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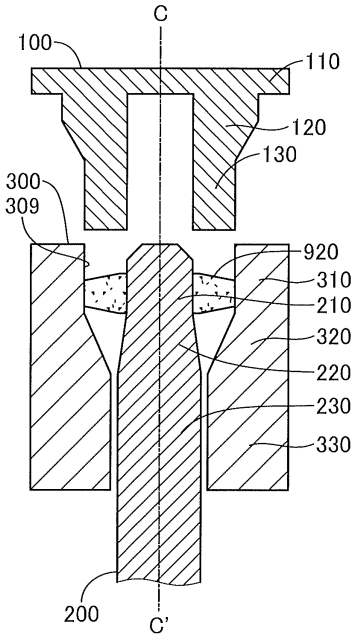
(54) PIPE MEMBER MANUFACTURING METHOD

(57) To provide a technique that reduces an amount of energy consumption at manufacture of a pipe material having a high strength and improves a recyclability of the manufactured pipe material.

First, a long, solid raw material made of a steel material containing 0.05 to 0.25 weight% C is prepared. Subsequently, the prepared raw material is cut to form a solid billet. After that, the solid billet is processed into a hollow blank 920. Then, warm extrusion molding is performed on the hollow processed blank 920 to be molded in a tubular shape.

Fig 2A



EP 4 039 382 A1

Description

TECHNICAL FIELD

[0001] This invention relates to a technique that manufactures a steel pipe having a high strength.

BACKGROUND ART

[0002] Recently, a request for improvement of fuel economy of an automobile has been more and more increasing, and further weight reduction has been strongly demanded. Therefore, for the components used for the automobile, it has been in progress to replace conventional components molded from a wire rod and a rod material that are made of steel with components molded from pipe materials (hereinafter, referred to as "steel pipe," alternatively, simply referred to as "pipe material") made of steel. Furthermore, thinning to reduce weight is required for also the component manufactured by conventionally molding the pipe material, meanwhile, maintaining a sufficient strength is required. Such demands are common in the pipe material used in manufacture of a component for a moving body, such as a rail vehicle and an aircraft, components used for various mechanical devices, and the like, which are not limited to the pipe material used for manufacture of the components for automobile.

[0003] Typically, in order that an outer diameter and an inner diameter (pipe diameter) match a size of the component, the pipe material used to mold the component is manufactured by performing a cold drawing processing on a pipe material (base pipe) having the pipe diameter larger, thicker than that of this pipe material. However, it is not necessarily easy to sufficiently enhance a strength of the pipe material obtained through the cold drawing processing. Therefore, the strength is enhanced by performing a heat treatment, such as quenching and tempering, on the pipe material whose composition has been appropriately adjusted and that has been preliminarily formed into a desired shape through the cold drawing processing. For example, Patent Document 1 proposes that, in order to manufacture a pipe material for air bag, a cold drawing processing is performed on a steel pipe obtained by adding chrome (Cr), molybdenum (Mo), and the like, and after that, quenching and tempering are performed under predetermined temperature conditions.

[0004] Furthermore, Patent Document 1 describes that a crystal structure is fine-grained by adding an element, such as titanium (Ti) and niobium (Nb), to a steel pipe on which the cold drawing processing is to be performed. Generally, it is known that the smaller a crystal grain diameter is, the higher a yield stress of a steel material becomes. Therefore, a strength of a pipe material can be expected to be more enhanced by adding the element, such as Ti and Nb, to cause the crystal structure to be fine-grained.

[0005] Patent Document 1: Japanese Unexamined Patent Application Publication No. 2004-76034

DISCLOSURE OF THE INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0006] However, when a heat treatment, such as quenching and tempering, is performed, along with performing the heat treatment, pickling and neutralization are required, and furthermore, baking is required along with performing the pickling. Therefore, while an amount of energy consumption can be reduced in a cold drawing processing that reduces a pipe diameter, since much energy is consumed through the heat treatment and the baking, an amount of energy consumption for the entire manufacturing steps of a pipe material increases. Further, when the element, such as Ti and Nb, that causes a crystal structure to be fine-grained is added in order to further enhance a strength of the pipe material, a recyclability of the pipe material decreases.

[0007] The present invention has been made to solve the above-described conventional problems, and the object of the present invention is to provide a technique that reduces an amount of energy consumption at manufacture of a pipe material having a high strength and improves a recyclability of the pipe material.

SOLUTIONS TO THE PROBLEMS

[0008] In order to achieve at least a part of the above-described object, the present invention is achievable as the following forms or application examples.

[Application Example 1]

[0009] A method for manufacturing a pipe material includes:

a step of preparing a long, solid raw material made of a steel material containing 0.05 to 0.25 weight% C;

a raw material cutting step of cutting the raw material to form a solid billet;
a hollowing processing step of processing the billet into a hollow blank; and
a warm extrusion step of performing warm extrusion molding on the blank to have a tubular shape.

[0010] According to this application example, a crystal structure of the obtained pipe material can be fine-grained, and a yield stress can be more enhanced, and a brittle transition temperature can be lower. Therefore, since performing a heat treatment, such as quenching, on the obtained pipe material can be omitted, an amount of energy consumption for the entire manufacturing steps of the pipe material having a high strength can be reduced. Furthermore, since the grain refinement of the crystal structure is expressed without adding the element that causes the crystal structure to be fine-grained, decrease in recyclability of the pipe material due to the adding of this element can be reduced.

[Application Example 2]

[0011] The method for manufacturing a pipe material according to claim 1, wherein
a spheroidizing annealing is performed on the raw material. According to this application example, the ductility of the obtained pipe material can be properly improved.

[Application Example 3]

[0012] The method for manufacturing a pipe material according to claim 1 or 2, wherein
the hollowing processing step processes the billet into the blank through cold forging. Processing the billet into the blank through cold forging ensures the reduced consumption of the energy required for heating the billet.

[Application Example 4]

[0013] The method for manufacturing a pipe material according to any one of claims 1 to 3, wherein
the steel material further contains 0.60 to 1.5 weight% Mn. A tensile strength of the obtained pipe material can be more enhanced by adding Mn to the steel material that serves as the raw material.

[Application Example 5]

[0014] The method for manufacturing a pipe material according to any one of claims 1 to 3, wherein
the steel material further contains 0.30 to 0.85 weight% Mn, 0.85 to 1.25 weight% Cr, and 0.15 to 0.35 weight% Mo. The tensile strength of the obtained pipe material is improved by adding Cr and Mo to the steel material that serves as the raw material because of work hardening. Therefore, a strength of the component obtained by processing the pipe material can be more enhanced.

[0015] Note that the present invention is achievable in various aspects. It is achievable in, for example, the aspects of the method for manufacturing the pipe material, the pipe material manufactured through the manufacturing method, various components where those pipe materials are used, and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

Fig. 1A is a process drawing (cutting a raw material) illustrating a manufacturing step of a pipe material according to a first embodiment.
Fig. 1B is a process drawing (hollowing processing) illustrating a manufacturing step of the pipe material according to the first embodiment.
Fig. 1C is a process drawing (warm extrusion molding) illustrating a manufacturing step of the pipe material according to the first embodiment.
Fig. 1D is a process drawing (clipping the pipe material) illustrating a manufacturing step of the pipe material according to the first embodiment.
Fig. 2A is an explanatory drawing (charging a blank) illustrating a configuration of a mold used for the warm extrusion molding and a state where the warm extrusion molding is performed with this mold.
Fig. 2B is an explanatory drawing (start of extrusion) illustrating the configuration of the mold used for the warm extrusion molding and a state where the warm extrusion molding is performed with this mold.
Fig. 2C is an explanatory drawing (extrusion proceeding) illustrating the configuration of the mold used for the warm extrusion molding and a state where the warm extrusion molding is performed with this mold.

Fig. 3A is an electron micrograph (outer diameter side and 5000-fold) showing a result of evaluation for a crystal grain diameter of the pipe material.

Fig. 3B is an electron micrograph (outer diameter side and 10000-fold) showing a result of evaluation for the crystal grain diameter of the pipe material.

Fig. 3C is an electron micrograph (intermediate portion and 5000-fold) showing a result of evaluation for the crystal grain diameter of the pipe material.

Fig. 3D is an electron micrograph (intermediate portion and 10000-fold) showing a result of evaluation for the crystal grain diameter of the pipe material.

Fig. 3E is an electron micrograph (inner diameter side and 5000-fold) showing a result of evaluation for the crystal grain diameter of the pipe material.

Fig. 3F is an electron micrograph (inner diameter side and 10000-fold) showing a result of evaluation for the crystal grain diameter of the pipe material.

Fig. 4A is an electron micrograph (cold compression processing and S15C) showing a result of evaluation for a crystal grain diameter of a specimen on which compression processing has been performed.

Fig. 4B is an electron micrograph (cold compression processing and Q345B) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 4C is an electron micrograph (cold compression processing and SCM415) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 5A is an electron micrograph (S15C, processing rate of 0%, and heating temperature of 450 °C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 5B is an electron micrograph (S15C, processing rate of 40%, and heating temperature of 450°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 5C is an electron micrograph (S15C, processing rate of 0%, and heating temperature of 550°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 5D is an electron micrograph (S15C, processing rate of 40%, and heating temperature of 550°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 5E is an electron micrograph (S15C, processing rate of 0%, and heating temperature of 650°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 5F is an electron micrograph (S15C, processing rate of 40%, and heating temperature of 650°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 6A is an electron micrograph (Q345B, processing rate of 0%, and heating temperature of 450°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 6B is an electron micrograph (Q345B, processing rate of 40%, and heating temperature of 450°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 6C is an electron micrograph (Q345B, processing rate of 0%, and heating temperature of 550°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 6D is an electron micrograph (Q345B, processing rate of 40%, and heating temperature of 550°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 6E is an electron micrograph (Q345B, processing rate of 0%, and heating temperature of 650°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 6F is an electron micrograph (Q345B, processing rate of 40%, and heating temperature of 650°C) showing a result of evaluation for a crystal grain diameter of a specimen on which the compression processing has been performed.

Fig. 7A is a graph (including cold processed products) showing results of evaluation for the crystal grain diameters of the specimens on which the compression processing has been performed.

Fig. 7B is a graph (not including cold processed products) showing results of evaluation for the crystal grain diameters of the specimens on which the compression processing has been performed.

Fig. 8 is a flowchart illustrating a manufacturing step of a pipe material according to a second embodiment.

Fig. 9A is an electron micrograph showing a result of evaluation for influence of spheroidizing annealing on a crystal grain diameter (without spheroidizing annealing).
Fig. 9B is an electron micrograph showing a result of evaluation for influence of the spheroidizing annealing on the crystal grain diameter (with spheroidizing annealing).
Fig. 10A is an explanatory drawing showing a result of evaluation for influence of the spheroidizing annealing on ductility (without spheroidizing annealing and upper surface).
Fig. 10B is an explanatory drawing showing a result of evaluation for influence of the spheroidizing annealing on ductility (without spheroidizing annealing and side surface).
Fig. 10C is an explanatory drawing showing a result of evaluation for influence of the spheroidizing annealing on ductility (with spheroidizing annealing and upper surface).
Fig. 10D is an explanatory drawing showing a result of evaluation for influence of the spheroidizing annealing on ductility (with spheroidizing annealing and side surface).

DESCRIPTION OF PREFERRED EMBODIMENTS

[0017] Forms to embody the present invention are described below in the following order.

A. First Embodiment:

[0018]

A1. Manufacturing Step of Pipe Material According to First Embodiment:
A2. Warm Extrusion Molding:
A3. Example of First Embodiment:

B. Second Embodiment:

[0019]

B1. Manufacturing Step of Pipe Material According to Second Embodiment:
B2. Example of Second Embodiment:

[0020] A1. Manufacturing Step of Pipe Material According to First Embodiment:
A2. Warm Extrusion Molding:
Fig. 1A to Fig. 1D are process drawings illustrating a manufacturing step of a pipe material as a first embodiment of the present invention. Fig. 1A to Fig. 1D illustrate forms of a workpiece on which processing has been performed at each of steps, that is, a billet 910, a hollow blank 920, an extrusion material 950, and a final pipe material 960. Furthermore, in Fig. 1A to Fig. 1D, the one dot chain line C-C' denotes an axis line of the billet 910, the hollow blank 920, the extrusion material 950, and the pipe material 960.

[0021] In the manufacturing step of the pipe material of the first embodiment, first, a solid, long steel material (raw material) as a starting material of the pipe material is prepared. As the raw material, a coil material obtained by forming a linear steel material into a coil form may be used, and furthermore, a rod material (rod steel) as a rod-shaped steel material may be used. Note that it is only necessary that a material of the raw material is a steel material based on a carbon steel having a content amount of carbon (C) of 0.05 to 0.25 weight%. As illustrated in Fig. 1A, the approximately column-shaped billet 910 is obtained by cutting the raw material thus prepared to have an appropriate length.

[0022] As illustrated in Fig. 1B, the billet 910 thus obtained is processed into the hollow blank 920. In the example of Fig. 1B, the hollow blank 920 includes a circular hole 929 disposed at the center and includes an inner peripheral portion 922 formed to have an approximately annular shape thicker than an outer peripheral portion 921. Processing (hollowing processing) such a billet 910 into the hollow blank 920 can be performed by a typical cold forging technique using, for example, a part former. Note that the hollowing processing can be performed through warm forging and hot forging, not limited to cold forging. However, since a consumption of the energy required for heating the billet 910 can be suppressed, it is preferred that the hollowing processing is performed through cold forging.

[0023] Note that while at the processes exemplified in Fig. 1A to Fig. 1D the hollow blank 920 is formed to have the inner peripheral portion 922 thicker than the outer peripheral portion 921, the shape of the hollow blank is variously changeable. The hollow blank may have, for example, a shape having a uniform thickness from an outer peripheral portion to an inner peripheral portion, and furthermore, the outer peripheral portion may have a shape thicker than the inner peripheral portion.

[0024] The hollow blank 920 obtained through the hollowing processing is molded into the approximately tubular

extrusion material 950 (Fig. 1C) by warm extrusion molding (described later in detail) where extrusion is performed from a rear side (C direction side) toward a front side (C' direction side). Note that, hereinafter, a direction (C' direction) where the extrusion is thus performed is referred to as a front, and the opposite direction thereof (C direction) is referred to as a rear.

[0025] The extrusion material 950 molded through the warm extrusion molding has a tubular distal end portion 951 and a rear end portion 952 deformed along a shape of a mold (described later). Then, as illustrated in Fig. 1D, the cylindrically-shaped pipe material 960 is obtained by clipping the distal end portion 951 from the extrusion material 950.

[0026] Note that at the processes exemplified in Fig. 1A to Fig. 1D, the steps up to clipping the pipe material in Fig. 1D are the manufacturing step of the pipe material. However, since the form of the extrusion material 950 illustrated in Fig. 1C is also an approximately tubular shape, it can be assumed that the manufacture of the pipe material is completed at the phase of the warm extrusion molding illustrated in Fig. 1C. Therefore, in the present invention, the steps up to the warm extrusion molding means a method for manufacturing the pipe material.

[0027] A2. Warm Extrusion Molding:

Fig. 2A to Fig. 2C are explanatory drawings illustrating a configuration of a mold used for the warm extrusion molding and a state where the warm extrusion molding is performed with this mold. Fig. 2A to Fig. 2C illustrate a state where the hollow blank 920 is deformed through the warm extrusion molding and the extrusion material 950 (Fig. 1C) is formed. Note that Fig. 2A to Fig. 2C illustrate cross-sectional surfaces taking each of: a punch 100, a counter punch 200, and a die 300 that constitute the mold for the warm extrusion molding; and the hollow blank 920 and intermediate materials 930 and 940 as workpieces in the middle of molding along the axis line C-C'.

[0028] The punch 100 includes a flat plate-shaped base 110 mounted to a ram of a press device used for the warm extrusion molding, an approximately cylindrically-shaped intermediate portion 120 extending from the base 110 to the front (C' direction), and a cylindrically-shaped distal end portion 130 that extends from the intermediate portion 120 to the front and enters the cavity between the counter punch 200 and the die 300.

[0029] The counter punch 200 is a rod-shaped member and includes a column-shaped small-diameter portion 210 positioned on the rear side and configured to have a small outer diameter, a tapered portion 220 positioned on a front side of the small-diameter portion 210 and having an outer diameter increasing toward the front, and a large-diameter portion 230 positioned on a front side of the tapered portion 220 and having an outer diameter larger than the small-diameter portion 210.

[0030] The die 300 is an approximately cylindrically-shaped member and includes a diameter-expanded portion 310 configured to have a large inner diameter, a tapered portion 320 positioned on a front side of the diameter-expanded portion 310 and having an inner diameter reduced toward the front, and a reduced diameter portion 330 positioned on a front side of the tapered portion 320 and having an inner diameter smaller than the diameter-expanded portion 310.

[0031] As illustrated in Fig. 2A to Fig. 2C, the counter punch 200 and the die 300 are arranged such that the large-diameter portion 230 of the counter punch 200 and the reduced diameter portion 330 of the die 300 are opposed, and the counter punch 200 is coaxial with an inner surface 309 of the die 300. Furthermore, the distal end portion 130 of the punch 100 is configured to have an inner diameter approximately the same as the outer diameter of the small-diameter portion 210 of the counter punch 200 and configured to have an outer diameter approximately the same as the inner diameter of the diameter-expanded portion 310 of the die 300. Then, the counter punch 200 and the inner surface 309 of the die 300 are arranged to be coaxial with the distal end portion 130 of the punch 100, and the extrusion molding is performed by moving the punch 100 to the front.

[0032] In the warm extrusion molding, first, in order that extrusion molding proceeds in a warm temperature region (described later), a temperature of the hollow blank 920 is increased to a preliminarily set blank temperature, and temperatures of the counter punch 200 and the die 300 are increased to a preliminarily set mold temperature. In order that the extrusion molding proceeds in the warm temperature region, such blank temperature and mold temperature can be set by, for example, simulation in consideration of a heat generation (plastic heat generation) due to a plastic deformation. Note that since the warm temperature region typically has a temperature of 600 to 650°C, and the temperature rise due to the plastic heat generation is around 100 to 150°C, the blank temperature and the mold temperature are set to 450 to 550°C.

[0033] Subsequently, as illustrated in Fig. 2A, the hollow blank 920 whose temperature has been increased is charged into the mold. Specifically, the hollow blank 920 is arranged between the small-diameter portion 210 of the counter punch 200 and the diameter-expanded portion 310 of the die 300.

[0034] Note that in the example of Fig. 2A, in order to avoid generating a large gap between the hollow blank 920 and the counter punch 200 and between the hollow blank 920 and the die 300, the hollow blank 920 is configured to have an inner diameter approximately the same as the outer diameter of the small-diameter portion 210 of the counter punch 200 and is configured to have an outer diameter approximately the same as the inner diameter of the diameter-expanded portion 310 of the die 300. However, the inner diameter and the outer diameter of the hollow blank are variously changeable when the hollow blank 920 can be arranged between the small-diameter portion 210 of the counter punch 200 and the diameter-expanded portion 310 of the die 300. However, as in Fig. 2A, it is preferred to avoid generating a large gap

between the hollow blank 920 and the counter punch 200 and/or between the hollow blank 920 and the die 300 so as to reduce the void in the extrusion material 950 (Fig. 1C) formed through the warm extrusion molding.

[0035] As illustrated in Fig. 2A, after the hollow blank 920 is charged into the mold, when the punch 100 is moved to the front, the hollow blank 920 is deformed, and the clearance between: the small-diameter portion 210 and the tapered portion 220 of the counter punch 200; and the diameter-expanded portion 310 and the tapered portion 320 of the die 300 is filled with the deformed hollow blank. Then, when the punch 100 is further moved to the front, as illustrated in Fig. 2B, extrusion is started, the deformed hollow blank, that is, the intermediate material 930 has a rear end portion 931 that is extruded to the clearance (narrowing portion) between the large-diameter portion 230 of the counter punch 200 and the reduced diameter portion 330 of the die 300, and in this narrowing portion, a tubular distal end portion 932 is formed.

[0036] Further, as illustrated in Fig. 2B, after the extrusion is started, when the punch 100 is moved to the front to cause the extrusion to proceed, the rear end portion 931 of the intermediate material 930 is extruded to the clearance between the large-diameter portion 230 of the counter punch 200 and the reduced diameter portion 330 of the die 300. Therefore, as illustrated in Fig. 2C, a volume of a rear end portion 941 of the intermediate material 940 is reduced, the narrowing portion is filled with an intermediate portion 942 of the intermediate material 940, and a molded tubular portion 943 is formed at a front position with respect to the die 300.

[0037] Thus, in the state where the extrusion proceeds, in the intermediate portion 942 of the intermediate material 940, many dislocations due to a plastic deformation are introduced, and a deformation texture is formed. Furthermore, because of the plastic heat generation, a temperature of the intermediate portion 942 rises up to the warm temperature region (600 to 650°C) where a recrystallization proceeds. Then, since the temperature of the intermediate portion 942 is in the warm temperature region, a primary recrystallization due to a nucleation and a growth proceeds, and the deformation texture, into which the dislocations have been introduced, becomes a fine crystal structure (subgrain) through a return process where the dislocations are removed or rearranged.

[0038] In the first embodiment, since the molded tubular portion 943 is exposed outside the die 300, a temperature of the tubular portion 943 is decreased lower than the warm temperature region, and a grain growth of the subgrain is suppressed. Therefore, a state where a size (crystal grain diameter) of a crystal structure of the tubular portion 943 is fine (the crystal grain diameter is 1.5 μm or less) is maintained. Then, the crystal structure of the tubular portion 943 is fine-grained, and thus the distal end portion 951 of the extrusion material 950 (Fig. 1C) and a crystal structure of the pipe material 960 (Fig. 1D) that correspond to the tubular portion 943 are also fine-grained.

[0039] Thus, according to the first embodiment, the crystal structure of the pipe material 960 obtained by performing the warm extrusion molding where the extrusion molding proceeds in the warm temperature region is fine-grained. Furthermore, typically, the smaller the crystal grain diameter is, the higher a yield stress of the steel material becomes, and the smaller the crystal grain diameter is, the lower a brittle transition temperature becomes (Hall-Petch relationship). Therefore, according to the first embodiment, since the obtained crystal structure of the pipe material 960 is fine-grained, a yield stress of the pipe material 960 can be more enhanced, and the brittle transition temperature can be lower. Therefore, since performing a heat treatment, such as quenching, on the obtained pipe material 960 can be omitted, an amount of energy consumption for the entire manufacturing steps of the pipe material having a high strength can be reduced.

[0040] Furthermore, in the first embodiment, for the manufacture of the pipe material, the solid, long steel material is used as a raw material. Therefore, according to the first embodiment, a space for storing the raw material can be smaller than that of a common pipe material manufacturing method where a pipe material (base pipe) as a starting material is processed to manufacture a pipe material having a desired shape.

[0041] Furthermore, in the first embodiment, also in a case where a carbon steel having a content amount of C is 0.05 to 0.25 weight% is used as a material (that is, a material of the raw material) of the pipe material 960, the crystal structure of the pipe material 960 can be sufficiently fine-grained. Therefore, since the addition of alloying element, such as titanium (Ti) or niobium (Nb), which promotes the grain refinement of the crystal structurer can be omitted, a recyclability of the pipe material 960 can be enhanced, and a price of the pipe material 960 can be reduced.

[0042] Note that the material (that is, the material of the pipe material) of the raw material for manufacturing the pipe material by applying the first embodiment can be appropriately changed depending on the mechanical characteristic required for the final pipe material. For example, in order to enhance a tensile strength, a raw material where manganese (Mn) as an alloying element that enhances the tensile strength similarly to C is added can also be used. In this case, as described later, it is preferred that a content amount of Mn is adjusted depending on a presence/absence of chrome (Cr) and molybdenum (Mo) to be selectively added. It is preferred that a content amount of Mn is 0.30 to 0.85% when Cr and Mo are added, and it is preferred that the content amount of Mn is 0.60 to 1.5% when Cr or Mo are not added. Furthermore, in order to promote improvement of the tensile strength due to work hardening, the raw material where Cr and Mo are added can also be used. In this case, it is preferred that a content amount of Cr is 0.85 to 1.25%, and a content amount of Mo is 0.15 to 0.35%.

A3. Example of First Embodiment:

[Evaluation of Crystal Grain Diameter of Pipe Material]

[0043] In order to confirm the effects of the first embodiment, the pipe material was generated from a raw material of a carbon steel (S15C) where an alloying element was not added, and a crystal grain diameter of the generated pipe material was evaluated. Specifically, a coil material of S15C was prepared as the raw material. The prepared coil material has a chemical composition as in the following Table 1. Note that in Table 1, Si, Cu, and Ni denote silicon, copper, and nickel, respectively.

[Table 1]

Material	Content amount of contained element [weight%]						
	C	Si	Mn	Cu	Ni	Cr	Mo
S15C	0.17	0.21	0.44	0.01	0.01	0.03	0

[0044] Subsequently, the prepared coil material was cut using a part former to generate a billet, and cold forging was performed on the cut billet to generate the hollow blank. Then, a temperature of the hollow blank was increased to 550°C, temperatures of the counter punch and the die were increased to 472°C, and extrusion molding was performed. A cross-sectional surface perpendicular to the axial direction (C-C' direction) of the distal end portion (that is, the pipe material) of the extrusion material (see Fig. 1C) thus obtained through the extrusion molding was observed with a scanning electron microscope (hereinafter simply referred to as "electron microscope"). The observation with the electron microscope was performed on the outer diameter side of the pipe material, the inner diameter side of the pipe material, and an intermediate part thereof (intermediate portion).

[0045] Fig. 3A to Fig. 3F are electron micrographs showing results of the evaluation for the crystal grain diameter of the pipe material. Fig. 3A and Fig. 3B illustrate crystal structures on the outer diameter side, Fig. 3C and Fig. 3D illustrate crystal structures in the intermediate portion, and Fig. 3E and Fig. 3F illustrate crystal structures on the inner diameter side. Furthermore, Fig. 3A, Fig. 3C, and Fig. 3E illustrate states of observations at 5000-fold magnification, and Fig. 3B, Fig. 3D and Fig. 3F illustrate states of observations at 10000-fold magnification.

[0046] As can be seen from Fig. 3A, Fig. 3C and Fig. 3E, in any of the outer diameter side, the intermediate portion, and the inner diameter side of the pipe material on which the evaluation was performed, that is, in the whole thickness of the pipe material, the crystal structure was formed through recrystallization. Furthermore, as can be seen from Fig. 3B, Fig. 3D and Fig. 3F, the whole thickness of the pipe material was confirmed to have the crystal grain diameter of 1.5 μm.

[0047] From the above, it was found that applying the first embodiment, which performs the warm extrusion molding, to manufacture the pipe material enabled the fine-grained crystal structure of the obtained pipe material even when S15C where an element that promotes the grain refinement of the crystal structure was not added was used as the raw material.

[Confirmation of Expression Condition of Fine Grain]

[0048] After the evaluation for the crystal grain diameter of the pipe material, the material of the raw material, a processing state of the raw material, and the temperatures of the blank and the mold were changed to examine the condition where the fine grain was expressed. Specifically, as a processing method for corresponding to extrusion processing where the plastic deformation proceeds due to a strong compressive stress, compression processing was performed in a heated state, and a crystal structure of a compressed specimen was observed using the electron microscope. Furthermore, as a comparison target, a crystal structure of the specimen compressed through cold compression processing was observed using the electron microscope.

[0049] As materials of the specimens on which the compression processing was performed in the heated state, the carbon steel (S15C) where the crystal grain diameter of the pipe material was evaluated and a manganese steel (Q345B) that was allowed to increase in strength were used. Furthermore, as materials of the specimens on which the cold compression processing were performed as the comparison target, S15C and Q345B that were used for the compression processing in the heated state and a chromium-molybdenum steel (SCM415) that has an approximately the same content amount of C and is used as a structural steel were used. These steel materials used as the specimens have chemical compositions as in the following Table 2. Note that in Table 2, items to which an underline is attached denote an additive element to the steel material.

[Table 2]

Material	Content amount of contained element [weight%]						
	C	Si	Mn	Cu	Ni	Cr	Mo
S15C	0.17	0.21	0.44	0.01	0.01	0.03	0
Q345B	0.15	0.38	1.47	0	0	0.08	0
SCM415	0.14	0.19	0.77	0.001	0.003	1.13	0.16

[0050] As the specimen for the compression processing, rod materials of S15C, Q345B, and SCM415 were cut and clipped in surfaces perpendicular to its axial direction to prepare flat plate-shaped ones having a thickness of 7.7 mm. Furthermore, in the first embodiment, in order to confirm a presence/absence of influence on the hollowing processing performed prior to a warm extrusion processing, after upset forging in the axial direction was performed on the rod materials of S15C and Q345B at a processing rate of 40%, the materials on which the upset forging had been performed were cut and clipped in surfaces perpendicular to the upset direction to prepare flat plate-shaped specimens having a thickness of 7.7 mm. Note that, in the following, the specimen obtained by cutting the material on which the upset forging was thus performed is expressed as a processing rate of the specimen is 40%, and the specimen obtained by cutting the rod material in a surface perpendicular to the axial direction is expressed as a processing rate of the specimen is 0%.

[0051] In the compression processing, an upper die and a lower die that have a protrusion shape were arranged such that protrusion portions are opposed. After the specimen was placed on the lower die, the upper die was moved down to perform the compression processing such that a thickness between the protrusion portions of the upper die and the lower die is configured to be 1 mm (that is, a processing rate of the compression processing is configured to be 87%). When the compression processing was performed in the heated state, temperatures of the specimen, the upper die, and the lower die were increased in a heating furnace whose heating temperature is preliminarily set, the heated state was maintained for 15 minutes after the increase in the temperatures. After that, the compression processing was promptly performed on the specimen using the upper die and the lower die took out from the heating furnace. On the other hand, when the cold compression processing was performed, the compression processing was performed on the specimen at room temperature using the upper die and the lower die at room temperature.

[0052] Fig. 4A to Fig. 4C, Fig. 5A to Fig. 5F, and Fig. 6A to Fig. 6F are electron micrographs showing results of evaluation for the crystal grain diameter of the specimen on which the compression processing has been performed. Fig. 4A to Fig. 4C illustrate crystal structures of the specimens on which the cold compression processing has been performed, regarding the respective specimens where S15C, Q345B, and SCM415 have been used as the material. Fig. 5A to Fig. 5F illustrate crystal structures of the specimens whose material of S15C is used and on which the compression processing has been performed in the heated state, and Fig. 6A to Fig. 6F illustrate crystal structures of the specimens whose material of Q345B is used and on which the compression processing has been performed in the heated state.

[0053] Note that Fig. 5A, Fig. 5C, Fig. 5E, Fig. 6A, Fig. 6C, and Fig. 6E illustrate the crystal structures of the specimens configured to be the processing rate of 0%, and Fig. 5B, Fig. 5D, Fig. 5F, Fig. 6B, Fig. 6D, and Fig. 6F illustrate the crystal structures of the specimens configured to be the processing rate of 0%. Furthermore, Fig. 5A, Fig. 5B, Fig. 6A, and Fig. 6B illustrate the crystal structures of the specimens configured to be a heating temperature of 450°C, Fig. 5C, Fig. 5D, Fig. 6C, and Fig. 6D illustrate the crystal structures of the specimens configured to be a heating temperature of 550°C, and Fig. 5E, Fig. 6E, Fig. 5F, and Fig. 6F illustrate the crystal structures of the specimens configured to be a heating temperature of 550°C.

[0054] As can be seen from Fig. 4A to Fig. 4C, the fine grain was not expressed in the specimen on which the cold compression processing had been performed regardless of the material of the specimen. On the other hand, as can be seen from Fig. 5A, Fig. 5B, Fig. 6A, and Fig. 6B, the fine grain was expressed in the specimen configured to be the heating temperature of 450°C regardless of the material of the specimen and the processing rate. In contrast to this, while the fine grain was expressed in the specimen (Fig. 5C to Fig. 5F and Fig. 6C to Fig. 6F) configured to be the heating temperature of 550°C or 650°C, the crystal grain diameter was larger than that of the specimen configured to be the heating temperature of 450°C. It is considered that this means that since the temperatures of the specimen and the mold at a starting time point of the compression processing were excessively high, grain growth progressed to cause the crystal structure of the specimen to be coarsened.

[0055] Fig. 7A and Fig. 7B are graphs showing results of evaluation for the crystal grain diameters of the specimens on which the compression processing has been performed. Fig. 7A illustrates the crystal grain diameters of the specimens including a cold-compression-processed product, and Fig. 7B illustrates the crystal grain diameters of the specimens not including the cold-compression-processed product.

[0056] As illustrated in Fig. 7A, in the specimen on which the cold compression processing was performed, when the

material of the specimen was SCM415, the crystal grain diameter was approximately 20 μm. When the material of the specimen was S15C or Q345B, the crystal grain diameter was approximately 50 μm. In contrast to this, in the specimen on which a warm compression processing had been performed, the crystal grain diameter of the specimen was close to the fine-grained crystal grain diameter of 1.5 μm (dashed line in Fig. 7A) as a target.

[0057] Further, as illustrated in Fig. 7B, when the heating temperature of the specimen was 550°C or 650°C, the crystal grain diameter was 2 μm or more. On the other hand, when the heating temperature of the specimen was 450°C, the crystal grain diameter was 1 μm or less and was confirmed to be less than the crystal grain diameter of 1.5 μm as the target.

[0058] Note that, in the compression processing in the heated state, the temperature of the specimen during the compression processing is assumed to rise to approximately 150°C because of plastic heating. Therefore, when the heating temperature of the specimen, that is, the temperatures of the specimen and the mold at the starting time point of the compression processing was 450°C, since the compression processing proceeded in the warm temperature region, it is considered that the crystal grain diameter was 1 μm or less. On the other hand, when the heating temperature of the specimen was 550°C or 650°C, since the compression processing proceeded at a temperature higher than the warm temperature region, it is considered that the crystal grain diameter was 2 μm or more.

[0059] Thus, according to the first embodiment, manufacturing the pipe material through the warm extrusion molding where the extrusion processing proceeds in the warm temperature region enables the crystal structure to be fine-grained such that the obtained pipe material has the crystal grain diameter of 1.5 μm or less. Therefore, since the yield stress of the obtained pipe material can be more enhanced, and the brittle transition temperature can be lower, the heat treatment, such as quenching can be omitted, and the amount of energy consumption for the entire manufacturing steps of the pipe material having a high strength can be reduced. Further, since the grain refinement is expressed without adding the element that promotes the grain refinement of the crystal structure, the recyclability of the obtained pipe material can be enhanced, and a price of the pipe material can be reduced.

B. Second Embodiment:

[0060] B1. Manufacturing Step of Pipe Material According to Second Embodiment:

Fig. 8 is a flowchart illustrating a manufacturing step of a pipe material according to a second embodiment. The second embodiment is different from the first embodiment in that the second embodiment includes a step (Step S1) of performing spheroidizing annealing on the raw material prior to a step (Step S2) of cutting the raw material to form the billet. Since the respective steps from cutting the raw material (Step S2) to clipping the pipe material (Step S5) are similar to those of the first embodiment, their explanations are omitted here.

[0061] Iron carbide (Fe_3C) where pearlite is formed by laminating with ferrite in the raw material is dispersed into the raw material by performing the spheroidizing annealing on the raw material and is deposited as a micro, spherical cementite. Then, in the second embodiment, in the entire manufacturing steps (Steps S2 to S5) from forming the billet to forming the pipe material, a temperature of the workpiece is not higher than the warm temperature region. Therefore, since also in the final pipe material, the iron carbide is maintained in a spherical cementite state, a ductility of the obtained pipe material can be more enhanced.

[0062] Meanwhile, in the second embodiment, similarly to the first embodiment, the pipe material is formed through the warm extrusion processing. Therefore, similarly to the first embodiment, the crystal structure of the finally obtained pipe material is fine-grained. Therefore, according to the second embodiment, the yield stress of the pipe material can be more enhanced, the brittle transition temperature can be lower, and the ductility can be more enhanced.

[0063] Note that while in the second embodiment the spheroidizing annealing is performed on the raw material at Step S1 in the manufacturing step of the pipe material, Step S1 can be omitted when the raw material on which the spheroidizing annealing has been preliminarily performed is prepared. Furthermore, the step of performing the spheroidizing annealing at Step S1 can be considered as a step of preparing the raw material on which the spheroidizing annealing has been performed.

B2. Example of Second Embodiment:

[0064] In order to confirm the effects of the second embodiment, influence of the spheroidizing annealing on the expression of the fine grain in the pipe material and mechanical properties of the pipe material was evaluated. Specifically, a plurality of rod materials made of Q345B were prepared, and the spheroidizing annealing was performed on a part of them. Similarly to the example of the first embodiment, the specimen for the warm compression processing and the billet for manufacturing the pipe material were generated from the rod materials on which the spheroidizing annealing was not performed and the rod materials on which the spheroidizing annealing was performed. Note that the chemical compositions of the prepared rod materials are the same as those of the example of the first embodiment shown in Table 2.

[0065] On the specimen for the warm compression processing, the warm compression processing was performed at the heating temperature of 450°C, a presence/absence of the expression of the fine grain was confirmed, and mechanical

properties were evaluated. On the other hand, on the billet for manufacturing the pipe material, the warm extrusion molding was performed to generate the pipe material after the hollowing processing, a flattening test was performed on the obtain pipe material. Note that, in addition, various conditions, such as conditions of the compression processing and manufacturing conditions of the pipe material are similar to those of the example of the first embodiment.

[0066] Fig. 9A and Fig. 9B are electron micrographs showing results of evaluation for influence of the spheroidizing annealing on the crystal grain diameters. Fig. 9A illustrates the crystal structure of the specimen on which the spheroidizing annealing has not been performed, and Fig. 9B illustrates the crystal structure of the specimen on which the spheroidizing annealing has been performed.

[0067] As can be seen from Fig. 9A and Fig. 9B, it was confirmed that performing the warm compression processing caused the crystal structure to be fine-grained with or without the spheroidizing annealing. Furthermore, it was confirmed that performing the spheroidizing annealing caused the crystal structure to be sufficiently fine-grained while the crystal grain diameter was slightly increased.

[0068] The mechanical properties of the specimen on which the warm compression processing was performed were evaluated through a tensile test at room temperature and a low temperature (-40°C). The following Table 3 shows the crystal grain diameters of the respective specimens and the evaluation results of the tensile test.

[Table 3]

Spheroidizing annealing	Crystal grain diameter	Room temperature tensile test		Low temperature tensile test	
		Tensile strength	Extension	Tensile strength	Extension
No	0.8 μm	767 MPa	11.1%	804 MPa	13.4%
Yes	1 μm	695 MPa	16.4%	744 MPa	17.1%

[0069] As shown in Table 3, at the test at any of room temperature and low temperature, it is found that when the spheroidizing annealing was performed on the raw material, while a tensile strength was slightly decreased (-10% at room temperature), an extension was significantly increased (+47% at room temperature). From this result, it is found that when the spheroidizing annealing is performed on the raw material, a ductility of the specimen on which the warm compression processing corresponding to the warm extrusion molding is performed can be properly improved.

[0070] Fig. 10A to Fig. 10D are explanatory drawings showing results of evaluation for influence of the spheroidizing annealing on the ductility. Fig. 10A and Fig. 10B are respective photographs in which an upper surface and a side surface of the pipe material as a sample on which the flattening test has been performed are observed, without the spheroidizing annealing on the raw material of the pipe material. Fig. 10C and Fig. 10D are respective photographs in which an upper surface and a side surface of the pipe material as a sample on which the flattening test has been performed are observed, with the spheroidizing annealing on the raw material of the pipe material.

[0071] As illustrated in Fig. 10A and Fig. 10B, while cracking did not occur on the side surface side on the pipe material on which the spheroidizing annealing was not performed, cracking occurred on the upper surface side. In contrast to this, as illustrated in Fig. 10C and Fig. 10D, in the pipe material on which the spheroidizing annealing had been performed, cracking did not occur on any of the upper surface side and the side surface side. From this result, it was found that performing the spheroidizing annealing on the raw material also enabled the ductility of the pipe material formed through the warm extrusion molding to be properly improved.

[0072] From the above-described results, it was found that since applying the second embodiment enabled the crystal structure of the pipe material to be sufficiently fine-grained, the yield stress of the pipe material can be more enhanced, the brittle transition temperature can be lower, and furthermore, the spheroidizing annealing of the raw material enabled the ductility of the pipe material to be more enhanced.

INDUSTRIAL APPLICABILITY

[0073] This invention is applicable to the manufacture of various steel pipes required to have a high strength, such as a steel pipe used for a component for a moving body, such as an automobile, a rail vehicle, and an aircraft, and steel pipes used for components of various mechanical devices.

DESCRIPTION OF REFERENCE SIGNS

[0074]

100 Punch

110 Base
120 Intermediate portion
130 Distal end portion
200 Counter punch
210 Small-diameter portion
220 Tapered portion
230 Large-diameter portion
300 Die
309 Inner surface
310 Diameter-expanded portion
320 Tapered portion
330 Reduced diameter portion
910 Billet
920 Hollow blank
921 Outer peripheral portion
922 Inner peripheral portion
929 Hole
930 Intermediate material
931 Rear end portion
932 Distal end portion
940 Hollow blank
941 Rear end portion
942 Intermediate portion
943 Tubular portion
950 Extrusion material
951 Distal end portion
952 Rear end portion
960 Pipe material

Claims

1. A method for manufacturing a pipe material comprising:

a step of preparing a long, solid raw material made of a steel material containing 0.05 to 0.25 weight% C;
a raw material cutting step of cutting the raw material to form a solid billet;
a hollowing processing step of processing the billet into a hollow blank; and
a warm extrusion step of performing warm extrusion molding on the blank to have a tubular shape.

2. The method for manufacturing a pipe material according to claim 1, wherein
a spheroidizing annealing is performed on the raw material.

3. The method for manufacturing a pipe material according to claim 1 or 2, wherein
the hollowing processing step processes the billet into the blank through cold forging.

4. The method for manufacturing a pipe material according to any one of claims 1 to 3, wherein
the steel material further contains 0.60 to 1.5 weight% Mn.

5. The method for manufacturing a pipe material according to any one of claims 1 to 3, wherein
the steel material further contains 0.30 to 0.85 weight% Mn, 0.85 to 1.25 weight% Cr, and 0.15 to 0.35 weight% Mo.

Fig 1A

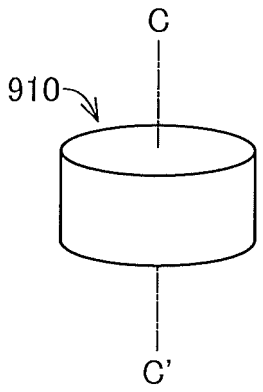


Fig 1B

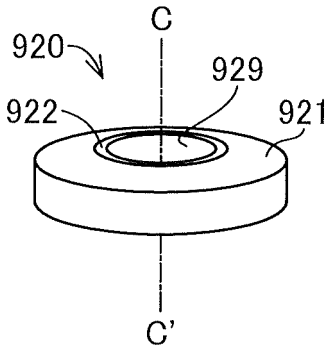


Fig 1C

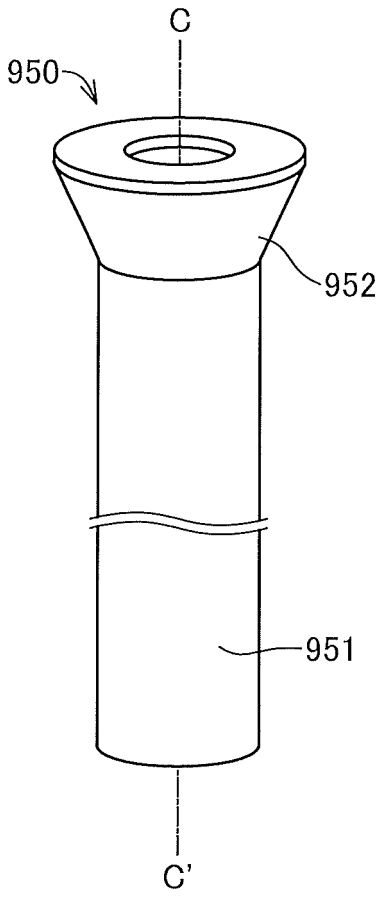


Fig 1D

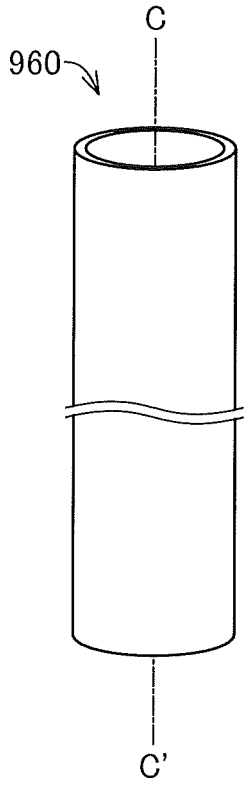


Fig 2A

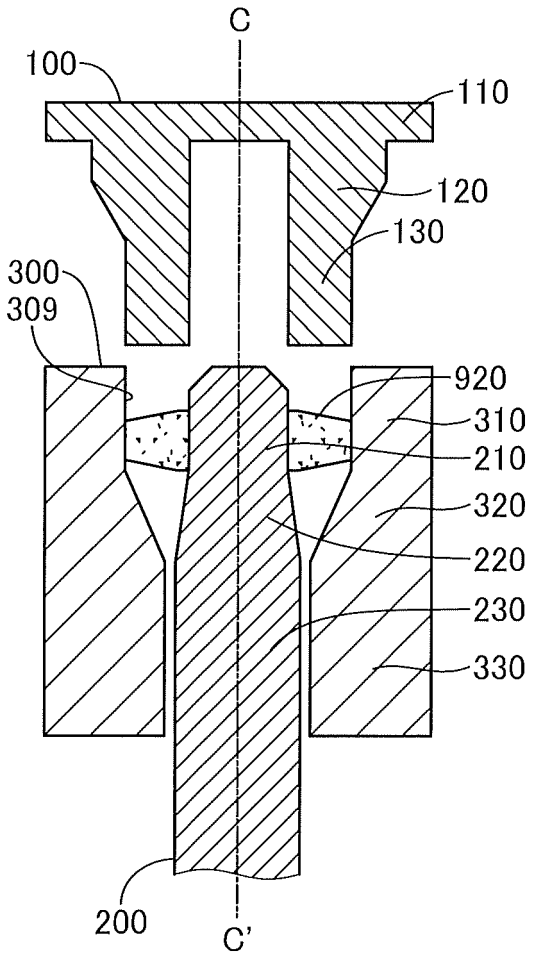


Fig 2B

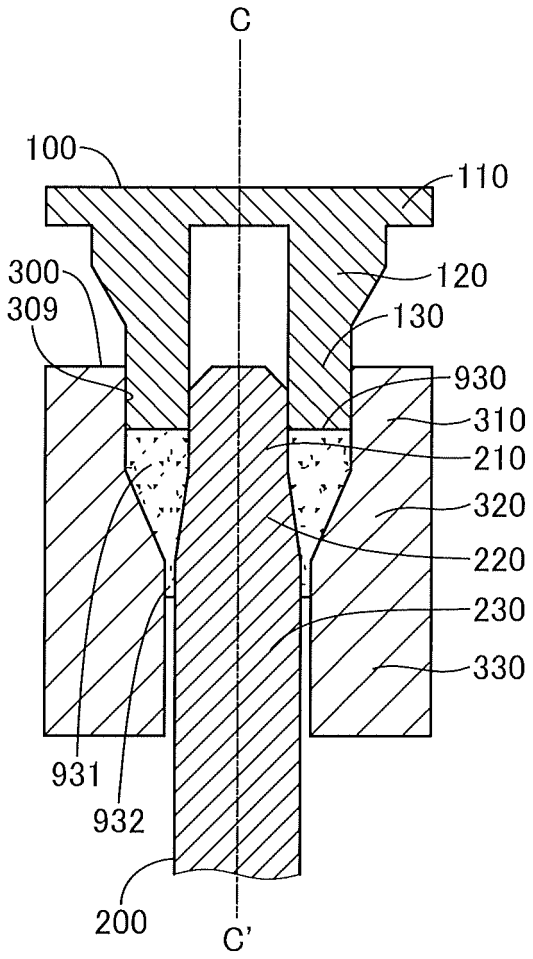
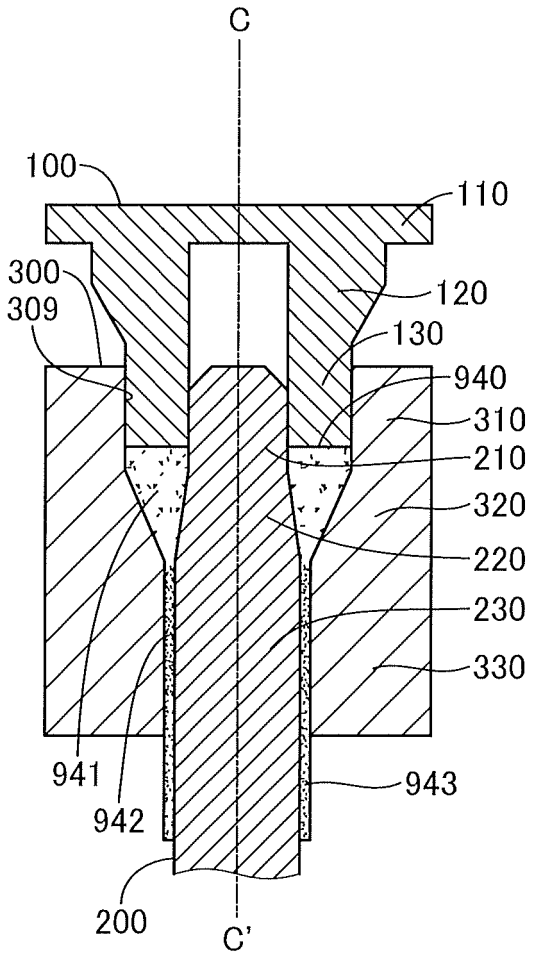

C
100
110
300
309
120
130
930
310
210
320
220
230
330
931
932
200
C'

Fig 2C


C
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C'

Fig 3A

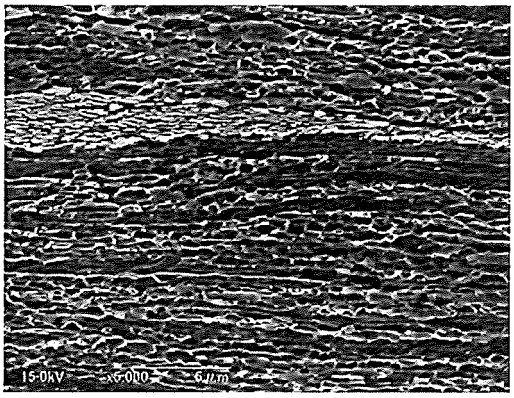


Fig 3B

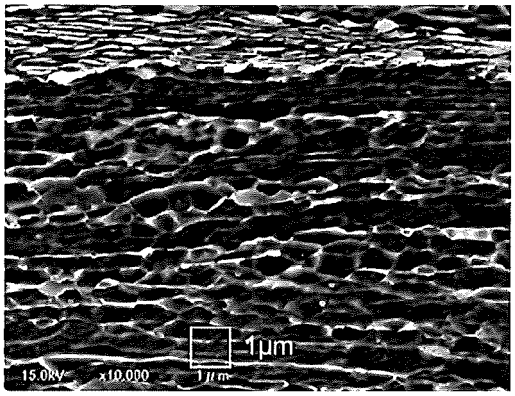


Fig 3C

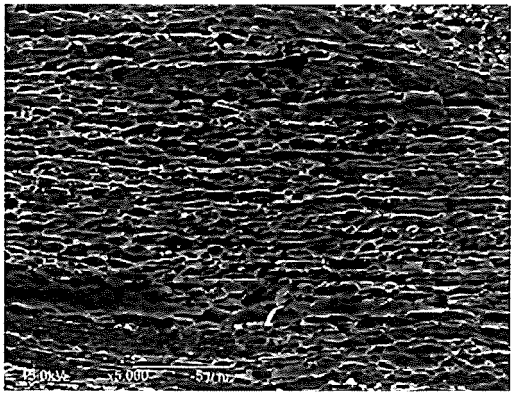


Fig 3D

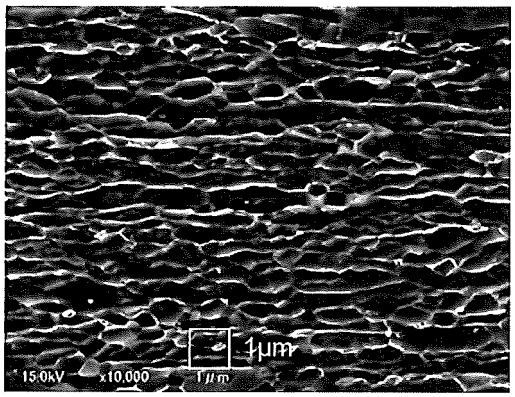


Fig 3E

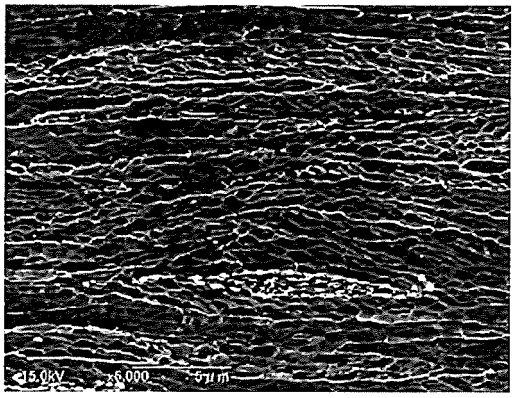


Fig 3F

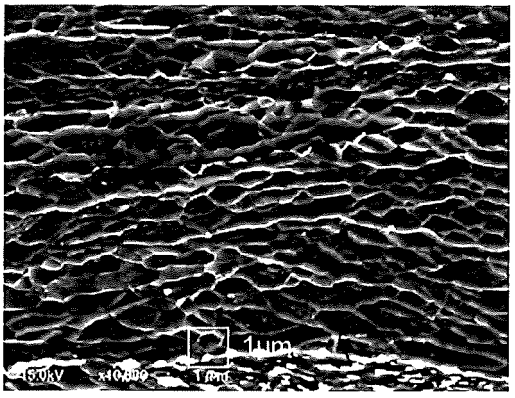


Fig 4A

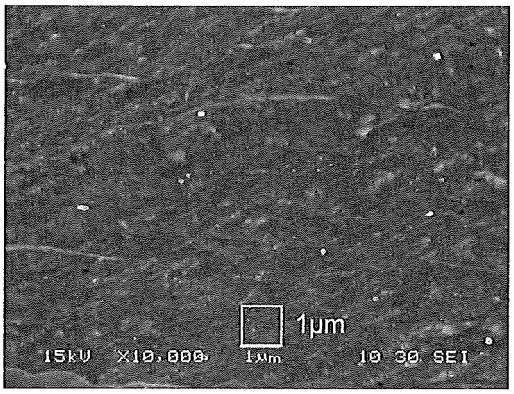


Fig 4B

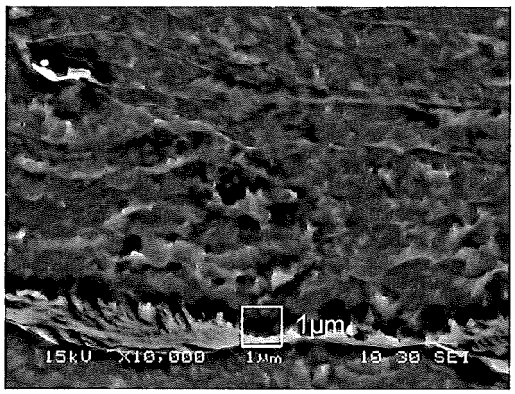


Fig 4C

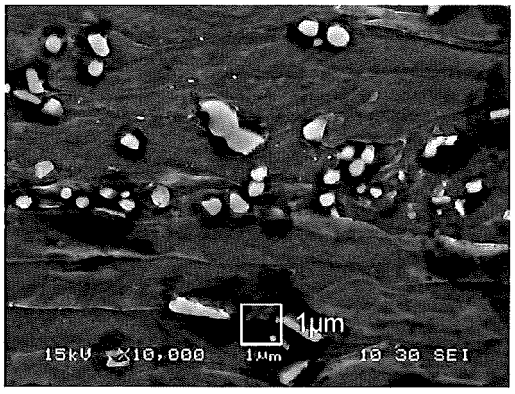


Fig 5A

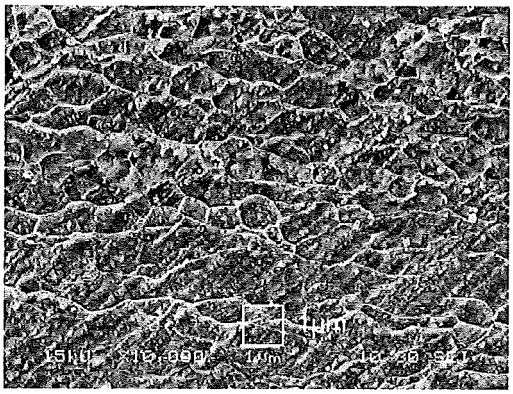


Fig 5B

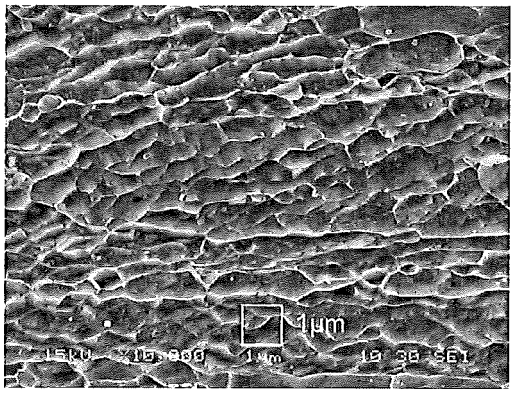


Fig 5C

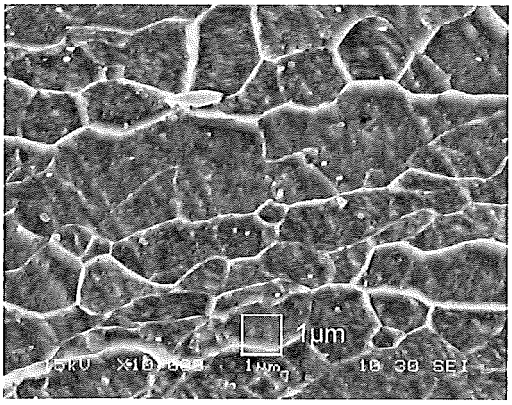


Fig 5D

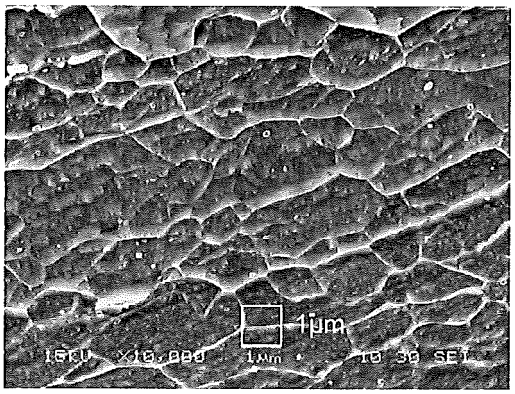


Fig 5E

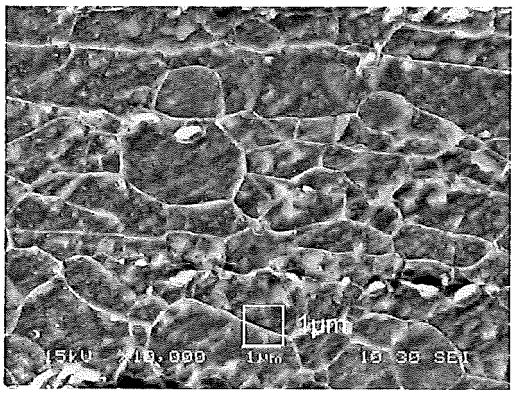


Fig 5F

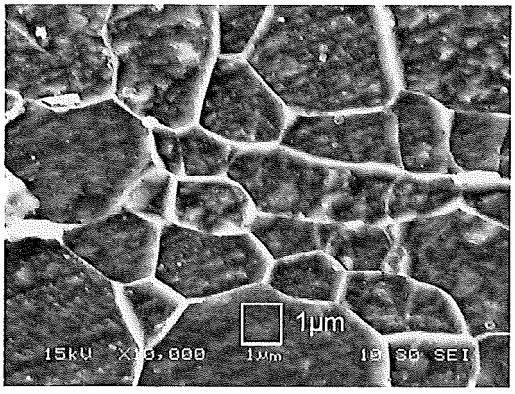


Fig 6A

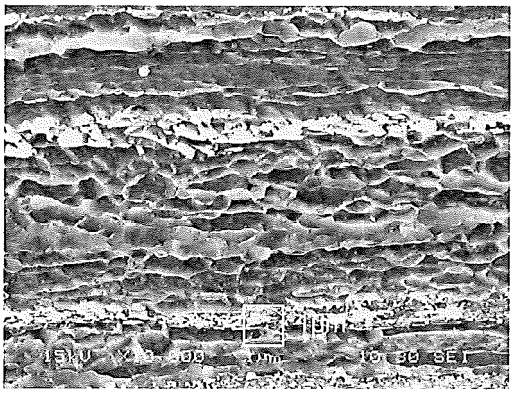


Fig 6B

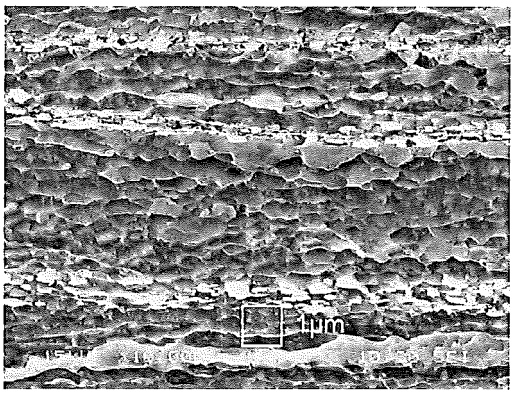


Fig 6C

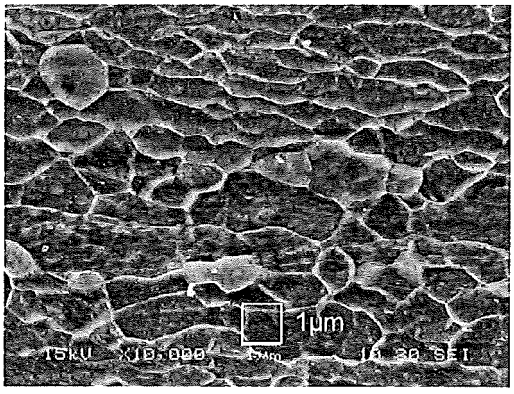


Fig 6D

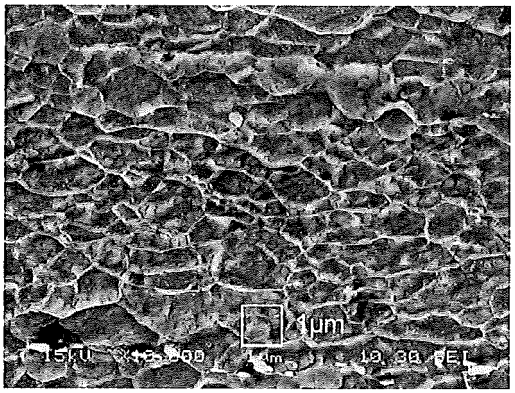


Fig 6E

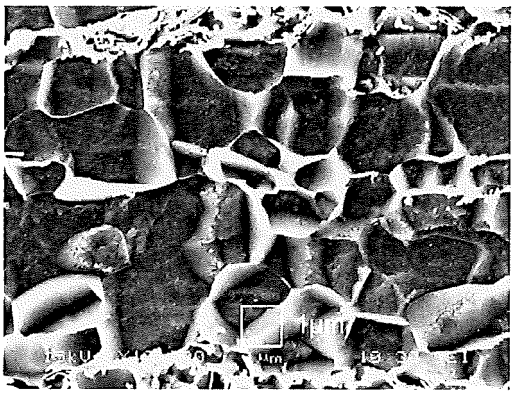


Fig 6F

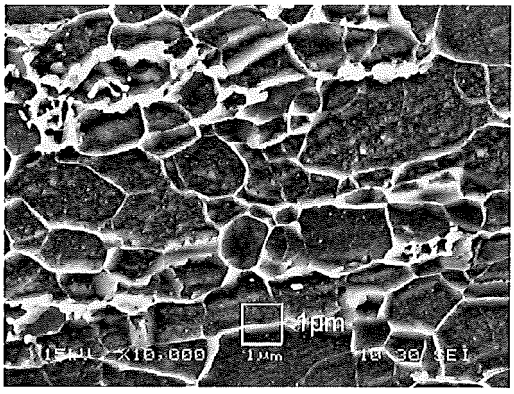


Fig 7A

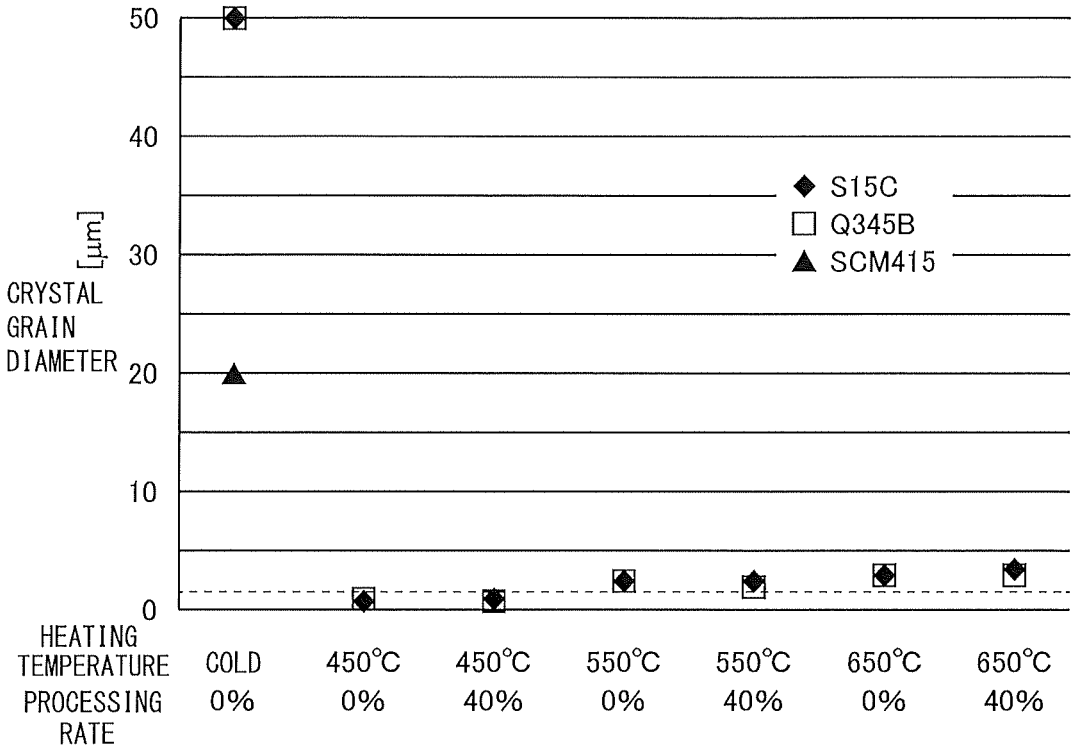

50
40
30
20
10
0
[μm]
CRYSTAL GRAIN DIAMETER
S15C
Q345B
SCM415
HEATING TEMPERATURE
PROCESSING RATE
COLD 0%
450°C 0%
450°C 40%
550°C 0%
550°C 40%
650°C 0%
650°C 40%

Fig 7B

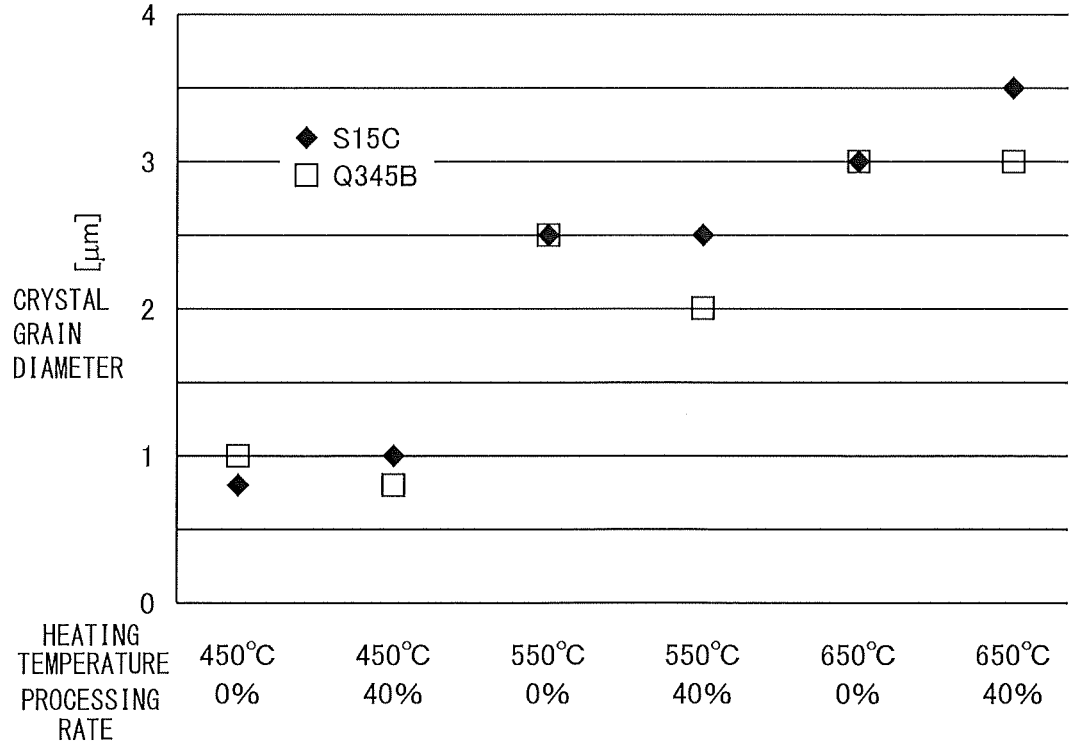

4
3
2
1
0
[μm]
CRYSTAL GRAIN DIAMETER
S15C
Q345B
HEATING TEMPERATURE
PROCESSING RATE
450°C 0%
450°C 40%
550°C 0%
550°C 40%
650°C 0%
650°C 40%

Fig 8

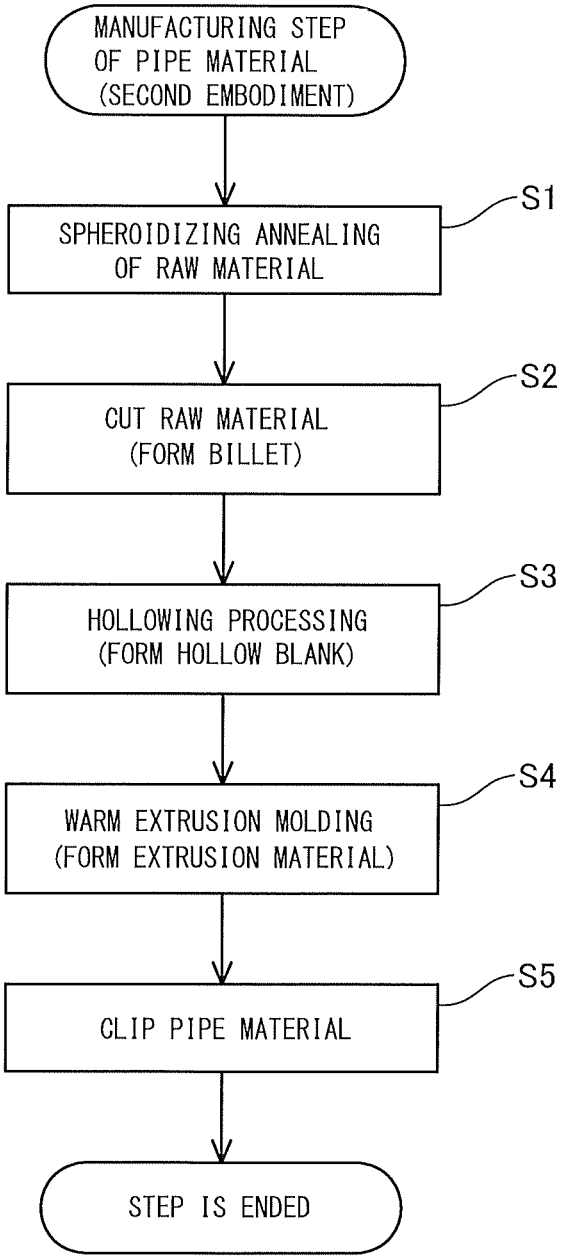

MANUFACTURING STEP
OF PIPE MATERIAL
(SECOND EMBODIMENT)
SPHEROIDIZING ANNEALING
OF RAW MATERIAL
S1
CUT RAW MATERIAL
(FORM BILLET)
S2
HOLLOWING PROCESSING
(FORM HOLLOW BLANK)
S3
WARM EXTRUSION MOLDING
(FORM EXTRUSION MATERIAL)
S4
CLIP PIPE MATERIAL
S5
STEP IS ENDED

Fig 9A

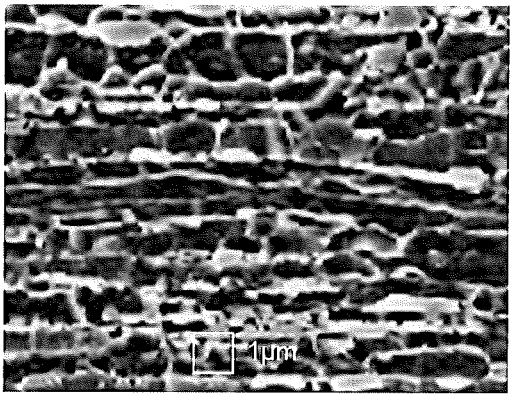


Fig 9B

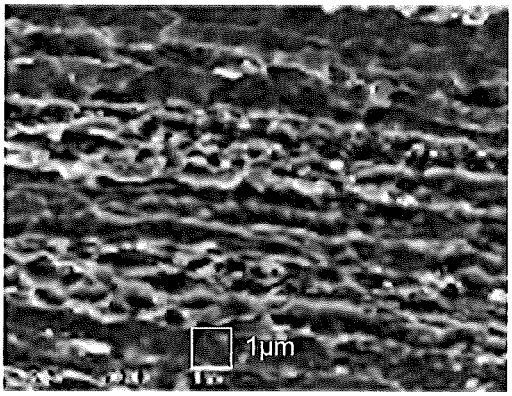


Fig 10A

Fig 10B

Fig 10C

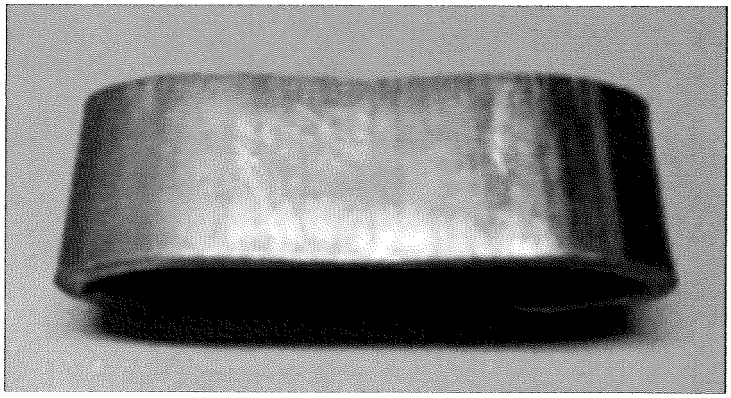
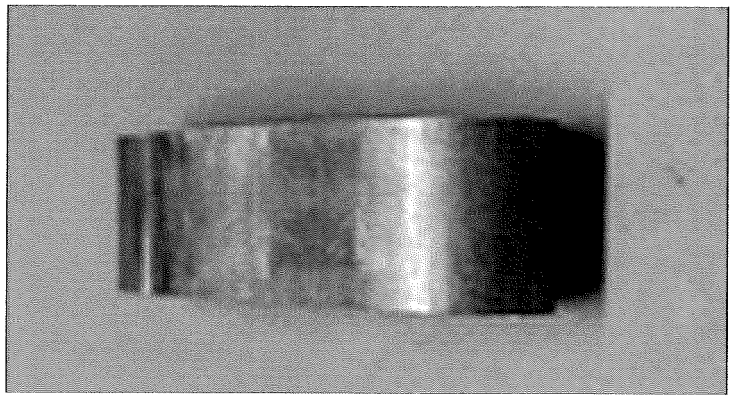


Fig 10D



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2021/001208

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl. B21C23/01(2006.01)i
FI: B21C23/01 Z

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)
Int. Cl. B21C23/01

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2021
Registered utility model specifications of Japan	1996-2021
Published registered utility model applications of Japan	1994-2021

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
CiNii

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2007-231353 A (KOBE STEEL, LTD.) 13 September 2007 (2007-09-13), claims, paragraphs [0067], [0076], [0098]	1-5
A	JP 2012-166238 A (KOBE STEEL, LTD.) 06 September 2012 (2012-09-06), claims, paragraph [0042]	1-5
A	CN 1425513 A (INSTITUTE OF METAL RESEARCH CHINESE ACADEMY OF SCIENCES) 25 June 2003 (2003-06-25), example 3	1-5

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
04.02.2021	16.02.2021

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/JP2021/001208

Patent Documents referred to in the Report	Publication Date	Patent Family	Publication Date
JP 2007-231353 A	13.09.2007	(Family: none)	
JP 2012-166238 A	06.09.2012	(Family: none)	
CN 1425513 A	25.06.2003	(Family: none)	

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP 2004076034 A **[0005]**