deterioration of hot deformability in a piercing-rolling mill and an elongation rolling mill in case of the low-temperature rolling.

[0040]

The present invention has been made based on the above focus, and the summaries of the present invention consists in the following controlled rolling method of a seamless steel tube.

[0041]

(1) A controlled rolling method of a seamless steel tube excellent in strength and low-temperature toughness to be applied to a process of making a seamless steel tube in which using a round steel bar (billet) heated at a predetermined temperature in a heating furnace, a piercing-rolling step, an elongation rolling step, and a reducing rolling step are carried out, the reducing rolling step being performed, if needed, after reheating treatment, the controlled rolling method comprising: in the piercing-rolling step, performing piercing-rolling in a recrystallization region of a γ phase (950°C or more); in the elongation rolling step and in the reducing rolling step, performing elongation rolling and reducing rolling within a non-recrystallization

region of a γ phase (950°C to Ar3 transformation point), respectively; and performing controlled cooling or quenching immediately after the reducing rolling.

[0042]

(2) As similar to the above described (1), a controlled rolling method of a seamless steel tube, the controlled rolling method comprising: in the piercing-rolling step, performing piercing-rolling in a recrystallization region of a γ phase (950°C or more); in the elongation rolling step, performing elongation rolling within a non-recrystallization region of a γ phase (950°C to Ar3 transformation point); in the reducing rolling step, performing reducing rolling in a ($\alpha + \gamma$) dual phase temperature region (Ar3 transformation point to Ar1 transformation point); and performing controlled cooling or quenching immediately after the reducing rolling.

[0043]

(3) In the controlled rolling method of a seamless steel tube as set forth in (1) and (2), wherein in the piercing-roll step, preferably an inclined cross piercing mill having cone-type main rolls (cross angle: 3° to 30°, feed angle: 5° to 18°) is employed, and diameter-expansion piercing (expansion ratio: 1.05 to 2.50) is applied by setting a high cross angle and a high feed angle, so as to cope with significant increase in hot deformation resistance and significant deterioration of hot deformability (hot workability) due to low-temperature rolling.

[0044]

(4) In the controlled rolling method of a seamless steel tube as set forth in (1) to (3), wherein when performing the elongation rolling within the non-recrystallization region of the γ phase (950°C to Ar3 transformation point) in the elongation rolling step, preferably the elongation rolling is performed at least at a wall-thickness reduction rate of 40 % or more.

ADVANTAGEOUS EFFECTS OF INVENTION

[0045]

The controlled rolling method of a seamless steel tube according to the present invention can solve the problems of significant increase in hot deformation resistance and significant deterioration of hot deformability (hot workability) due to

low-temperature rolling, and can produce a seamless steel tube excellent in strength and low-temperature toughness, along with use of the controlled cooling process.

BRIEF DESCRIPTION OF DRAWINGS

[0046]

[FIG. 1] FIGS. 1 are drawings of explaining configurations of apparatuses used in the Mannesmann-mandrel mill process, and (a) illustrates a rotary hearth type heating furnace, (b) illustrates a rotary piercing mill (inclined cross roll piercing mill) (c) illustrates a mandrel mill (elongation rolling mill), (d) illustrates a reheating furnace, and (e) illustrates a stretch reducer (reducing rolling mill), respectively.

[FIG. 2] FIG. 2 is a diagram of iron - carbon equilibrium.

[FIG. 3] FIG. 3 is a drawing of explaining the three phases of the metallurgical mechanism in the controlled rolling step.

[FIG. 4] FIGS. 4 are drawings of showing the respective relations between the rolling temperature and the deformation resistance: (a) in low-carbon killed steel; (b) in 0.5%Mo steel; and (c) in 1.0%Cr steel.

[FIG. 5] FIG. 5 is a drawing of illustrating influence of rolling temperature on hot deformation of medium carbon steel.

[0047]

[FIG. 6] FIG. 6 is a drawing of illustrating the piercing principle of the diameter-expansion piercing method by using an inclined cross piercing mill.

[FIG. 7] FIG. 7 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the rolling torque in the piercing-rolling.

[FIG. 8] FIG. 8 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the rolling power.

[FIG. 9] FIG. 9 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the number of rotary forging times.

[FIG. 10] FIG. 10 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the circumferential shear strain $\gamma_{r\theta}$.

DESCRIPTION OF EMBODIMENTS

[0048]

[Control of rolling temperature in piercing-rolling step and elongation rolling step]

The controlled rolling method of a seamless steel tube according to the present invention is a controlled rolling method to be applied to a process of making a seamless steel tube, that is, the steps of making a seamless steel tube including: a heating furnace → a piercing-rolling mill → an elongation rolling mill (reheating furnace) → a reducing rolling mill.

In the piercing-rolling step, piercing-rolling is carried out in the recrystallization temperature region of the γ phase (approximately 950°C or more), and in the elongation rolling step and the reducing rolling step, the elongation rolling and the reducing rolling are carried out within the non-recrystallization temperature region of the γ phase (approximately 950°C to Ar3 transformation point), and then the controlled cooling or the quenching is carried out immediately after the reducing rolling.

[0049]

Similarly, the controlled rolling method of a seamless steel tube according to the present invention is a controlled rolling method that is applied to the process of making a seamless steel tube, in which in the piercing-rolling step, the piercing-rolling is carried out in the recrystallization temperature region of the γ phase (950°C or more), then, in the elongation rolling step, the elongation rolling is carried out in the non-recrystallization temperature region of the γ phase (950°C to Ar3 transformation point), and thereafter in the reducing rolling step, the reducing rolling is carried out in the ($\alpha + \gamma$) dual phase temperature region (Ar3 transformation point to Ar1 transformation point), and the controlled cooling or the quenching is carried out immediately after this reducing rolling. Note that this method is limitedly applied to the case of using a sizer as a reducing rolling mill.

[0050]

In the controlled rolling method of a seamless steel tube according to the present invention, various studies were made on temperature control for accomplishing such low-temperature rolling in the non-recrystallization temperature region of the γ phase in the elongation rolling step. If performing low-temperature rolling in the non-recrystallization temperature region of the γ phase in the elongation rolling step, it is common to perform the low temperature rolling also in the

foregoing piercing-rolling step to some extent. In some cases, it is common to consider the low-temperature heating in further upstream heating step.

[0051]

As described later, in the controlled rolling method of a seamless steel tube according to the present invention, it is preferable to perform the thin-wall piercing at high reduction rate through the diameter-expansion piercing method in the piercing-rolling step. During the piercing-rolling of a billet, more processing heat is generated as the temperature decreases. Hence, it is unreasonable to attempt performing the low-temperature rolling while generating processing heat.

[0052]

Therefore, it was envisaged that the moderately low-temperature rolling should be carried out in the piercing-rolling step, and the piercing be carried out at a higher temperature within the recrystallization temperature region of the γ phase, preferably at the temperature of 1050°C or more. Conveniently, if performing the thin-wall piercing at high reduction rate through the diameter-expansion piercing method, the cooling speed of a hollow piece after the piercing becomes higher even if processing heat is generated in the piercing-rolling step, so that the non-recrystallization temperature region of the γ phase can be maintained relatively easily in the elongation rolling step.

[0053]

In the thin-wall piercing at high reduction rate through the diameter-expansion piercing method, temperature drop of a pierced hollow shell becomes more significant as its absolute wall thickness becomes thinner and as its outer diameter becomes smaller. Therefore, it can be considered, particularly in the piercing-rolling step of a small-diameter seamless steel tube, to perform the piercing at a higher temperature within the recrystallization temperature region of the γ phase, and to perform the heating at a higher temperature than usual in the foregoing heating step.

[0054]

[Thin-wall piercing at high reduction rate through diameter-expansion piercing method]

In the controlled rolling method of a seamless steel tube according to the present invention, it is preferable to apply a technical philosophy of employing an inclined cross piercing mill so as to perform the thin-wall piercing at high reduction rate through the diameter-expansion piercing method. This is because it is possible to cope with significant increase in rolling load and significant deterioration of hot deformability that are caused in a piercing-rolling mill and in an elongation rolling mill due to low-temperature rolling.

[0055]

Specifically, an inclined cross piercing mill having cone-type main rolls is employed in the piercing-rolling step, so as to not only drastically reduce load in the piercing-rolling by performing the thin-wall piercing at high reduction rate through the diameter-expansion piercing method, and but also undertake, in the piercing-rolling step, substantially half of the amount of wall thickness reduction that should occur in the elongation rolling step, thereby drastically reducing load in the elongation rolling.

[0056]

FIG. 6 is a drawing of illustrating the piercing principle of the diameter-expansion piercing method by using an inclined cross piercing mill. The diameter-expansion piercing suppresses the rotary forging effect in front of a plug. The feed angle β and the roll cross angle γ are defined respectively in the same drawing.

[0057]

FIG. 7 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the rolling torque in the piercing-rolling. FIG. 8 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the rolling power. In these drawings, γ denotes the roll cross angle and β denotes the feed angle, respectively. In both drawings, it is obvious that the rolling load decreases significantly as the expansion ratio becomes larger. The source of FIG. 6 to FIG. 8 is cited from " 'Production Method of Steel Tube', The Iron and Steel Institute of Japan".

[0058]

From the results of FIG. 7 and FIG. 8, in the controlled rolling method of a seamless steel tube according to the present invention, it is obvious that it is

preferable to utilize the diameter-expansion piercing method as a solution of coping with excessive load in a piercing-rolling mill. Note that the rolling load increases slightly as the roll cross angle becomes larger and as the roll feed angle becomes larger.

[0059]

In the diameter-expansion piercing method, if the number of rotary forging times before a round steel bar (billet) reaches a tip end of a plug after being fed in the cone-type main rolls is significantly reduced, and if a stress field of additional shear deformation inherent in the cross roll piercing is released by high feed and high cross angle piercing, it is also possible to cope with the significant deterioration of hot deformability.

[0060]

Since the rotary forging effect (Mannesmann effect) in the piercing-rolling causes inner surface defects, and the stress field of the additional shear deformation causes propagation of the inner surface defects, it is also possible to cope with the significant deterioration of hot deformability due to the low-temperature rolling by employing the diameter-expansion piercing method.

[0061]

FIG. 9 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the number of rotary forging times. FIG. 10 is a drawing of showing influences of the expansion ratio, the roll cross angle and the feed angle on the circumferential shear strain $\gamma_{r\theta}$. As similar to FIG. 7 and FIG. 8, γ denotes the roll cross angle and β denotes the feed angle, respectively in FIG. 9 and FIG. 10. The source of FIG. 9 and FIG. 10 is cited from " 'Production Method of Steel Tube', The Iron and Steel Institute of Japan".

[0062]

As obvious in FIG. 9, the number of rotary forging times significantly decreases as the expansion ratio becomes larger and as the roll cross angle and the feed angle become larger. Accordingly, it is obvious that the cause of generating the inner surface defects is minimized.

[0063]

As obvious in FIG. 10, the circumferential shear strain $\gamma_{r\theta}$ is significantly reduced as the roll cross angle and the feed angle become larger. Accordingly, it is obvious that the cause of propagating the inner surface defects disappear. Note that the influence of the expansion ratio on the circumferential shear strain $\gamma_{r\theta}$ is reverse to the influences of the roll cross angle and the feed angle, thus, as the expansion ratio becomes larger, the circumferential shear strain $\gamma_{r\theta}$ slightly increases. Namely, slight deterioration takes place to an extent without causing any problem.

[EXAMPLES]

[0064]

Hereinafter, descriptions will be provided on the advantageous effects achieved by "the controlled rolling method of a seamless steel tube" according to the present invention, influencing on strength and low-temperature toughness based on the following Examples. The rolling temperature in each step in the Examples is represented by the temperature on the delivery side of each rolling mill.

[0065]

[Example 1]

A 147.0 mm ϕ medium-carbon round steel bar having a chemical composition of 0.30 %C - 1.10 %Mn - 0.30 %Mo was used as a test sample, and this sample was rolled into a size of 76.2 mm $\phi \times 4.0$ mm t by a small-diameter Mannesmann mandrel mill process including a heating furnace → an inclined cross piercing mill → a mandrel mill → a reheating furnace → a stretch reducer. The rolling condition in each step is as follows.

[0066]

(1) Heating step

Steel bar size: 147.0 mm ϕ , heating temperature: 1200°C

(2) Piercing-rolling step

Piercing size: 196.0 mm $\phi \times 11.8$ mm t

Rolling temperature: 1110°C (recrystallization temperature region of γ phase)

Rolling condition: roll cross angle: 10°, roll feed angle: 12°, expansion ratio: 1.333, piercing ratio: 3.39

[0067]

(3) Elongation rolling step

Elongation size: 151.0 mm ϕ $\times$ 4.25 mm t

Rolling temperature: 900°C (non-recrystallization temperature region of γ phase)

Rolling condition: number of stands: 8, wall thickness reduction: 64.0 %, elongation ratio: 3.47

(4) Reheating step

Heating temperature: 920°C

[0068]

(5) Reducing rolling step

Reducing size: 76.2 mm ϕ $\times$ 4.0 mm t

Rolling temperature: 840°C (non-recrystallization temperature region of γ phase)

Rolling condition: number of stands: 16, outer diameter reduction: 49.5 %, elongation ratio: 2.16

(6) Controlled cooling: cold water quenching

(7) Results of characterization test: strength: YS = 770 Mpa low-temperature toughness: vTrs = - 88°C

[0069]

[Example 2]

A 225.0 mm ϕ medium-carbon round steel bar having a chemical composition of 0.40 %C - 1.20 %Mn - 0.35 %Mo was used as a test sample, and this sample was rolled into a size of 273.0 mm ϕ $\times$ 6.5 mm t by a medium-diameter Mannesmann mandrel mill process including a heating furnace $\rightarrow$ an inclined cross piercing mill $\rightarrow$ a mandrel mill $\rightarrow$ sizer. The rolling condition in each step is as follows.

[0070]

(1) Heating step

Steel bar size: 225.0 mm ϕ , heating temperature: 1180°C

(2) Piercing-rolling step

Piercing size: 335.0 mm ϕ $\times$ 15.5 mm t

Rolling temperature: 1090°C (recrystallization temperature region of γ phase)

Rolling condition: roll cross angle: 20°, roll feed angle: 10°, expansion ratio:

1.488, piercing ratio: 2.55

[0071]

(3) Elongation rolling step

Elongation size: 295.0 mm $\phi \times 6.5$ mm t

Rolling temperature: 920°C (non-recrystallization temperature region of γ phase)

Rolling condition: number of stands: 5, wall thickness reduction: 58.0 %, elongation ratio: 2.64

(4) Reducing rolling step

Reducing size: 273.0 mm $\phi \times 6.5$ mm t

Rolling temperature: 870°C (non-recrystallization temperature region of γ phase)

Rolling condition: number of stands: 8, outer diameter reduction: 7.5 %, elongation ratio: 1.08

(5) Controlled cooling: cold water quenching

(6) Results of characterization test: strength: YS = 765 Mpa low-temperature toughness: $vTrs = -86^{\circ}C$

[0072]

[Example 3]

A 225.0 mm ϕ low-carbon round steel bar having a chemical composition of 0.10 %C - 0.65 %Mn - 0.05 %Mo was used as a test sample, and this sample was rolled into a size of 273.0 mm $\phi \times 6.5$ mm t by a medium-diameter Mannesmann mandrel mill process including a heating furnace $\rightarrow$ an inclined cross piercing mill $\rightarrow$ a mandrel mill $\rightarrow$ sizer. The rolling condition in each step is as follows. The rolling size in each step is the same as that in Example 2.

[0073]

(1) Heating step

Steel bar size: 225.0 mm ϕ , heating temperature: 1160°C

(2) Piercing-rolling step

Piercing size: 335.0 mm $\phi \times 15.5$ mm t

Rolling temperature: 1070°C (recrystallization temperature region of γ phase)

Rolling condition: roll cross angle: 20°, roll feed angle: 10°, expansion ratio:

1.488, piercing ratio: 2.55

[0074]

(3) Elongation rolling step

Elongation size: 295.0 mm $\phi \times 6.5$ mm t

Rolling temperature: 900°C (non-recrystallization temperature region of γ phase)

Rolling condition: number of stands: 5, wall thickness reduction: 58.0 %, elongation ratio: 2.64

(4) Reducing rolling step

Reducing size: 273.0 mm $\phi \times 6.5$ mm t

Rolling temperature: 830°C ($(\alpha + \gamma)$ dual phase temperature region)

Rolling condition: number of stands: 8, outer diameter reduction: 7.5 %, elongation ratio: 1.08

(5) Controlled cooling: cold water quenching

(6) Results of characterization test: strength: YS = 760 Mpa, low-temperature toughness: $vTrs = -84^{\circ}\text{C}$

[0075]

In this case, the reducing rolling step performs the $(\alpha + \gamma)$ dual phase region rolling, but the rolling of reducing wall thickness was not carried out although the outer diameter reduction rolling, while slight reduction, was carried out, so that no grains were elongated and no side effects such as separations were observed.

[0076]

If a stretch reducer is used as a reducing rolling mill, it is preferable to avoid to perform the reducing rolling in the $(\alpha + \gamma)$ dual phase region as much as possible. Strains are accumulated by the outer-diameter reduction rolling in back-to-back multiple stands, which may cause separations in a Charpy test or the like. In the case of using a stretch reducer in the reducing rolling step, a reheating furnace is disposed, thus, there are no hindrances in the reducing rolling in the non-recrystallization temperature region of the γ phase.

[0077]

The strength required for an oil well tube and a line pipe is usually 740 Mpa or more in terms of YS, and the required low-temperature toughness is usually -80°C

in terms of vTrs. Specific explanations have been provided on the effects of the controlled rolling process based on the three Examples, and the advantageous effects achieved by the present invention are obvious.

[0078]

[Issue to be addressed in future]

As described above, according to present invention, it is supposed to perform the controlled cooling subsequent to the controlled rolling, and the controlled rolling method is the specific subject matter of the present invention, but the controlled cooling process is not the subject of the present invention. In the above three Examples, the description of "cold water quenching" in the item of the "controlled cooling" merely indicates a simulation of ultimate controlled cooling by using the existing quenching system.

[0079]

The company to which the applicants of the present patent application belong does not have any controlled cooling system dedicated to producing a seamless steel tube. There is nothing to be heard about that some other companies may be constructing such a controlled cooling system in the same industry through the world, so far. It is a future issue to develop a specific controlled cooling method that promises further enhancement of strength and low-temperature toughness.

INDUSTRIAL APPLICABILITY

[0080]

The present invention can solve the problems of significant increase in hot deformation resistance and significant deterioration of hot deformability (hot workability) due to low temperature rolling, resulted from applying the controlled rolling method to the process of making a seamless steel tube, and can produce a seamless steel tube excellent in strength and low-temperature toughness, along with use of the controlled cooling process.

In the present invention, the discussion has been provided on the controlled rolling method for enhancing strength and toughness only by performing the rolling without performing discrete quenching-tempering after the hot rolling step, but it should be appreciated that this technical philosophy is also applicable to the

controlled rolling method of a seamless steel tube configured to accomplish further refinement of crystal grains in a discrete quenching-tempering step after the hot rolling step.

CLAIMS

1. A controlled rolling method of a seamless steel tube excellent in strength and low-temperature toughness to be applied to a process of making a seamless steel tube in which using a round steel bar (billet) heated at a predetermined temperature in a heating furnace, a piercing-rolling step, an elongation rolling step, and a reducing rolling step are carried out, the reducing rolling step being performed, if needed, after reheating treatment, characterized in that the controlled rolling method comprises:

in the piercing-rolling step, performing piercing-rolling in a recrystallization region of a γ phase (950°C or more);

in the elongation rolling step and in the reducing rolling step, performing elongation rolling and reducing rolling within a non-recrystallization region of a γ phase (950°C to Ar3 transformation point), respectively; and

performing controlled cooling or quenching immediately after the reducing rolling.

2. A controlled rolling method of a seamless steel tube excellent in strength and low-temperature toughness to be applied to a process of making a seamless steel tube in which using a round steel bar (billet) heated at a predetermined temperature in a heating furnace, a piercing-rolling step, an elongation rolling step, and a reducing rolling step by means of a sizer are carried out, the reducing step being performed, if needed, after reheating treatment, characterized in that the controlled rolling method comprises:

in the piercing-rolling step, performing piercing-rolling in a recrystallization region of a γ phase (950°C or more);

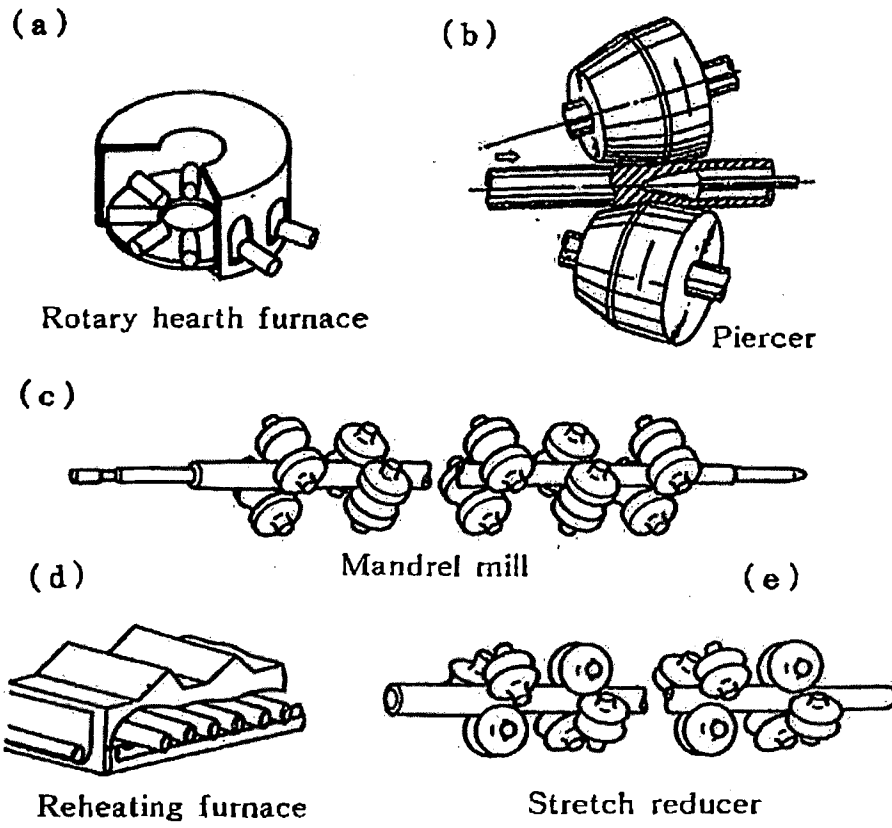
in the elongation rolling step, performing elongation rolling within a non-recrystallization region of a γ phase (950°C to Ar3 transformation point);

in the reducing rolling step, performing reducing rolling in a ($\alpha + \gamma$) dual phase temperature region (Ar3 transformation point to Ar1 transformation point); and

performing controlled cooling or quenching immediately after the reducing rolling.

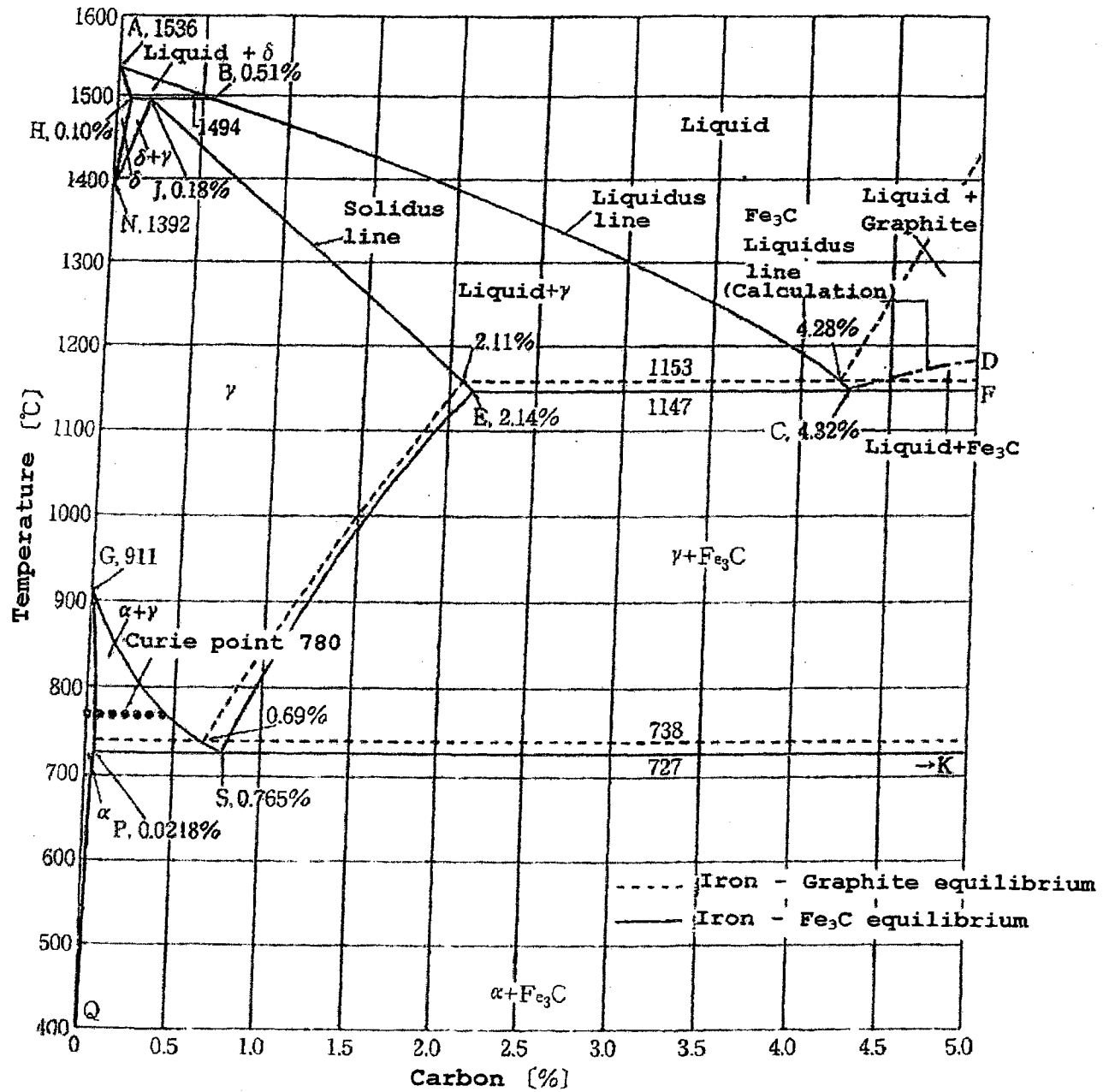
3. The controlled rolling method of a seamless steel tube excellent in strength and low-temperature toughness according to claim 1 or 2, characterized in that in the piercing-roll step, an inclined cross piercing mill having cone-type main rolls (cross angle: 3° to 30° , feed angle: 5° to 18°) is employed, and diameter-expansion piercing (expansion ratio: 1.05 to 2.50) is applied by setting a high cross angle and a high feed angle, so as to cope with significant increase in hot deformation resistance and significant deterioration of hot deformability (hot workability) due to low-temperature rolling.
4. The controlled rolling method of a seamless steel tube excellent in strength and low-temperature toughness according to any one of claims 1 to 3, characterized in that when performing the elongation rolling within the non-recrystallization region of the γ phase (950°C to Ar3 transformation point) in the elongation rolling step, the elongation rolling is performed at least at a wall-thickness reduction rate of 40 % or more.

FIG. 1



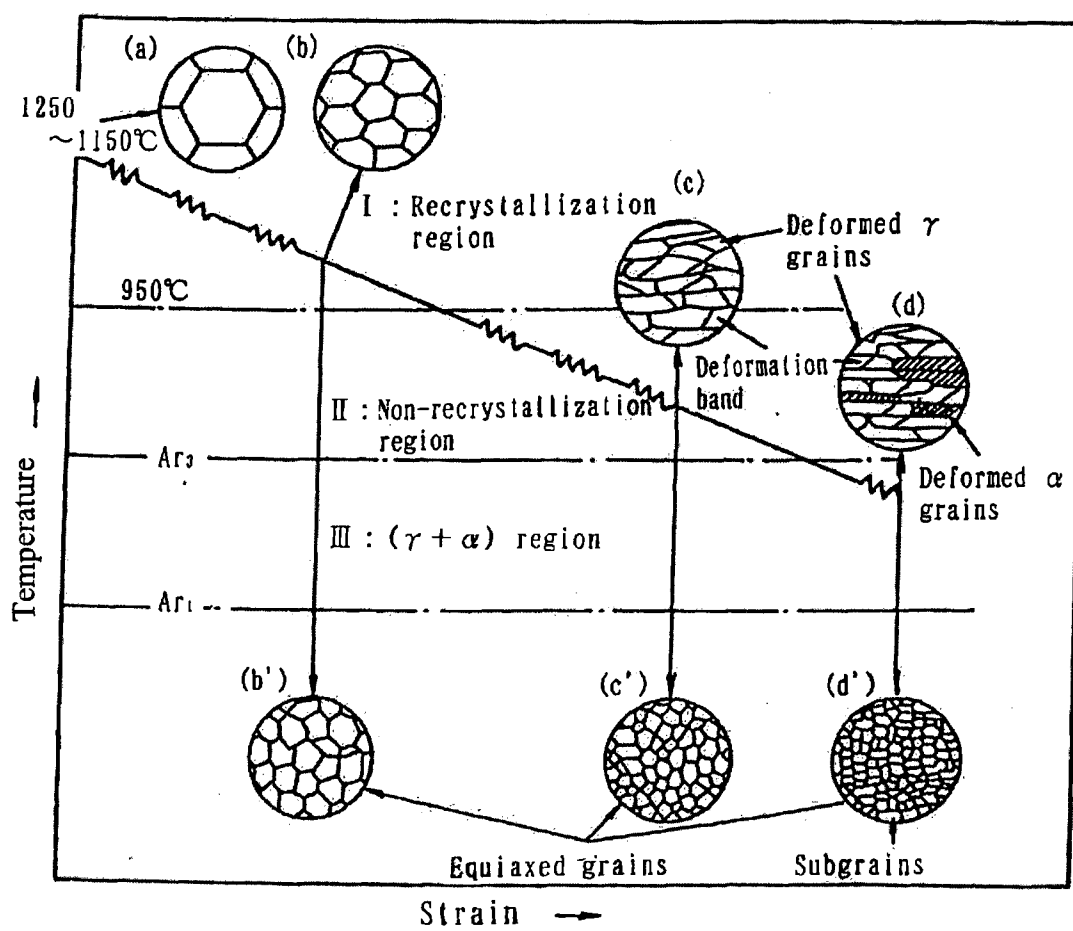
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FIG. 2

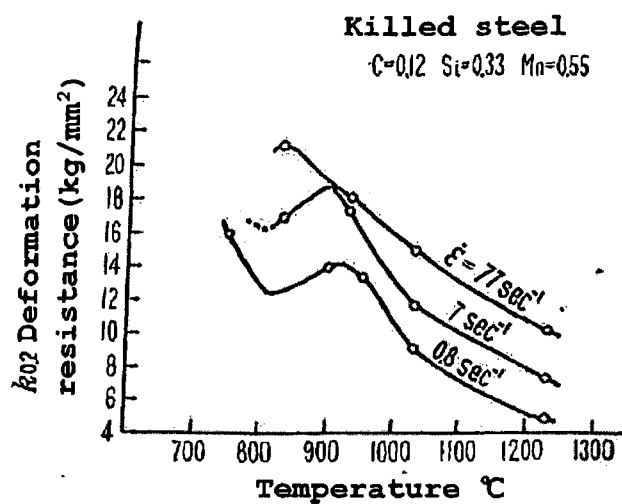


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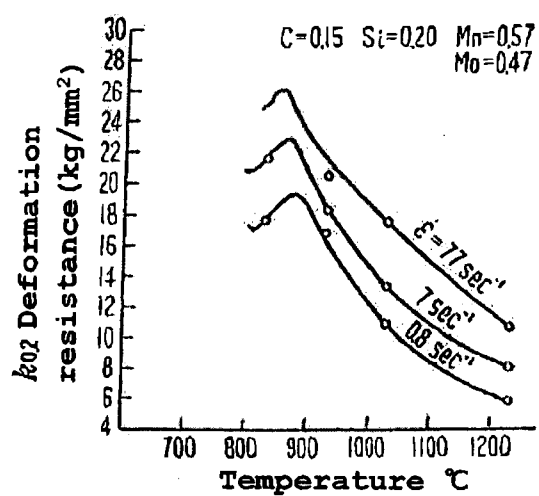
FIG. 3



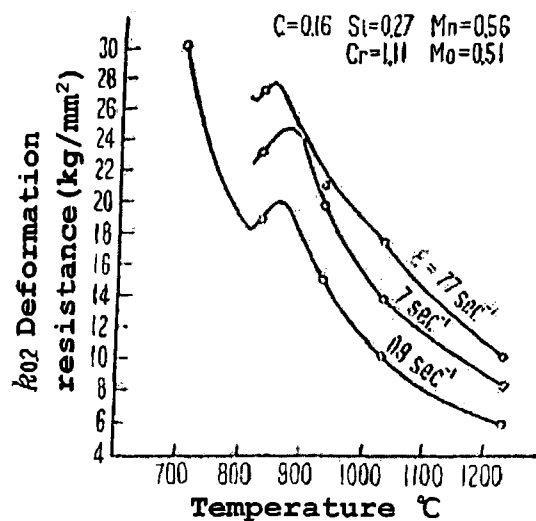
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FIG. 4
(a)

(b)

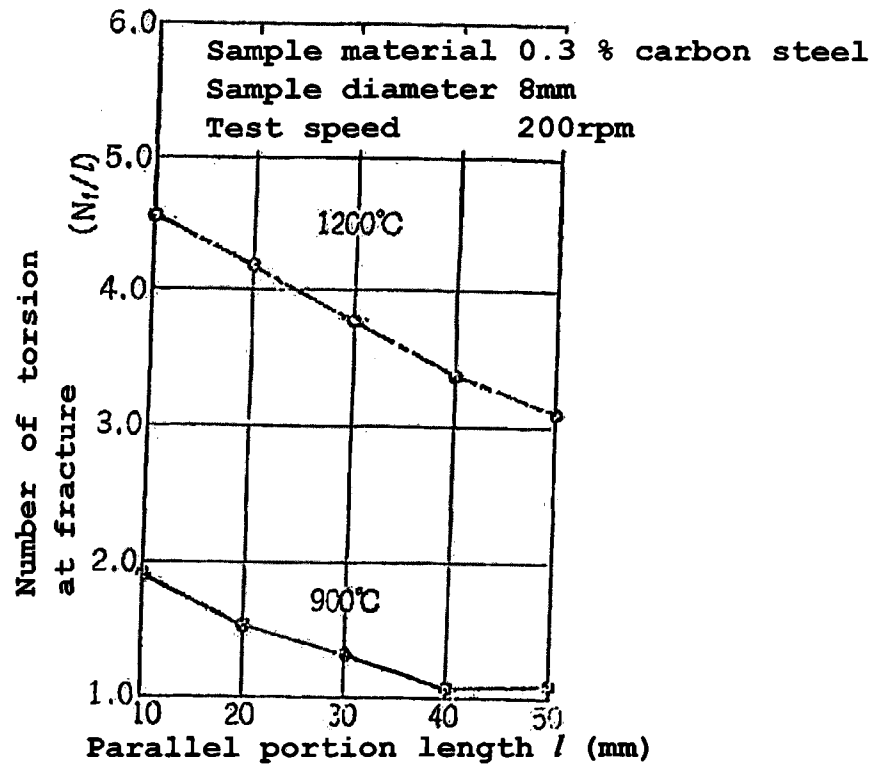


(c)



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FIG. 5



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FIG. 6

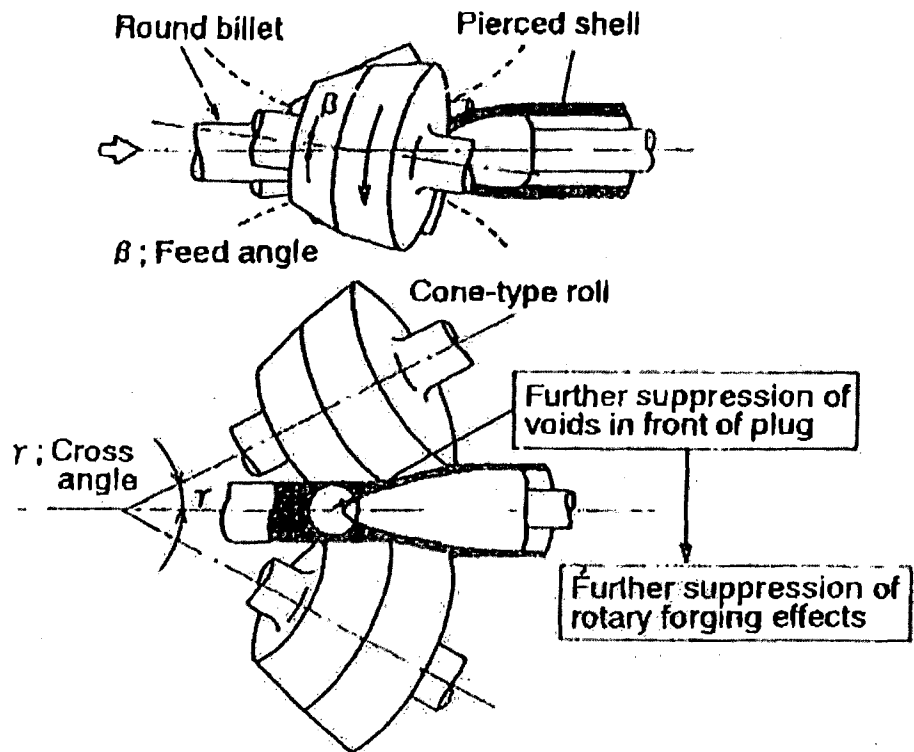


FIG. 7

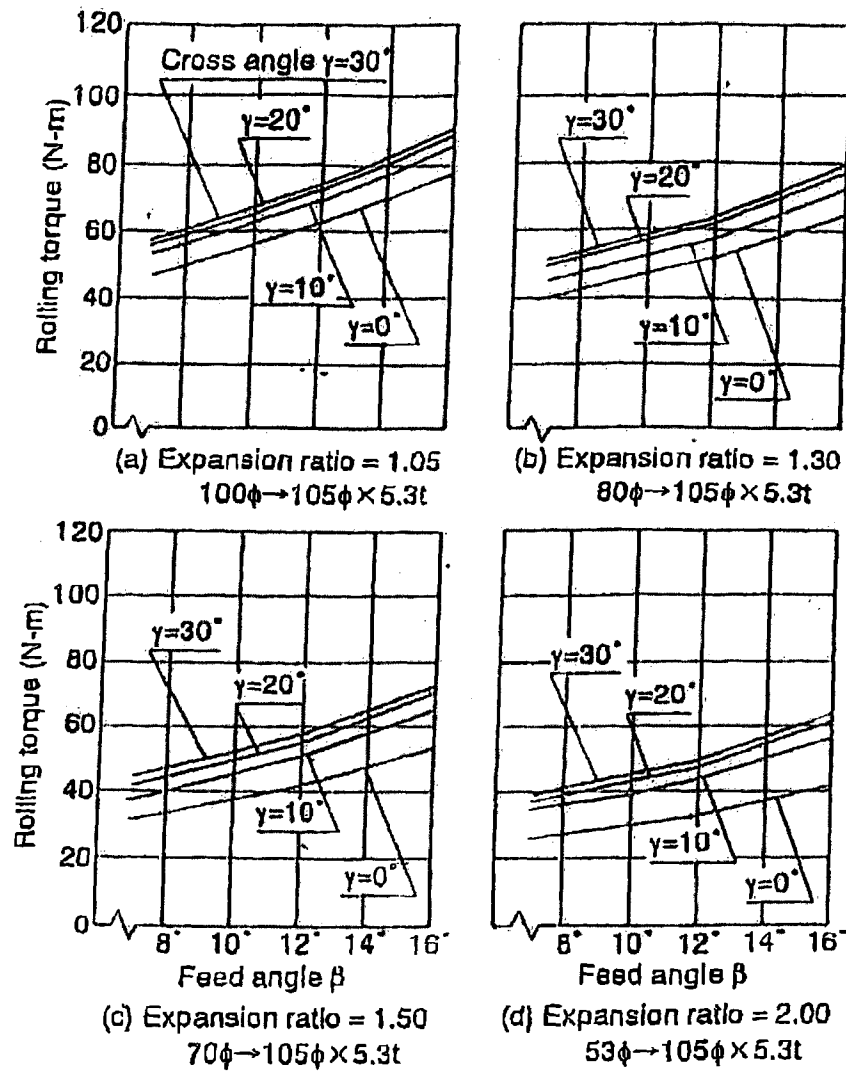


FIG. 8

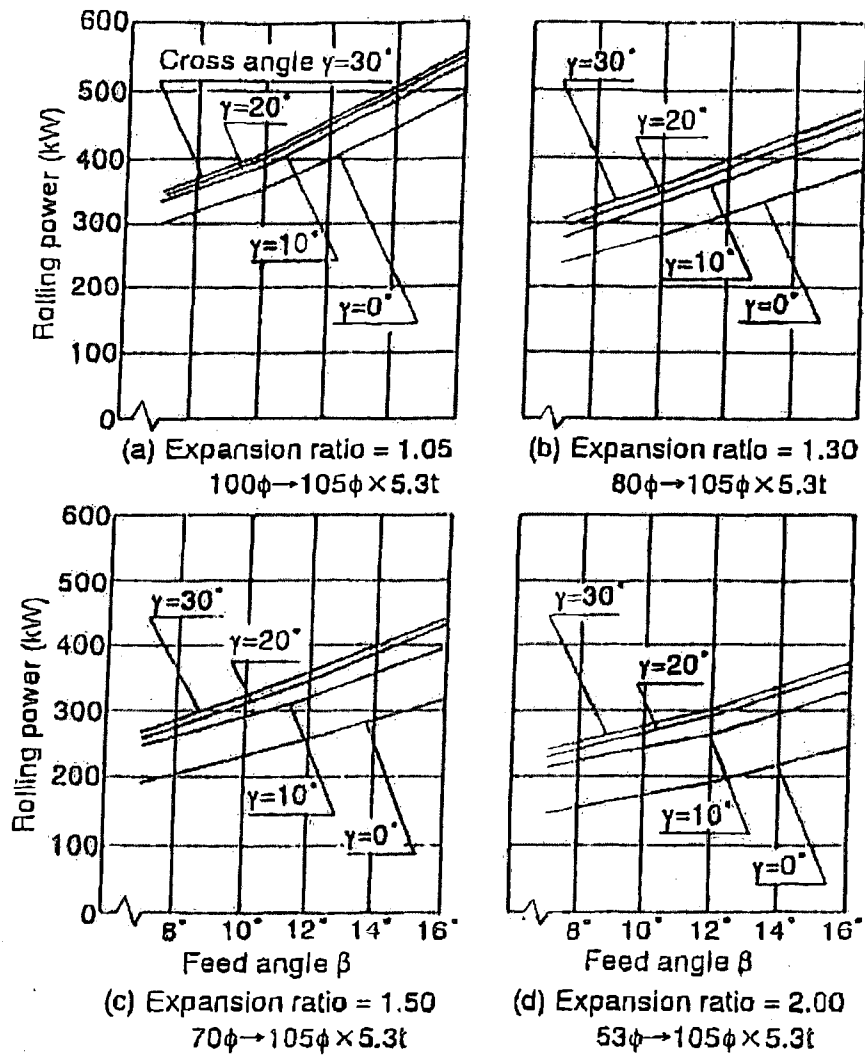


FIG. 9

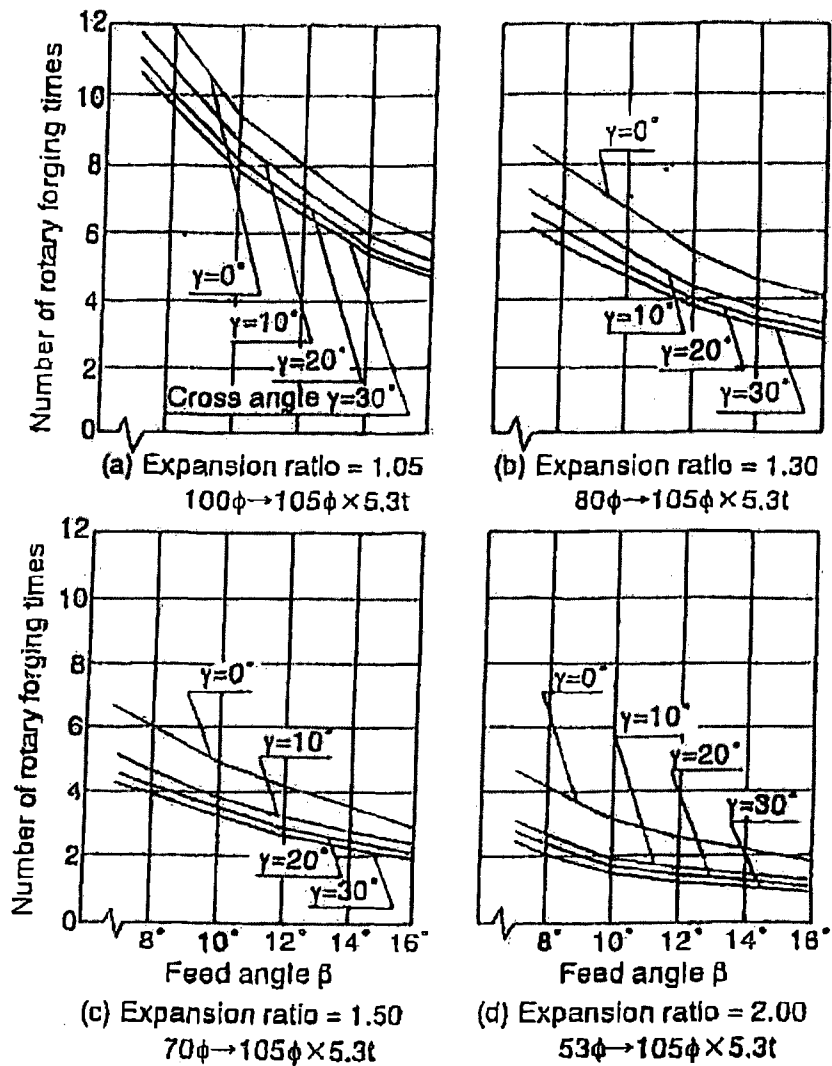
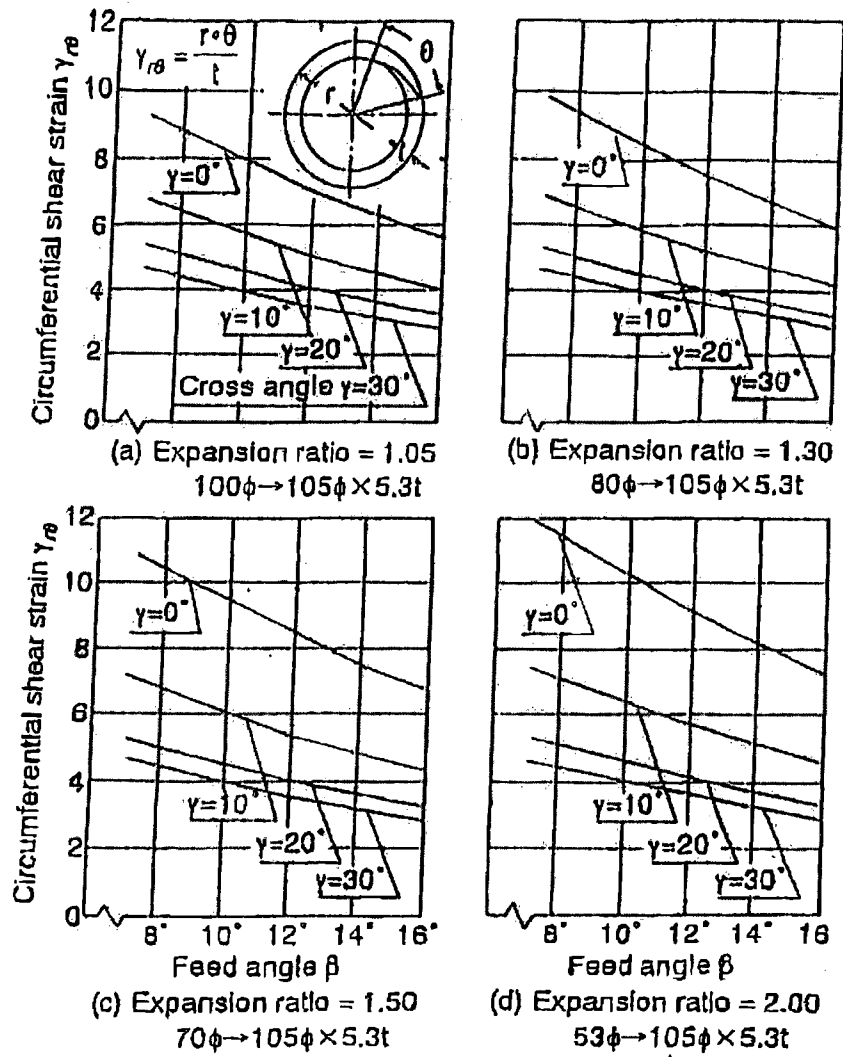


FIG. 10



INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2012/068547

A. CLASSIFICATION OF SUBJECT MATTER INV. C21D8/10 C21D9/08 C21D9/14 B21B17/10 B21B17/14 B21B19/04 ADD. According to International Patent Classification (IPC) or to both national classification and IPC														
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) C21D B21B Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data														
C. DOCUMENTS CONSIDERED TO BE RELEVANT <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Category*</th> <th style="width: 70%;">Citation of document, with indication, where appropriate, of the relevant passages</th> <th style="width: 20%;">Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td style="vertical-align: top;">X A</td> <td style="vertical-align: top;"> JP 6 172855 A (NIPPON STEEL CORP) 21 June 1994 (1994-06-21) abstract paragraph [0013] - paragraph [0019]; tables 1-2 ----- </td> <td style="vertical-align: top;"> 1,4 3 </td> </tr> <tr> <td style="vertical-align: top;">X A</td> <td style="vertical-align: top;"> US 5 186 769 A (HUNT PATRICK J [CA] ET AL) 16 February 1993 (1993-02-16) column 5, line 38 - column 7, line 5; claims 1,5,9; figures 1,2 ----- </td> <td style="vertical-align: top;"> 1 3,4 </td> </tr> <tr> <td style="vertical-align: top;">X A</td> <td style="vertical-align: top;"> US 5 226 978 A (HUNT PATRICK J [CA] ET AL) 13 July 1993 (1993-07-13) column 3 column 6, line 47 - column 7; figures 1-2 ----- -/-- </td> <td style="vertical-align: top;"> 1 3,4 </td> </tr> </tbody> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	X A	JP 6 172855 A (NIPPON STEEL CORP) 21 June 1994 (1994-06-21) abstract paragraph [0013] - paragraph [0019]; tables 1-2 -----	1,4 3	X A	US 5 186 769 A (HUNT PATRICK J [CA] ET AL) 16 February 1993 (1993-02-16) column 5, line 38 - column 7, line 5; claims 1,5,9; figures 1,2 -----	1 3,4	X A	US 5 226 978 A (HUNT PATRICK J [CA] ET AL) 13 July 1993 (1993-07-13) column 3 column 6, line 47 - column 7; figures 1-2 ----- -/--	1 3,4
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.												
X A	JP 6 172855 A (NIPPON STEEL CORP) 21 June 1994 (1994-06-21) abstract paragraph [0013] - paragraph [0019]; tables 1-2 -----	1,4 3												
X A	US 5 186 769 A (HUNT PATRICK J [CA] ET AL) 16 February 1993 (1993-02-16) column 5, line 38 - column 7, line 5; claims 1,5,9; figures 1,2 -----	1 3,4												
X A	US 5 226 978 A (HUNT PATRICK J [CA] ET AL) 13 July 1993 (1993-07-13) column 3 column 6, line 47 - column 7; figures 1-2 ----- -/--	1 3,4												
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Date of the actual completion of the international search 27 November 2012	Date of mailing of the international search report 04/12/2012													
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Lilimpakis, Emmanuel													

INTERNATIONAL SEARCH REPORT

International application No
PCT/JP2012/068547

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Information on patent family members

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