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(54) **ROLLED MATERIAL FOR FRACTURE SPLIT CONNECTING ROD EXCELLING IN FRACTURE SPLITTABILITY, HOT FORGED PART FOR FRACTURE SPLIT CONNECTING ROD EXCELLING IN FRACTURE SPLITTABILITY, AND FRACTURE SPLIT CONNECTING ROD**

GEROLLTES MATERIAL FÜR EINEN BRUCHGESPALTENEN VERBINDUNGSSTAB MIT HERVORRAGENDER BRUCHSPALTBARKEIT, GESCHMIEDETES TEIL FÜR EINEN BRUCHGESPALTENEN VERBINDUNGSSTAB MIT HERVORRAGENDER BRUCHSPALTBARKEIT UND BRUCHGESPALTENER VERBINDUNGSSTAB

MATERIAU LAMINE POUR BIELLE A FISSURE DE RUPTURE PRESENTANT UNE EXCELLENTE CAPACITE DE FISSURE DE RUPTURE, ELEMENT FORGE A CHAUD POUR BIELLE PRÉSENTANT UNE EXCELLENTE CAPACITÉ DE FISSURE DE RUPTURE ET BIELLE A FISSURE DE RUPTURE

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Description

[Technical Field]

[0001] The present invention relates to a rolled material for a fracture splitting-type connecting rod with excellent fracture splitting characteristics, a hot-forged part for a fracture splitting-type connecting rod with excellent splitting characteristics, and a fracture splitting-type connecting rod, and more particularly relates to a rolled material suitable for the manufacture of a connecting rod having a through-hole section for assembly with a crankshaft that is fracture split into substantially semicircles, a hot-forged part obtained using this rolled material, and furthermore a fracture splitting-type connecting rod obtained using this hot-forged part.

[Prior Art]

[0002] A connecting rod (also known as conrod) constitutes a component part of internal combustion engines including gasoline engines and diesel engines employed for coupling a piston to a crankshaft and transmitting the reciprocal motion of the piston to the crankshaft for conversion to rotational motion. The connecting rod comprises a through-hole (substantially circular) for assembly with the crankshaft and, for ease of assembly and for removal for the purpose of maintenance, it is configured with the through-hole split into two substantially semicircles. The side of the split connecting rod directly coupled with the piston is referred to as a connecting rod main body, while the other side is referred to as a connecting rod cap.

[0003] Conventional connecting rods as described above are manufactured by individual hot forging of the connecting rod main body and connecting rod cap, and then cut-machining of the mating faces thereof, and machining of a knock pin to prevent displacement administered in accordance with need. However, this kind of machining has the inherent problem of not only lowered material yield but also inflated cost due to the large number of steps necessitated thereby.

[0004] With this in mind, a method for integrally hot forging a connecting rod based on machining (such as through-hole forming machining (hole drilling) or bolt-hole drilling for assembly with a crankshaft) and then cold fracture splitting of the through-hole section into two substantially semicircles has been implemented. Random unevenness on the mating faces produced using this method prevents the generation of gaps between the mating faces of the connecting rod main body and the connecting rod cap and affords precision assembly with a crankshaft.

[0005] The material used in Europe for the manufacture of the connecting rod based on the fracture splitting process described above is a DIN standard C70S6 material. Although this material is suitable for the fracture splitting process described above, the problems inherent to this material are its inability to meet the high level of fatigue strength and proof stress demanded and, furthermore, its unsatisfactory machinability. Accordingly, a need exists for a steel for the manufacture of a fracture splitting-type connecting rod of a type that has excellent fatigue strength and proof stress and, furthermore, good machinability.

[0006] A variety of steel materials have been hitherto developed with this in mind, an example of which is given in patent document 1 which discloses a fracture-splittable high-strength as-rolled steel and an intermediate product thereof. This publication discloses how controlling both the aspect ratio of a sulfide of which MnS is the main constituent and the area ratio of pearlite produces random unevenness on fracture faces and reduces the likelihood of displacement subsequent to a mating thereof. However, the prescribed area ratio of pearlite is not more than 40% and, where ferrite is the remaining component, the area ratio of ferrite is not less than 60%. The ferrite exists in a soft phase and a large area ratio of ferrite is regarded as a factor in deformation that occurs when the fracture-splitting process is performed.

[0007] Patent document 2 discloses an as-rolled steel of high strength, low ductility and excellent machinability having a C content of 0.25 to 0.70% and an area ratio of ferrite suppressed to not more than 10%. However, this technology is based on formation of a hard layer of high pliability and, accordingly, with the increased load required when the fracture splitting process is performed, it is thought that this will lead to increased deformation.

[0008] Patent document 3 discloses a technology to ensure machinability and low ductility of a hot forged steel for the manufacture of a connecting rod with a C content of 0.5% to 0.7% and an area ratio of ferrite of 5 to 15%. In addition, patent document 4 discloses a steel of a C content of 0.2 to 0.6% in which the fracture splitting characteristics are ensured by the addition of V or Ti. Furthermore, patent documents 5 to 7 disclose steels for a fracture splitting-type connecting rod in which both the C content and the ferrite fraction are suppressed to ensure machinability and mateability. However, the morphology of the sulfide-based inclusion of MnS or the like is not controlled in the technologies of patent documents 3 to 7 and, accordingly, deformation in the fracture-splitting process cannot always be adequately suppressed. Moreover, while patent documents 4 to 7 describe the addition of Ca which is considered an effective element for controlling the morphology of MnS, there is no specific mention therein of the method for the addition thereof, and the fracture splitting characteristics are not regarded as being adequately increased by controlling the morphology of the sulfide-based inclusion of which MnS is the main constituent.

[0009] Patent document 8 discloses a hot as-rolled steel in which the fracture splitting characteristics are improved with the aspect ratio of the sulfide-based inclusion being not more than 10. However, even if the MnS is formed in a spherical shape, it is thought that a large number of voids originating in the MnS will be generated in the fracture-splitting process when the S content is comparatively large. Because, as a result, ductile fracture of the ferrite portion attributable thereto is more likely to occur and the fracture faces of the connecting rod cap and the connecting rod main body cannot be mated, an apparent greater deformation is thought to occur in the fracture-splitting process.

[Patent document 1] Japanese Laid-Open Patent Publication No. 2003-342671
[Patent document 2] Japanese Laid-Open Patent Publication No. 2002-356743
[Patent document 3] Japanese Laid-Open Patent Publication No. 2004-35916
[Patent document 4] Japanese Laid-Open Patent Publication No. 2004-277817
[Patent document 5] Japanese Laid-Open Patent Publication No. 2002-275578
[Patent document 6] Japanese Laid-Open Patent Publication No. 2004-277848
[Patent document 7] Japanese Laid-Open Patent Publication No. 2003-193184
[Patent document 8] Japanese Laid-Open Patent Publication No. 2000-73141

[0010] Furthermore, relevant to the above, for ductility non-heat treated steel suitable for conrod manufacturing is disclosed in JP-A-2003119545.

[Disclosure of the Invention]

[Problems to be Solved by the Invention]

[0011] The present invention was made in view of the above circumstances it is an object of the invention to provide a rolled material ideal for manufacturing a connecting rod in which a through-hole section for assembly with a crankshaft is fracture split in substantially semicircles, a hot-forged part obtained using this rolled material and, furthermore, a fracture splitting-type connecting rod obtained using this hot-forged part.

[Means for Solving the Problems]

[0012] The rolled material for a fracture splitting-type connecting rod having excellent fracture splitting characteristics pertaining to the present invention is characterized in that a chemical composition comprises, by mass% (hereinafter the same for each component),

C : 0.25 to 0.60%,
Mn : 0.5 to 2%,
S : 0.05 to 0.2%,
Si : 0.05 to 1.5%,
V : 0.05 to 0.3%,
P : 0.010 to 0.15%.
Al : 0.0010 to 0.06%,
N : 0.03% or less and
Cr : 0.1 to 2%,

and further comprises at least one type selected from a group consisting of

Zr : 0.005 to 0.2%,
Ti : 0.005 to 0.1%,
Ca : 0.0005 to 0.01%,
Te : 0.0010 to 0.1%, and
REM : 0.0005 to 0.3%,

and a balance of iron and unavoidable impurities,
ferrite and pearlite occupies in total an area ratio to the whole of not less than 95%,
an average aspect ratio of a sulfide-based inclusion is not more than 10.0 when observed in a D/4 portion (D being the diameter of the rolled material) in a cross-section parallel to a longitudinal direction of a rod-shaped rolled material, and a Pc indicated in Equation (1) below is between 0.41 and 0.75 and a Veq indicated in Equation (2) below is not less than 0.18 mass%

$$Pc = C/(1-\alpha/100) \quad (1)$$

{In Equation (1), C represents a carbon content in steel (mass%) and α represents a ferrite fraction (area ratio%))

$$Veq = V + Ti/2+Si/20 \quad (2)$$

{In Equation (2), V, Ti and Si represent the content of each element in steel (mass %)}.

[0013] In addition, the rolled material should further comprise a Ceq of not less than 0.80 mass% as indicated in Equation (.3) below and a PM of not more than 500 mass% as indicated in Equation (4) below

$$Ceq = C + 0.28Mn - 1.0S + 0.32Cr + 1.7V + 1.3Ti \quad (3)$$

$$PM = 554C + 71Mn - 262S + 82Cr + 429V \quad (4)$$

{In Equations (3) and (4), C, Mn, S, Cr, V and Ti represent the content of each element in steel (mass%)}.

[0014] The rolled material may further comprise, as an additional element,
Se: 0.0010 to 0.1% and/or Bi and Pb: 0.01 to 0.2% in total.

[0015] The present invention includes a hot-forged part for a fracture splitting-type connecting rod with excellent splitting characteristics, obtained by hot forging a rolled material and, furthermore, a fracture splitting-type connecting rod obtained using this hot-forged part.

[0016] The average aspect ratio of the sulfide-based inclusion refers to a value measured by a method indicated in the later-described examples.

[Effect of the Invention]

[0017] According to the present invention, a rolled material for a connecting rod in which the costs of the splitting processing can be reduced because the through-hole section of the connecting rod can be satisfactorily fracture split into substantially semicircles and, in addition, that exhibits a higher strength and better machinability than the C70S6 material used in the USA, as well as a hot-forged part obtained using this rolled material and, furthermore, a fracture splitting-type connecting rod obtained using this hot-forged part, can be actualized.

[Brief Description of the Drawings]

[0018]

FIG. 1 is a graph showing the relationship between Pc and distortion (splitting distortion) generated in the fracture splitting process;
FIG. 2 is a graph showing the relationship between the average aspect ratio (L/W) of the sulfide-based inclusion and the distortion (splitting distortion) generated in the fracture splitting process;
FIG. 3 is a graph showing the relationship between Veq and distortion (splitting distortion) generated in the fracture splitting process;
FIG. 4 is a schematic perspective view for explaining an observed region of the sulfide-based inclusion;
FIG. 5 is a schematic (a) upper view and (b) side view of the shape of test pieces used for appraising the fracture splitting characteristics;
FIG. 6 is a cross-sectional side view that schematically shows the fracture splitting state using a press testing apparatus; and
FIG. 7 is an upper view showing the state before and after fracture splitting (before and after testing) of the test pieces used for appraising the fracture splitting characteristics.

[Explanation of Numerals]

[0019]

1 Press
2 Support base
3, 3' Holder
4, 5 Wedge
6 Test piece

[Best Mode for Carrying out the Invention]

[0020] The inventors conducted earnest research of steel materials of low C content and increased S content which ensures a workability (in particular, machinability) in order to obtain a rolled material for a connecting rod in which fracture splitting can be satisfactorily implemented when a through-hole section for assembly with a crankshaft is split into two substantially semicircles. As a result, using a rolled material of low C content and high S content in which significant distortion is likely to occur when a fracture splitting process is performed, the inventors discovered a specific method for actualizing a connecting rod material for a connecting rod having excellent machinability and adequately improved fracture splitting characteristics based on the concept of controlling the relationship between the ferrite fraction and the C content and, in addition, controlling the aspect ratio of the sulfide-based inclusion thereof. The present invention will be hereinafter described in detail.

[0021]

$$<Pc = 0.41 \text{ to } 0.75$$

$$\text{Wherein } Pc = C/(1- \alpha /100) \qquad (1)$$

{In Equation (1), C represents the content of carbon contained in the material (mass%), and α represents the ferrite fraction (area ratio%)}>

Using a rolled material of comparatively high S content, even if the morphology of the sulfide-based inclusion such as MnS is controlled, ductility fracture will sometimes occur when the fracture splitting process is performed. When ductility fracture occurs, the fracture faces of the connecting rod main body and connecting rod cap cannot be mated and, accordingly, the precision mating thereof in assembly with a crankshaft is prevented. In addition, when gaps arise between the fracture faces of the connecting rod main body and the connecting rod cap because of the inability for these fracture faces to be mated with precision, the strength of the connecting rod cannot be ensured. Thereupon, a range of investigations of the factors causing this ductility fracture was carried out in the present invention with a view to the prevention thereof. As a result, it was discovered that Pc: $C/(1- \alpha /100)$ which expresses the relationship of the area ratio of ferrite in the system as a whole with respect to the steel C content in a prescribed C content range should be maintained in a fixed range.

[0022] FIG. 1 is a graph showing the relationship between Pc and distortion (splitting distortion) generated in the fracture splitting process that depicts the test results of later-described examples (aspect ratio of sulfide-based inclusion in each case within a prescribed range) (notably, the line drawn in FIG. 1 represents the trend at C content 0.33%). It is clear from FIG. 1 that the splitting distortion can be reliably controlled by not only controlling the sulfide-based inclusion within a later-described prescribed range but by controlling the Pc. More specifically, it is clear that for each C content the minimum splitting distortion when fracture splitting is performed occurs in the range close to Pc 0.5, and that to suppress the splitting distortion to not more than 200μm (the maximum splitting distortion of the C70S6 material is of the order of 200μm and, accordingly, a figure of not more than 200μm is targeted) the lower limit of Pc must be 0.41. To reduce the splitting distortion to not more than 150μm, the Pc should be not less than 0.45. In addition, the upper limit of the Pc should be 0.75. In order to minimize the splitting distortion to not more than 100μm, the Pc should be between 0.47 and 0.60.

[0023] As is described above, excellent fracture splitting characteristics can be ensured in the present invention by controlling the morphology of the later-described sulfide-based inclusion to promote development of the fracture faces in the fracture splitting process, and controlling the relationship between the ferrite fraction and the C content. Furthermore, because voids proximal to notches that are generated when the sulfide-based inclusion content is increased can be suppressed, excellent machinability can also be ensured.

<Average aspect ratio of a sulfide-based inclusion when observed in a D/4 portion (D being the diameter of the rolled material) in a cross-section parallel to a longitudinal direction of a rod-shaped rolled material: 10.0 or less>

[0024] Sulfide-based inclusions of large aspect ratio created by an expanding step in the manufacturing process inhibit the development of cracks in the fracture splitting process. As a result, because of the increased load that is applied in the fracture splitting processing, the deformation (distortion) occurring in the fracture splitting process increases.

[0025] FIG. 2 is a graph showing the relationship between the distortion (splitting distortion) generated in the fracture splitting process and the average aspect ratio (L/W) of the sulfide-based inclusion (the Pc in each case falls within the prescribed range). Based on FIG. 2, to suppress the splitting distortion to not more than 200μm the average aspect ratio of the sulfide-based inclusion must be not more than 10.0. To reduce the splitting distortion to not more than 150μm, it is preferable that the aspect ratio be not more than 9.5.

[0026] While the "sulfide-based inclusion" of the present invention principally implies MnS, it incorporates other sulfides apart from Mn including Zr, Ti, Mg, Ca, Se, Te and REM, as well as composite sulfides thereof, and composite compounds of these sulfides and composite sulfides with an oxide nucleus.

[0027]

$$<Veq \geq 0.18$$

$$\text{wherein } Veq = V + Ti/2 + Si/20 \qquad (2)$$

{[In Equation (2), V, Ti and Si represent the content of each element in steel (mass %)}>

Irrespective of whether or not an inclusion such as MnS or the like is present, voids are caused and ductility fractures are induced when the fracture splitting process is performed. The origin thereof is thought to be attributable to insufficient ferrite hardness. Thereupon, subsequent to an examination carried out to determine those elements affecting ferrite hardness, the inventors discovered that the elements effecting ferrite hardness were V, Ti and Si and, through various tests, discovered that a correlation exists between the Veq described above containing V, Ti and Si, and ferrite hardness.

[0028] FIG. 3 is a graph that shows the relationship between Veq and distortion (splitting distortion) generated in the fracture splitting process which depicts the test results of the later-described examples. It is clear from FIG. 3 that to suppress the splitting distortion to not more than 200μm and to ensure excellent fracture splitting characteristics, the Veq must be not less than 0.18 mass%. More preferably, this is not less than 0.22 mass%. As the effect thereof is saturated when the Veq is 0.40 mass% or more, from the viewpoint of cost the Veq is preferably not more than 0.40 mass%.

[0029]

$$<Ceq \geq 0.80$$

$$\text{wherein } Ceq = C + 0.28Mn - 1.0S + 0.32Cr + 1.7V + 1.3Ti \qquad (3)$$

{In Equation (3), C, Mn, S, Cr, V and Ti represent the content of each element in steel (mass%)}>

Ceq constitutes a correlation parameter of the hardness of the steel material. The Ceq should be controlled to not less than 0.80 mass% (more preferably not less than 0.90 mass%) to ensure a strength of the steel material that facilitates the use thereof as a connecting rod. On the other hand, because of the deterioration in machinability that occurs when the Ceq is too high, the upper limit thereof is preferably 1.50 mass%.

[0030]

$$<PM \leq 500$$

$$\text{wherein } PM = 554C + 71Mn - 262S + 82Cr + 429V \qquad (4)$$

{In Equation (4), C, Mn, S, Cr and V represent the content of each element in steel (mass%)}>

PM constitutes a correlation parameter of machinability. To ensure a level of cuttability appropriate for bulk manufacture, PM should be not more than 500 mass% (more preferably not more than 400 mass%).

[0031] The basis for restriction of the chemical components of the present invention will be hereinafter described in detail.

<C: 0.25 to 0.60%>

[0032] C is an element necessary for ensuring strength and reducing distortion in the fracture splitting process. It has the additional effect of facilitating the formation of a pearlite system or the like for controlling the generation in the ferrite portion of voids having a sulfide-based inclusion nucleus. Accordingly, the C content must be not less than 0.25%. More preferably, this is not less than 0.30%. However, because of the deterioration in machinability that occurs when the C content is excessive, the content thereof should be not more than 0.60%. More preferably, this is not more than 0.55%.

<Mn: 0.5 to 2%>

[0033] Mn increases the strength of the steel material and, in addition, improves the quenching characteristics thereof and, when the carbon content is high, it facilitates the generation of a fragile heat-affected layer in a laser-processed notch base portion that improves the ease of fracture splitting. In order to exhibit this effect, the Mn content is preferably not less than 0.5%. However, when the Mn content is excessive, bainite is generated following forging that, in turn, results in an increase in hardness and lowering of machinability. In addition, because bainite contains many movable dislocations, a lowering of the proof stress, which constitutes an essential characteristic of the connecting rod, occurs. Accordingly, the Mn content in the present invention is not more than 2%. More preferably, it is not more than 1.5%.

<S: 0.05 to 0.2%>

[0034] S generates a sulfide (MnS) with Mn and is an element effective for improving machinability. In the present invention this effect is exhibited in an S content not less than 0.05%. More preferably, this is not less than 0.08% and desirably not less than 0.10%. MnS formed in the manufacturing process in a long and narrow stretched shape by rolling or the like interferes with the development of the fracture faces when the fracture splitting process is performed. While this problem is solved in the present invention by the sulfide-based inclusion being formed in a spherical shape, when the S content is excessive, an excessive content of the sulfide-based inclusion, which serves as an initiator of the increased generation of voids in the ferrite portion, is also produced and, in turn, durability fracture is more likely to occur. Accordingly, the S content is not more than 0.2%. More preferably, it is not more than 0.12%.

<Si: 0.05 to 1.5%>

[0035] Si is useful as a deoxidizing element in the molten steel manufacture process and is also effective for, by solid dissolving in ferrite, improving the strength of the soft phase (ferrite) which constitutes the main cause of the plasticity deformation that occurs when the fracture splitting process is performed, and for improving the proof stress and fatigue strength of the steel. In addition, it is effective for suppressing deformation (roundness change) when the fracture splitting process is performed, and for improving the mateability of the fracture faces. These effects are adequately exhibited at a Si content not less than 0.05%. More preferably, this content is not less than 0.15%. However, because the hardness is increased to an unnecessary extent and deterioration in machinability occurs when the Si content is excessive, the content thereof is not more than 1.5%. More preferably, the content is not more than 0.5%.

<V: 0.05 to 0.3%>

[0036] V has the effect of suppressing deformation when the fracture splitting process is performed by increasing the strength of the ferrite in the same way as Si. In order to adequately demonstrate this effect, the V content is preferably not less than 0.05%. On the other hand, because the effect thereof is saturated when the. V content is excessive, the upper limit thereof is 0.3%.

<P: 0.010 to 0.15%>

[0037] The P in the present invention is effective for controlling deformation in the fracture-splitting process and improving the mateability of the fracture faces. In order to exhibit this effect, it may be actively contained in an amount not less than 0.010%. More preferably, this is not less than 0.02%. However, because P constitutes an element that increases the likelihood of defects being formed in a continuous forging process, the content thereof is not more than 0.15% (and more preferably not more than 0.08%).

<A1: 0.0010 to 0.06%>

[0038] Al is an element that exhibits a deoxidizing effect in the manufacture of molten steel. Because the sulfide-based inclusion can more easily be formed in a spherical shape as a result of a lowered oxygen concentration in the molten steel, it contributes to the sulfide-based inclusion being formed in a spherical shape. For these effects to be exhibited it is preferably contained in an amount not less than 0.0010%. More preferably, this is not less than 0.010%. However, the effect thereof is saturated if the Al content and so on is excessive, and formation of the sulfide-based inclusion in a spherical shape is prevented if the oxygen concentration in the molten steel is too low. Accordingly, the Al content is not more than 0.06% (and more preferably not more than 0.020%).

<N: 0.03% or less>

[0039] N is an element that is unavoidably contained in the steel. Because it is a cause of forging defects if contained in a large amount, the content thereof is suppressed to not more than 0.03% (and more preferably not more than 0.02%).

(Cr: 0.1 to 2%)

[0040] If Cr is added, the strength of the steel material is increased and the quenching characteristics are improved in the same way as Mn described above. In addition, when the carbon content is high, it facilitates the generation of a fragile heat-affected layer in a laser-processed notch base portion that improves ease of fracture splitting. In order to exhibit this effect it is preferably contained in an amount not less than 0.1% (and more preferably not less than 0.15%). When Cr is contained in a large amount bainite is generated following forging with a resultant increase in hardness and lowering of machinability. In addition, because bainite contains many movable dislocations, a lowering of the proof stress, which constitutes an essential characteristic of the connecting rod, occurs. Accordingly, the Cr content in the present invention is not more than 2% (and more preferably not more than 1.0%).

<At least one type selected from a group consisting of:

[0041]

Zr : 0.005 to 0.2%,
Ti : 0.005 to 0.1%
Ca : 0.0005 to 0.01%
Te : 0.0010 to 0.1% and
REM : 0.0005 to 0.3% >

These elements have the effect of controlling the morphology of the sulfide-based inclusion and suppressing deformation when the fracture splitting process is performed. Zr is an effective element for forming the sulfide-based inclusion in a spherical shape and, in order for this effect to be anticipated, the Zr content is preferably not less than 0.005%. More preferably, it is not less than 0.05%. However, because an excessive Zr content leads to excessive hardening and deterioration of machinability, it is contained in an amount not more than 0.2% (or more preferably not more than 0.10%).

[0042] Ti contributes to the formation of the sulfide-based inclusion in a spherical shape and, in addition, has the effect of suppressing deformation of the sulfide-based inclusion and increasing the strength of the ferrite in the same way as Si and V. In order to exhibit this effect, the Ti is preferably contained in an amount not less than 0.005%. More preferably, this is not less than 0.05%. However, because of the deterioration in machinability that occurs when the Ti content is excessive, the upper limit thereof is 0.1%. More preferably, this upper limit is not more than 0.08%.

[0043] Ca has the effect of affording formation of the sulfide-based inclusion in a spherical shape. In order to exhibit this effect, the Ca is contained in an amount not less than 0.0005%. Moreover, to suppress the formation of Ca oxides when Ca is added and to facilitate the formation of the sulfide-based inclusion in a spherical shape based on solid dissolving of Ca in the sulfide-based inclusion, Al or the like is added directly prior to the addition of Ca to reduce the oxygen content in the molten steel after which the Ca is added.

[0044] When the Ca content is excessive, a large amount of oxides are formed and a loss of mechanical characteristics occurs in the same way as with Mg. Accordingly, the Ca content should be not more than 0.01% (and more preferably not more than 0.0030%).

[0045] Te is another element that has the effect of forming the sulfide-based inclusion as a spherical shape. In order that this effect is exhibited, it is preferably contained in an amount not less than 0.0010%. However, because of the deterioration in heat deformation behavior that occurs when it is contained in a large amount, it should be contained in an amount not more than 0.1% (and preferably not more than 0.01%).

[0046] The REM (rare earth elements; for example, a mish metal) have an effect comparable to that of Mg for forming the sulfide-based inclusion as a fine structure and contributing to improved mechanical characteristics. The amount of REM that may be added with the anticipation of this effect in mind is not less than 0.0005%. More preferably, this amount should be not less than 0.0010%. However, when added in an excessive amount a large amount of oxides are formed and a loss of mechanical characteristics occurs. Accordingly, the REM should be contained in an amount not more than 0.3% (more preferably not more than 0.010%).

[0047] While the present invention contains the prescribed elements noted above, the balance thereof is made up of iron and unavoidable impurities, these unavoidable impurities being allowable as infiltrated elements introduced according to conditions such as the raw materials, materials and manufacturing equipment conditions and so on. In addition, these elements can be acceptably contained within a prescribed range that facilitates further improvement of the fracture splitting characteristics.

<Se: 0.0010 to 0.1% and/or

Bi and Pb: 0.01 to 0.2% in total>

[0048] Each of the elements Se, Bi and Pb has the effect of improving machinability. In order for this effect to be exhibited, it is preferable that Se is contained in an amount not less than 0.0010%. In addition, if the elements Bi and/or Pb are contained, it is preferable that they are contained in an amount not less than 0.01%. However, because of the deterioration in hot deformation behavior that occurs when Se is contained in a large amount, it is preferable that it is contained in an amount not more than 0.1% (and more preferably not more than 0.03%). In addition, because Bi and/or Pb contained in a large amount are a catalyst of forging defects in the steel material and faults during the rolling thereof, the Bi and/or Pb should be contained in a total amount of not more than 0.2% (and more preferably not more than 0.15$).

[0049] The rolling material of the present invention is a 2-phase ferrite and pearlite system in which the total area ratio of the ferrite and pearlite is 95% or more of the whole. Other systems apart from the ferrite and pearlite (for example beinite) may allowably occupy not more than 5% of the area ratio.

[0050] While the present invention does not prescribe the method for manufacturing of the rolling material, from the viewpoint of ease of establishment of the average aspect ratio of the sulfide-based inclusion in the prescribed range, a heating temperature for the hot forging of not less than 950°C is preferred. On the other hand, because defects and faults caused by scale and so on are produced when this temperature is too high, the temperature is preferably not more than 1200°C. In addition, while the addition of Ca, Zr, Te or the like is effective for controlling the morphology of the sulfide-based inclusion as described above, in the addition of these elements, Al or the like, which serves as a deoxidizing agent, should be added directly prior to the addition of the Ca or the like in the molten steel manufacturing stage to lower the oxygen content in the molten steel, and then the Ca added.

[0051] To control the Pc the C content must be adjusted and the ferrite fraction must be controlled. The ferrite fraction can be adjusted by well-known means such as adjustment of the rolled material temperature directly following forging, adjustment of the cooling speed directly following forging, or adjustment of alloy elements other than C. More specifically, the following method may be employed. That is to say, with the forging being implemented under suitable conditions, the ferrite fraction is measured and the Pc calculated. When the Pc does not fall within the prescribed range, adjustments to establish the Pc within the prescribed range based on lowering of the ferrite fraction include lowering the cooling speed, lowering the steel material temperature directly following forging, and lowering of the alloy components such as Mn within a prescribed range are implemented. The Pc can be constantly adjusted by repeating this trial and error process in this way until the Pc is of the order of 0.5.

[0052] The rolling material of the present invention is an as-rolled steel that in the manufacture of a hot forged component that uses this rolling material can be used unaltered in the cooled state without need for a heat treatment such as quenching or baking to be implemented to ensure the mechanical characteristics following forging. Provided the shape of the rolled material is rod-shape, there are no particular restrictions to the size thereof, the diameter thereof being normally of the order of 25 to 50mm.

[0053] The hot-forged part of the fracture splitting-type connecting rod of the present invention is obtained using this rolling material to form the external shape of the connecting rod by hot forging with a well-known method. In addition, production of this fracture splitting-type connecting rod involves implementation of a processing such as mold processing of the forged component part to form a through-hole for assembly with a crankshaft, and then fracture splitting of this through-hole section into two substantially semicircles.

[Examples]

[0054]

Example of bar steel manufacture

[0055] Steel of the chemical compositions indicated in Tables 1 and 2 were melted and forged in accordance with a common method for manufacturing molten steel, and then bloomed and rolled to produce a 70mmϕ steel roll. Next, this steel roll was forged by hot forging to a 25mm thickness. Notably, the adjustment of the Pc in the method of manufacturing described above was based on adjustment of the chemical components and adjustment of the average cooling speed following forging of 800 to 600°C. In addition, the average aspect ratio of the sulfide-based inclusion was controlled by altering the temperature of the steel material directly prior to rolling and adding Ca, Zr or Te or the like to facilitate the formation of the sulfide-based inclusion in a spherical shape. These elements were added subsequent to all the Al being added.

[0056] Using the bar steel produced, a measurement of ferrite fraction, a measurement of average aspect ratio of the sulfide-based inclusion, and an evaluation of the fracture splitting characteristic were carried out as outlined below.

<Measurement of ferrite fraction (α) >

[0057] Samples were taken from a cross-section parallel to the longitudinal direction to allow for observation of a D/4 section of the produced bar steel (see FIG. 4) and, following mirror-surface polishing of the surface thereof, test pieces were prepared for system observation by corrosion of the samples with Nital. The samples were observed in 1-visual field with a 100x magnification optical microscope (1-visual field photographic size: 9cm x 7cm), and an image analysis of the obtained photos was carried out. This measurement was carried out in the same way using a desired 3-visual field of the sample surface, the average value thereof being taken as the ferrite fraction (area ratio%).
In addition, the total area ratio of the ferrite and the pearlite was determined on the basis of this image analysis.

<Measurement of the aspect ratio of the sulfide-based inclusion (L/W)>

[0058] 1 sq mm of the D/4 portion (see FIG. 4) of the cross-section parallel to the longitudinal direction of the bar steel was observed with an optical microscope. The length L and width W of inclusions (thickness being the broadest width with respect to the long diameter) of thickness not less than 1μm was measured, the L/W determined, and the arithmetic mean value thereof calculated. While the possibility exists that the inclusions may include oxides as well as sulfide-based inclusions, the likelihood thereof is very small and, accordingly, the L/W determined by this method was taken as the average aspect ratio of the sulfide-based inclusion.

<Evaluation of the fracture splitting characteristics>

[0059] A hot forging was administered on the bar steel described above of 70mmϕ in the direction perpendicular to the direction of rolling of the bar steel forming to a thickness of 25mm, following which the sample pieces indicated in FIG. 5 were processed. FIG. 5(a) shows an upper surface view of a test piece and (b) shows a side view of a test piece, a denoting a notch, b denoting a bolthole, and the arrow c denoting the direction of rolling in each of the drawings. The test pieces were of a plate shape of 65mm x 65m x 22mm thickness, a ϕ40mm cylinder shape being bored in the center thereof. A notch was provided in the end part of the bored portion. In addition, a bolthole b (ϕ8.3mm) was provided along the direction of rolling of the test pieces.

[0060] Using the test pieces described above, as outlined in FIG. 6, a fracture splitting of the test pieces involving the setting thereof in a press setter (1600t press, press speed: 270mm/s [speed at time of jig contact (jig height 110mm), and, because the wedge angle between the wedge 4 and wedge 5 is 30°, a TP fracture speed of approximately 150mm/s]) was implemented. Thereupon, as outlined in FIG. 7, the hole diameter difference before and after fracture splitting (L2-L1) was measured as the splitting distortion, and the splitting characteristics were evaluated as excellent if the splitting distortion was 200mm or less.

[0061] These results are shown in Tables 3 and 4.

[0062]

[Table 1]

TEST NO.	CHEMICAL COMPOSITION ※1 (mass%)																	Veq ※2 (mass%)	Ceq ※3 (mass%)	PM ※4 (mass%)
	C	Si	Mn	P	S	Cr	V	Al	N	Ti	Zr	Ca	Mg	Se	Te	REM	Others			
a01	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0050	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
a02	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0050	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
a03	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0050	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
a04	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0050	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
a05	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0050	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
a06	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0050	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
a07	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0050	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
a08	0.40	0.18	1.20	0.020	0.098	0.19	0.18	0.004	0.0043	−	−	0.0010	−	−	−	−	−	0.19	1.00	374
a09	0.40	0.18	1.20	0.020	0.098	0.19	0.18	0.004	0.0043	−	−	0.0010	−	−	−	−	−	0.19	1.00	374
a10	0.25	0.18	1.20	0.019	0.105	0.20	0.18	0.006	0.0080	−	−	0.0010	−	−	−	−	−	0.19	0.85	290
a11	0.25	0.18	1.21	0.020	0.099	0.21	0.18	0.005	0.0080	−	−	0.0010	−	−	−	−	−	0.19	0.86	293
a12	0.25	0.19	1.21	0.020	0.102	0.21	0.18	0.005	0.0080	−	−	0.0010	−	−	−	−	−	0.19	0.86	292
b01	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0077	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
b02	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.004	0.0084	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
b03	0.33	0.20	1.21	0.020	0.100	0.20	0.26	0.007	0.0077	−	−	0.0010	−	−	−	−	−	0.27	1.07	371
c01	0.20	0.20	1.15	0.021	0.101	0.21	0.25	0.003	0.0082	−	−	0.0010	−	−	−	−	−	0.26	0.91	281
c02	0.28	0.19	1.10	0.020	0.105	0.20	0.248	0.003	0.0076	−	−	0.0010	−	−	−	−	−	0.26	0.96	328
c03	0.40	0.21	1.17	0.019	0.099	0.19	0.269	0.004	0.0084	−	−	0.0010	−	−	−	−	−	0.28	1.14	411
c04	0.50	0.20	1.22	0.020	0.101	0.19	0.259	0.002	0.0073	−	−	0.0010	−	−	−	−	−	0.27	1.24	464
c05	0.62	0.19	1.16	0.021	0.103	0.19	0.253	0.003	0.0084	−	−	0.0010	−	−	−	−	−	0.26	1.33	524
d01	0.32	0.02	1.16	0.020	0.101	0.20	0.26	0.002	0.0079	−	−	0.0010	−	−	−	−	−	0.26	1.05	362
d02	0.32	0.41	1.17	0.020	0.098	0.20	0.258	0.003	0.0082	−	−	0.0010	−	−	−	−	−	0.28	1.04	360
d03	0.34	0.96	1.17	0.020	0.099	0.21	0.254	0.004	0.0083	−	−	0.0010	−	−	−	−	−	0.30	1.06	369
e01	0.34	0.20	0.30	0.020	0.104	0.19	0.272	0.004	0.0080	−	−	0.0010	−	−	−	−	−	0.28	0.83	313
e02	0.32	0.20	0.60	0.020	0.105	0.20	0.253	0.003	0.0077	−	−	0.0010	−	−	−	−	−	0.26	0.87	319
e03	0.32	0.21	1.50	0.021	0.102	0.21	0.249	0.003	0.0078	−	−	0.0010	−	−	−	−	−	0.26	1.12	381
e04	0.33	0.21	2.00	0.021	0.102	0.21	0.249	0.003	0.0081	−	−	0.0010	−	−	−	−	−	0.26	1.27	421
f01	0.32	0.20	1.17	0.010	0.102	0.19	0.251	0.003	0.0078	−	−	0.0010	−	−	−	−	−	0.26	1.03	358
f02	0.32	0.20	1.18	0.030	0.103	0.20	0.253	0.003	0.0078	−	−	0.0010	−	−	−	−	−	0.26	1.03	358
f03	0.32	0.20	1.25	0.040	0.100	0.19	0.262	0.003	0.0086	−	−	0.0010	−	−	−	−	−	0.27	1.07	368
f04	0.34	0.19	1.23	0.080	0.098	0.21	0.269	0.003	0.0074	−	−	0.0010	−	−	−	−	−	0.28	1.10	381
f05	0.33	0.20	1.16	0.100	0.096	0.21	0.258	0.004	0.0079	−	−	0.0010	−	−	−	−	−	0.27	1.05	365

※1 Balance of iron and unavoidable impurities

※2 Veq=V+Ti/2+Si/20

※3 Ceq=C+0.28Mn-1.0S+0.32Cr+1.7V+1.3Ti

※4 PM=554C+71Mn-262S+82Cr+429V

[0063]

[Table 2]

TEST NO.	CHEMICAL COMPOSITION ※1 (mass%) C	Si	Mn	P	S	Cr	V	Al	N	Ti	Zr	Ca	Mg	Se	Te	REM	Others	Veq ※2 (mass%)	Ceq ※3 (mass%)	PM ※4 (mass%)
g01	0.33	0.18	1.17	0.020	0.030	0.02	0.248	0.002	0.0079	–	–	0.0010	–	–	–	–	–	0.26	1.05	364
g02	0.32	0.20	1.26	0.019	0.050	0.02	0.263	0.003	0.0078	–	–	0.0010	–	–	–	–	–	0.27	1.07	367
g03	0.33	0.19	1.16	0.021	0.080	0.02	0.253	0.004	0.0077	–	–	0.0010	–	–	–	–	–	0.26	1.01	356
g04	0.32	0.20	1.26	0.019	0.050	0.21	0.263	0.002	0.0076	–	–	0.0010	–	–	–	–	–	0.27	1.13	382
g05	0.33	0.19	1.16	0.021	0.080	0.20	0.253	0.003	0.0080	–	–	0.0010	–	–	–	–	–	0.26	1.07	371
g06	0.33	0.20	1.20	0.021	0.150	0.20	0.262	0.003	0.0078	–	–	0.0010	–	–	–	–	–	0.27	1.02	359
g07	0.33	0.19	1.23	0.021	0.200	0.19	0.268	0.003	0.0078	–	–	0.0010	–	–	–	–	–	0.28	0.99	351
h01	0.32	0.21	1.19	0.020	0.103	0.60	0.267	0.003	0.0083	–	–	0.0011	–	–	–	–	–	0.28	1.19	401
i01	0.33	0.21	1.19	0.019	0.102	0.19	0.100	0.002	0.0084	–	–	0.0011	–	–	–	–	–	0.11	0.79	298
i02	0.32	0.20	1.17	0.020	0.101	0.20	0.166	0.003	0.0077	–	–	0.0011	–	–	–	–	–	0.18	0.89	321
i03	0.33	0.20	1.23	0.021	0.098	0.20	0.207	0.004	0.0079	–	–	0.0011	–	–	–	–	–	0.22	0.99	350
i04	0.33	0.19	1.15	0.020	0.102	0.20	0.309	0.003	0.0081	–	–	0.0010	–	–	–	–	–	0.32	1.14	390
j01	0.32	0.21	1.23	0.020	0.103	0.20	0.253	0.004	0.0080	–	–	0.0010	–	–	–	–	–	0.26	1.05	364
j02	0.34	0.20	1.20	0.019	0.095	0.21	0.264	0.016	0.0078	–	–	0.0011	–	–	–	–	–	0.27	1.09	379
j03	0.32	0.21	1.16	0.021	0.095	0.20	0.264	0.035	0.0078	–	–	0.0009	–	–	–	–	–	0.27	1.06	365
k01	0.39	0.21	1.16	0.020	0.100	0.21	0.260	0.004	0.0037	–	–	0.0010	–	–	–	–	–	0.27	1.12	402
k02	0.39	0.20	1.27	0.020	0.102	0.20	0.256	0.002	0.0076	–	–	0.0009	–	–	–	–	–	0.27	1.14	407
k03	0.39	0.20	1.21	0.020	0.101	0.19	0.266	0.003	0.0146	–	–	0.0010	–	–	–	–	–	0.28	1.14	407
m01	0.40	0.22	1.19	0.020	0.098	0.20	0.140	0.002	0.0081	0.015	–	0.0009	–	–	–	–	–	0.16	0.95	362
m02	0.40	0.21	1.13	0.020	0.098	0.19	0.160	0.003	0.0080	0.060	–	0.0008	–	–	–	–	–	0.20	1.02	379
m03	0.40	0.20	1.19	0.018	0.096	0.20	0.165	0.003	0.0084	0.096	–	0.0010	–	–	–	–	–	0.22	1.10	400
* m04	0.41	0.20	1.20	0.017	0.100	0.22	0.170	0.003	0.0083	0.040	–	0.0010	–	–	–	–	0.0015B	0.20	1.05	391
m05	0.41	0.20	1.20	0.019	0.099	0.20	0.251	0.003	0.0078	–	0.03	0.0011	–	–	–	–	–	0.26	1.13	411
m06	0.42	0.20	1.18	0.020	0.105	0.19	0.250	0.003	0.0077	–	0.06	0.0009	–	–	–	–	–	0.26	1.13	412
m07	0.41	0.20	1.21	0.021	0.097	0.19	0.256	0.003	0.0084	–	0.10	0.0010	–	–	–	–	–	0.27	1.14	413
m08	0.32	0.20	1.27	0.020	0.092	0.20	0.284	0.003	0.0073	–	–	0.0019	–	–	–	–	–	0.29	1.13	382
m09	0.35	0.20	1.10	0.019	0.098	0.22	0.267	0.002	0.0083	–	–	0.0005	–	–	–	–	–	0.28	1.08	380
m10	0.33	0.18	1.28	0.021	0.107	0.22	0.253	0.002	0.0086	–	–	0.0003	–	–	–	–	–	0.26	1.07	370
* m11	0.32	0.20	1.10	0.021	0.099	0.18	0.264	0.003	0.0082	–	–	0.0009	0.0003	–	–	–	–	0.27	1.03	358
* m12	0.36	0.19	1.15	0.022	0.098	0.21	0.257	0.002	0.0086	–	–	0.0010	0.0010	–	–	–	–	0.27	1.08	381
* m13	0.35	0.21	1.10	0.019	0.097	0.19	0.251	0.003	0.0084	–	–	0.0010	0.0022	–	–	–	–	0.26	1.04	370
m14	0.32	0.19	1.31	0.019	0.107	0.21	0.249	0.004	0.0080	–	–	0.0010	–	0.010	–	–	–	0.26	1.06	364
m15	0.3	0.22	1.26	0.018	0.105	0.20	0.27	0.004	0.0075	–	–	0.0011	–	–	0.004	–	–	0.28	1.07	360
m16	0.34	0.18	1.16	0.021	0.093	0.19	0.249	0.003	0.0086	–	–	0.0011	–	–	–	0.002	–	0.26	1.05	369

※1 Balance of iron and unavoidable impurities

※2 Veq=V+Ti/2+Si/20

※3 Ceq=C+0.28Mn-1.0S+0.32Cr+1.7V+1.3Ti

※4 PM=554C+71Mn-262S+82Cr+429V

* Tests No. m04, m11, m12 and m13 do not belong to present invention.

[0064]

[Table 3]

TEST NO.	STEEL MATERIAL TEMP. DIRECTLY PRIOR TO ROLLING °C	STEEL MATERIAL TEMP. DIRECTLY FOLLOWING FORGING °C	COOLING SPEED FOLLOWING HOTFORGING*1 °C/s	α / 100	TOTAL AREA RATIO OF FERRITE AND PEARLITE %	ASPECT RATIO OF SULFIDE INCLUSION (-)	Pc*2	SPLITTING DISTORTION
	°C	°C	°C/ s	AREA RATIO%/ 100				μm
a01	900	1050	0.6	0.60	100	7.5	0.83	333
a02	900	1050	0.8	0.54	100	7.7	0.72	167
a03	900	1050	1.0	0.40	100	7.0	0.55	100
a04	900	1050	1.3	0.35	100	8.0	0.51	83
a05	900	1050	1.5	0.30	100	7.1	0.47	67
a06	900	1050	2.0	0.21	100	7.3	0.42	200
a07	900	1050	2.5	0.15	100	7.5	0.39	333
a08	1000	1050	1.0	0.40	100	7.0	0.55	100
a09	900	1050	0.6	0.55	100	7.0	0.89	320
a10	900	1050	2.5	0.00	100	7.5	0.40	230
a11	900	1050	0.6	0.70	100	7.2	0.83	320
a12	900	1050	1.0	0.50	100	7.0	0.50	150
a13	900	1050	2.0	0.30	100	6.0	0.36	335
b01	1000	1050	1.0	0.41	100	5.0	0.56	100
b02	900	1000	1.0	0.43	100	9.0	0.58	133
b03	900	950	1.0	0.45	100	12.0	0.60	367
c01	900	1050	1.0	0.50	100	7.5	0.40	350
c02	900	1050	1.0	0.38	100	7.1	0.45	117
c03	900	1050	1.0	0.30	100	8.0	0.57	93

(continued)

TEST NO.	STEEL MATERIAL TEMP. DIRECTLY PRIOR TO ROLLING °C	STEEL MATERIAL TEMP. DIRECTLY FOLLOWING FORGING °C	COOLING SPEED FOLLOWING HOTFORGING*1 °C/s	α / 100	TOTAL AREA RATIO OF FERRITE AND PEARLITE %	ASPECT RATIO OF SULFIDE INCLUSION (-)	Pc*2	SPLITTING DISTORTION
	°C	°C	°C/ s	AREA RATIO%/ 100				μm
c04	900	1050	1.0	0.25	100	6.9	0.67	83
c05	900	1050	1.0	0.10	100	7.2	0.69	67
d01	900	1050	1.0	0.40	100	7.1	0.54	133
d02	900	1050	1.0	0.42	100	6.9	0.54	100
d03	900	1050	1.0	0.38	100	6.9	0.54	83
e01	900	1050	1.0	0.60	100	6.8	0.84	207
e02	900	1050	1.0	0.54	100	7.3	0.70	100
e03	900	1050	1.0	0.30	99	6.8	0.46	150
e04	900	1050	1.0	0.15	97	6.8	0.39	217
f01	900	1050	1.0	0.40	100	6.8	0.54	133
fo2	900	1050	1.0	0.40	100	7.2	0.53	100
f03	900	1050	1.0	0.40	100	7.0	0.53	93
f04	900	1050	1.0	0.40	100	6.8	0.56	83
f05	900	1050	1.0	0.40	100	7.3	0.54	83

※1 Average cooling speed of 800 to 600°C
※2 $Pc=C/(1-\alpha/100)$

[0065]

[Table 4]

TEST NO.	STEEL MATERIAL TEMP. DIRECTLY PRIOR TO ROLLING °C	STEEL MATERIAL TEMP. DIRECTLY FOLLOWING FORGING °C	COOLING SPEED FOLLOWING HOT FORGING ※1 °C/s	α/100	TOTAL AREA RATIO OF FERRITE AND PEARLITE %	ASPECT RATIO OF SULFIDE INCLUSION (-)	Pc ※2	SPLITTING DISTORTION
	°C	°C	°C/s	AREA RATIO%/100				μm
g01	900	1050	1.5	0.60	100	6.8	0.81	217
g02	900	1050	1.5	0.60	100	7.3	0.80	217
g03	900	1050	1.5	0.60	100	7.3	0.83	267
g04	900	1050	1.0	0.41	100	7.3	0.54	100
g05	900	1050	1.0	0.39	100	7.3	0.55	140
g06	900	1050	1.0	0.40	100	7.3	0.56	150
g07	900	1050	1.0	0.42	100	6.9	0.57	167 1,303
h01	900	1050	1.0	0.30	100	7.1	0.46	133
i01	900	1050	1.0	0.42	100	6.9	0.56	333
i02	900	1050	1.0	0.39	100	6.8	0.52	198
i03	900	1050	1.0	0.36	100	6.7	0.51	167
i04	900	1050	1.0	0.35	100	6.7	0.51	0.55
j01	900	1000	1.5	0.42	100	6.9	0.55	83
j02	900	1000	1.5	0.40	100	7.3	0.56	107
j03	900	1000	1.5	0.42	100	7.0	0.55	97
k01	900	1000	1.5	0.41	100	6.7	0.66	117
k02	900	1000	1.5	0.41	100	7.2	0.67	107
k03	900	1000	1.5	0.40	100	6.9	0.68	83
m01	900	1000	1.5	0.31	100	7.6	0.58	340

(continued)

TEST NO.	STEEL MATERIAL TEMP. DIRECTLY PRIOR TO ROLLING °C	STEEL MATERIAL TEMP. DIRECTLY FOLLOWING FORGING °C	COOLING SPEED FOLLOWING HOT FORGING ※1 °C/s	α/100	TOTAL AREA RATIO OF FERRITE AND PEARLITE %	ASPECT RATIO OF SULFIDE INCLUSION (-)	Pc ※2	SPLITTING DISTORTION
	°C	°C	°C/s	AREA RATIO%/100				μm
m02	900	1000	1.5	0.24	100	8.1	0.52	133
m03	900	1000	1.5	0.21	99	7.9	0.50	93
m04	900	1000	1.5	0.32	99	7.7	0.60	130
m05	900	1000	1.5	0.40	100	5.9	0.68	103
m06	900	1000	1.5	0.38	100	6.2	0.68	98
m07	900	1000	1.5	0.36	100	6.2	0.64	104
m08	900	1000	1.5	0.39	100	7.1	0.53	96
m09	900	1000	1.5	0.37	100	8.1	0.56	104
m10	900	1000	1.5	0.37	100	10.1	0.51	201
m11	900	1000	1.5	0.40	100	7.4	0.54	99
m12	900	1000	1.5	0.38	100	6.0	0.58	101
m13	900	1000	1.5	0.38	100	5.8	0.56	96
m14	900	1000	1.5	0.41	100	7.3	0.53	104
m15	900	1000	1.5	0.38	100	6.3	0.48	102
m16	900	1000	1.5	0.37	100	6.6	0.54	95

※1 Average cooling speed of 800 to 600°C

※2 Pc=C/(1-α/100)

[0066] The following can be inferred from Tables 1 to 4 (the symbols used below correspond to the test symbols used in Tables 1 to 4). In a01 to a12, the cooling speed following rolling was altered to vary the ferrite fraction and, in addition, the C content was altered to vary the Pc. The splitting distortion was greater and the fracture splitting characteristics poorer in the test pieces in which the Pc is outside the prescribed range of-the present invention.

[0067] b01 to b03 constitute examples in which the average aspect ratio of the sulfide-based inclusion is controlled by altering the steel material temperature directly prior to rolling and altering the steel material temperature directly following forging. As is clear from these examples, it is clear that the aspect ratio does not necessarily fall within the prescribed range even if an element such as Ca for facilitating the formation of the sulfide-based inclusion in a spherical shape is added and, in addition, it is affected by the steel material temperature directly prior to rolling and the steel material temperature directly following forging. Because the splitting distortion exceeds 200μm (maximum fracture distortion of the C70S6 material is exceeded) when the aspect ratio exceeds 10.0 as in b03, excellent fracture splitting characteristics cannot be ensured.

[0068] The chemical compositions were varied for c01 and beyond. Of these, the C content of c01 to c05 was varied, the fracture splitting characteristics of c01 being poorer because of the insufficient C content and the Pc that is below the lower limit value. In addition, it is clear from c05 that machinability is ensured when the PM is in the prescribed range.

[0069] While the Mn content is varied in e01 to e04, the comparatively small Mn content in e01 promotes the generation of ferrite and results in the Pc exceeding the prescribed range. In addition, the comparatively large Mn content in e04 generates an insignificant amount of ferrite and, accordingly, the Pc is below the prescribed range. For this reason, the fracture splitting characteristics of e01 and e04 are poor.

[0070] While g01 to g07 constitute examples in which the S content is varied, it is clear that excellent fracture splitting characteristics can be ensured to an S content as high as 0.2%. On the other hand, it is clear from g01 to g03 that the Cr is preferably contained in a fixed amount to increase the fracture splitting characteristics.

[0071] i01 to i04 constitute examples in which the V content is varied, and while in i01 the average aspect ratio of the sulfide-based inclusion is suppressed to not more than 10.0 and the ferrite fraction lies within the prescribed range, voids are generated and the fracture splitting characteristics is poor because of the low Veq.

[0072] While m01 to m16 constitute examples in which a socalled selective element such as Ti and Zr or the like has been added, voids are generated and the fracture splitting characteristics of m01 is poor because of the low Veq in the same ways as i01. While m04 constitutes an example to which B has been added, it is clear that the addition of B in this way has no undesirable effect on the fracture splitting characteristics. In m10, because the Ca is comparatively small and the addition of other elements and the manufacturing conditions for forming the sulfide-based inclusion in a spherical shape are not controlled, the average aspect ratio of the sulfide-based inclusion is increased and the splitting distortion is increased.

[0073] The rolling material satisfying the conditions of the present invention and having a splitting distortion not more than the 200μm maximum distortion range of the C70S6 material used in Europe is suitable for the manufacture of a fracture splitting-type connecting rod. More particularly, because the C content thereof is less than in the C70S6 material and the S content can be added in a sufficient amount, this rolling material also has excellent machinability.

Example of connecting rod manufacture

[0074] The steel of the chemical compositions a01 to 07 of Table 1 was melted and forged in accordance with a method for manufacturing molten steel, and then bloomed and rolled (steel material temperature directly prior to rolling 950°C) to produce a 32mmΦ bar steel. This was then hot forged at the conditions shown in Table 5 and, by further mechanical processing, a hot-forged part (thickness 18mm) having the external shape of a connecting rod was manufactured. The hot-forged part has an integrated morphology of a connecting rod main body part having a coupling axis with a piston and a semi-circular portion for assembly with a crankshaft, and a connecting rod cap portion having a semi-circular portion for forming a through-hole together with the connecting rod main body part, the coupling axis being formed along the direction of rolling. The hot-forged part is split into the connecting rod main body portion and the connecting rod cap portion by creation of a notch therein using a laser and the action of a mechanical force causing it to fracture. The notch is formed so that the fracture faces are orthogonal to the direction of rolling.

[0075] The average aspect ratio of the sulfide-based inclusion and the ferrite fraction of the obtained fracture splitting-type connecting rod were measured in the same way as described above. In addition, the hole difference diameter (L2-L1) of the through-hole prior to and following fracture splitting was measured as the splitting distortion.

[0076] The results thereof are shown in Table 5.

[0077]

[Table 5]

TEST NO.	STEEL MATERIAL TEMP. DIRECTLY PRIOR TO ROLLING °C	STEEL MATERIAL TEMP. DIRECTLY FOLLOWING FORGING °C	COOLING SPEED FOLLOWING HOT FORGING ※1 °C/s	α/100	ASPECT RATIO OF SULFIDE INCLUSION (-)	Pc※2	SPLITTING DISTORTION
	°C	°C	°C/s	AREA RATIO%100			μm
x01	950	1050	1.0	0.53	7.9	0.70	35
x02	950	1050	1.5	0.41	8.1	0.56	25
x03	950	1050	4.0	0.15	8.5	0.39	80

※ 1 Average cooling speed of 800 to 600°C
※ 2 Pc=C/(1-α/100)

[0078] As is clear from Table 5, the splitting distortion in which the examples in which the value of the Pc is suitable (x01, x02) is less than in the example in which the Pc value is unsuitable (x03).

Claims

1. A rolled material for a fracture splitting-type connecting rod **characterized in that** a chemical composition comprises, by mass% applicable for each component,

C : 0.25 to 0.60%,
Mn : 0.5 to 2%,
S : 0.05 to 0.2%,
Si : 0.05 to 1.5%,
V : 0.05 to 0.3%,
P : 0.010 to 0.15%,
Al : 0.0010 to 0.06%,
N : 0.03% or less and
Cr : 0.1 to 2%,

and further comprises at least one type selected from a group consisting of

Zr : 0.005 to 0.2%,
Ti : 0.005 to 0.1%,
Ca : 0.0005 to 0.01%,
Te : 0.0010 to 0.1%, and
REM : 0.0005 to 0.3%,

and a balance of iron and unavoidable impurities, ferrite and pearlite occupies in total an area ratio to the whole of not less than 95%,
an average aspect ratio of a sulfide-based inclusion is not more than 10.0 when observed in a D/4 portion, D being the diameter of the rolled material, in a cross-section parallel to a longitudinal direction of a rod-shaped rolled material, and
a Pc indicated in Equation (1) below is between 0.41 and 0.75 and a Veq indicated in Equation (2) below is not less than 0.18 mass%

$$Pc = C(1-\alpha/100) \qquad (1)$$

In Equation (1), C represents a carbon content in steel (mass%) and α represents a ferrite fraction (area ratio%)

$$Veq = V + Ti/2+Si/20 \qquad (2)$$

In Equation (2), V, Ti and Si represent the content of each element in steel (mass %).

2. The rolled material for a fracture splitting-type connecting rod according to claim 1, further comprising a Ceq of not less than 0.80 mass% as indicated in Equation (3) below and a PM of not more than 500 mass% as indicated in Equation (4) below

$$Ceq = C + 0.28Mn - 1.0S + 0.32Cr + 1.7V + 1.3Ti \qquad (3)$$

$$PM = 554C + 71Mn - 262S + 82Cr + 429V \qquad (4)$$

In Equations (3) and (4), C, Mn, S, Cr, V and Ti represent the content of each element in steel (mass%).

3. The rolled material for a fracture splitting-type connecting rod according to claim 1, further comprising at least one type selected from a group consisting of
Se: 0.0010 to 0.1%, and
Bi and Pb: 0.01 to 0.2% in total.

4. A hot-forged part for a fracture splitting-type connecting rod with excellent fracture splitting characteristics, obtained by hot forging the rolled material for a fracture splitting-type connecting rod according to any of claims 1 to 3.

5. A fracture splitting-type connecting rod, obtained using the hot-forged part according to claim 4.

Patentansprüche

1. Gerolltes Material für einen Verbindungsstab des Bruchtrennungstyps, **dadurch gekennzeichnet, dass** eine chemische Zusammensetzung in Masse-%, anwendbar für jede Komponente,

C: 0,25 bis 0,60%,
Mn: 0,5 bis 2%,
S: 0,05 bis 0,2%,
Si: 0,05 bis 1,5%,
V: 0,05 bis 0,3%,
P: 0,010 bis 0,15%,
Al: 0,0010 bis 0,06%,
N: 0,03% oder weniger und
Cr: 0,1 bis 2% umfasst,

und weiter mindestens eine Art umfasst, ausgewählt aus einer Gruppe, bestehend aus

Zr: 0,005 bis 0,2%,
Ti: 0,005 bis 0,1 %,
Ca: 0,0005 bis 0,01 %,
Te: 0,0010 bis 0,1 % und
REM: 0,0005 bis 0,3%,

und einem Rest aus Eisen und unvermeidbaren Verunreinigungen,
wobei Ferrit und Perlit in der Gesamtheit einen Flächenanteil zu dem Ganzen von nicht weniger als 95% einnehmen, ein durchschnittliches Seitenverhältnis einer sulfidbasierten Einlagerung, falls beobachtet in einem D/4 Teilbereich, wobei D der Durchmesser des gerollten Materials ist, in einem Querschnitt parallel zu einer Längsrichtung eines

stabförmig gerollten Materials, nicht mehr als 10,0 beträgt und
ein Pc, angegeben in nachstehender Gleichung (1), zwischen 0,41 und 0,75 liegt und ein Veq, angegeben in nachstehender Gleichung (2), nicht weniger als 0,18 Masse-% beträgt

$$Pc = C/(1-\alpha/100) \qquad (1)$$

wobei in Gleichung (1) C einen Kohlenstoffgehalt (Masse-%) im Stahl darstellt und α einen Ferritanteil (Flächenanteils-%) darstellt

$$Veq = V + Ti/2+Si/20 \qquad (2)$$

wobei in Gleichung (2) V, Ti und Si den Gehalt (Masse-%) von jedem Element im Stahl darstellen.

2. Gerolltes Material für einen Verbindungsstab des Bruchtrennungstyps nach Anspruch 1, weiter umfassend ein Ceq von nicht weniger als 0,80 Masse-%, wie in nachstehender Gleichung (3) angegeben, und ein PM von nicht mehr als 500 Masse-%, wie in nachstehender Gleichung (4) angegeben

$$Ceq = C + 0{,}28Mn - 1{,}0S + 0{,}32Cr + 1{,}7V + 1{,}3Ti \qquad (3)$$

$$PM = 554C + 71Mn - 262S + 82Cr + 429V \qquad (4)$$

wobei in Gleichungen (3) und (4) C, Mn, S, Cr, V und Ti den Gehalt (Masse-%) von jedem Element im Stahl darstellen.

3. Gerolltes Material für einen Verbindungsstab des Bruchtrennungstyps nach Anspruch 1, weiter umfassend mindestens eine Art, ausgewählt aus einer Gruppe, bestehend aus
Se: 0,0010 bis 0,1% und
Bi und Pb: 0,01 bis 0,2% in der Gesamtheit.

4. Geschmiedetes Teil für einen Verbindungsstab des Bruchtrennungstyps mit hervorragenden Bruchtrennungseigenschaften, erhalten durch das Schmieden des gerollten Materials für einen Verbindungsstab des Bruchtrennungstyps nach einem der Ansprüche 1 bis 3.

5. Verbindungsstab des Bruchtrennungstyps, erhalten durch Verwenden des geschmiedeten Teils nach Anspruch 4.

Revendications

1. Matériau laminé pour une bielle à tête divisée **caractérisé en ce que** la composition chimique comprend, en % massique applicable à chaque composant,

C : 0,25 à 0,60%,
Mn : 0,5 à 2%,
S : 0,05 à 0,2%,
Si : 0,05 à 1,5%,
V : 0,05 à 0,3%,
P : 0,010 à 0,15%,
Al : 0,0010 à 0,06%,
N : 0,03% ou moins et
Cr : 0,1 à 2%,

et comprend en outre au moins un type de composant choisi d'un groupe constitué de

Zr : 0,005 à 0,2%,

Ti : 0,005 à 0,1%,
Ca : 0,0005 à 0,01%,
Te : 0,0010 à 0,1%, et
REM : 0,0005 à 0,3%,

et le reste est constitué du fer et d'impuretés inévitables,
la ferrite et la perlite occupent au total un rapport de surface par rapport à la surface totale d'au moins 95%,
un rapport moyen hauteur/largeur d'une inclusion à base de sulfure ne dépasse pas 10,0 lorsqu'on regarde dans une partie correspondant à D/4, D étant le diamètre du matériau laminé, dans une section transversale parallèle à une direction longitudinale d'un matériau laminé en forme de tige, et
un rapport Pc indiqué dans l'équation (1) ci-dessous se trouve entre 0,41 et 0,75 et un rapport Veq indiqué dans l'équation (2) ci-dessous est d'au moins 0,18% en masse

$$Pc = C/(1-\alpha/100) \quad (1)$$

dans l'équation (1), C représente une teneur en carbone dans l'acier (en % massique) et α représente une fraction de ferrite (rapport de surface en %)

$$Veq = V + Ti/2+Si/20 \quad (2)$$

dans l'équation (2), V, Ti et Si représentent la teneur de chaque élément en acier (en % massique).

2. Matériau laminé pour une bielle à tête divisée selon la revendication 1, comprenant en outre un rapport Ceq d'au moins 0,80% en masse comme indiqué dans l'équation (3) ci-dessous et un rapport PM d'au plus 500% en masse comme indiqué dans l'équation (4) ci-dessous

$$Ceq = C + 0{,}28Mn - 1{,}0S + 0{,}32Cr + 1{,}7V + 1{,}3Ti \quad (3)$$

$$PM = 554C + 71Mn - 262S + 82Cr + 429V \quad (4)$$

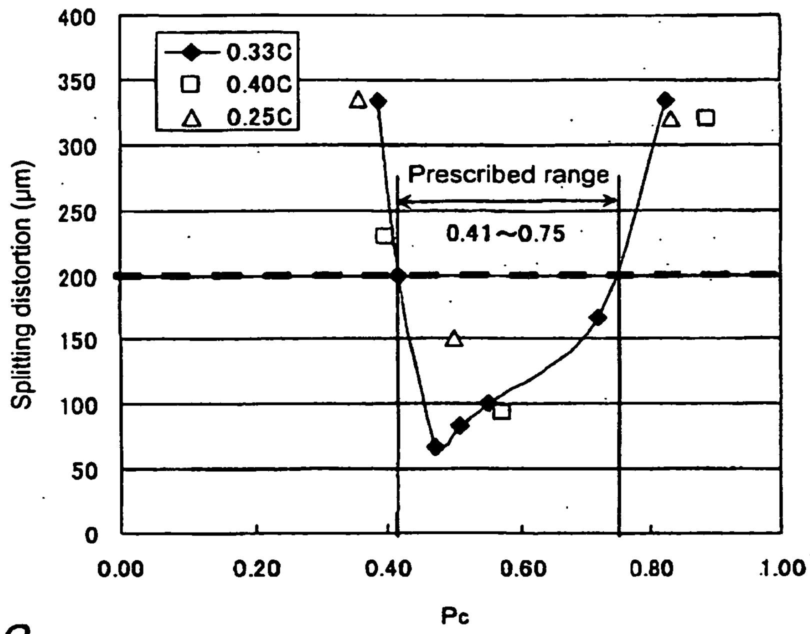
dans les équations (3) et (4), C, Mn, S, Cr, V et Ti représentent la teneur de chaque élément en acier (en % massique).

3. Matériau laminé pour une bielle à tête divisée selon la revendication 1, comprenant en outre au moins un type de composant choisi du groupe constitué de
Se : 0,0010 à 0,1 %, et
Bi et Pb : 0,01 à 0,2 % au total.

4. Pièce forgée à chaud pour bielle à tête divisée avec d'excellentes caractéristiques de division par fractionnement, obtenue par forgeage à chaud du matériau laminé pour une bielle à tête divisée selon l'une quelconque des revendications 1 à 3.

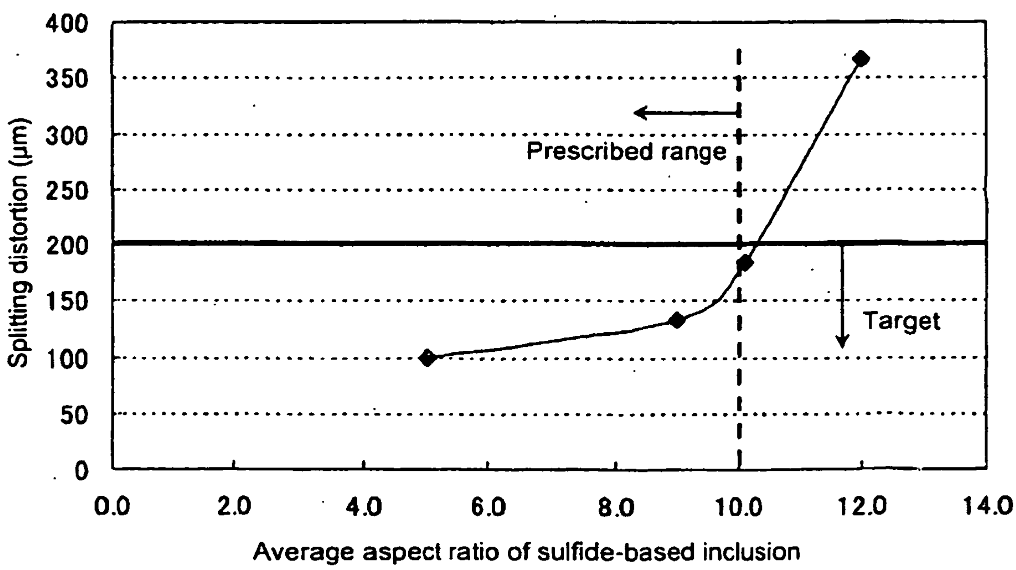
5. Bielle à tête divisée, obtenue en utilisant la pièce forgée à chaud selon la revendication 4.

Fig. 1



0.33C
0.40C
0.25C
Prescribed range
0.41~0.75
Splitting distortion (µm)
400
350
300
250
200
150
100
50
0
0.00
0.20
0.40
0.60
0.80
1.00
Pc

Fig.2



Prescribed range
Target
Splitting distortion (µm)
400
350
300
250
200
150
100
50
0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
Average aspect ratio of sulfide-based inclusion

Fig.3

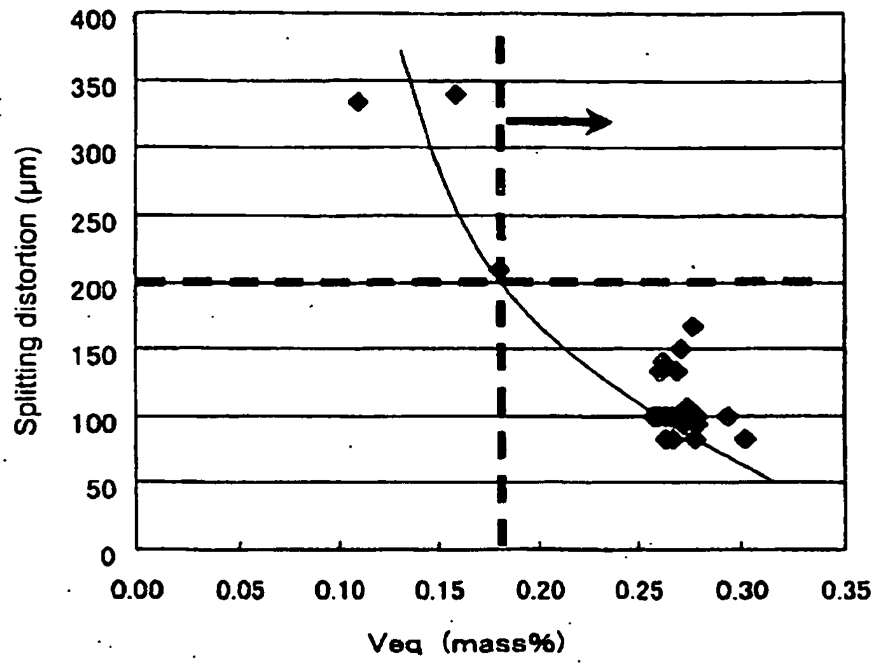

Splitting distortion (µm)
400
350
300
250
200
150
100
50
0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
Veq (mass%)

Fig.4

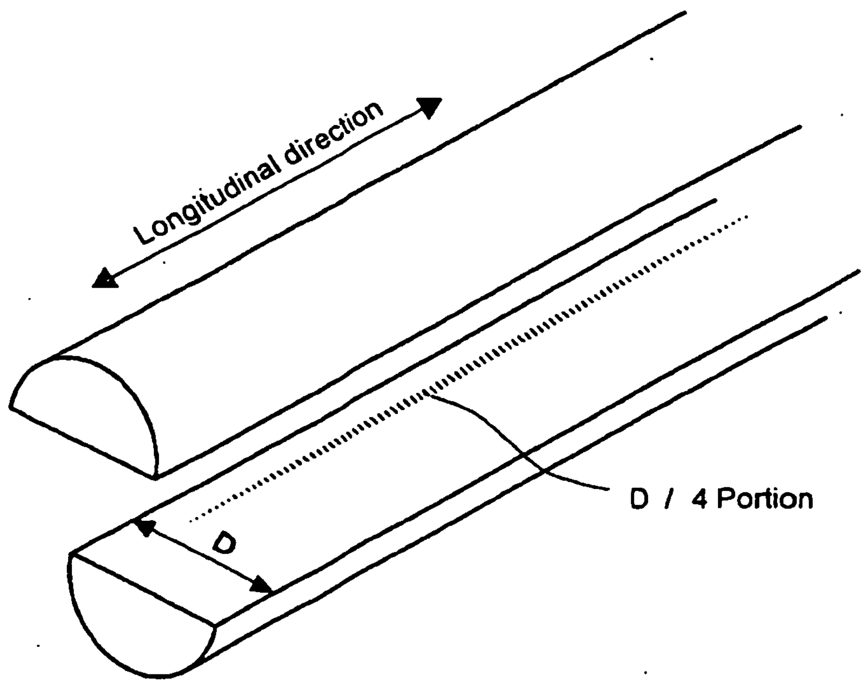

Longitudinal direction
D
D / 4 Portion

Fig.5

(a)

(b)

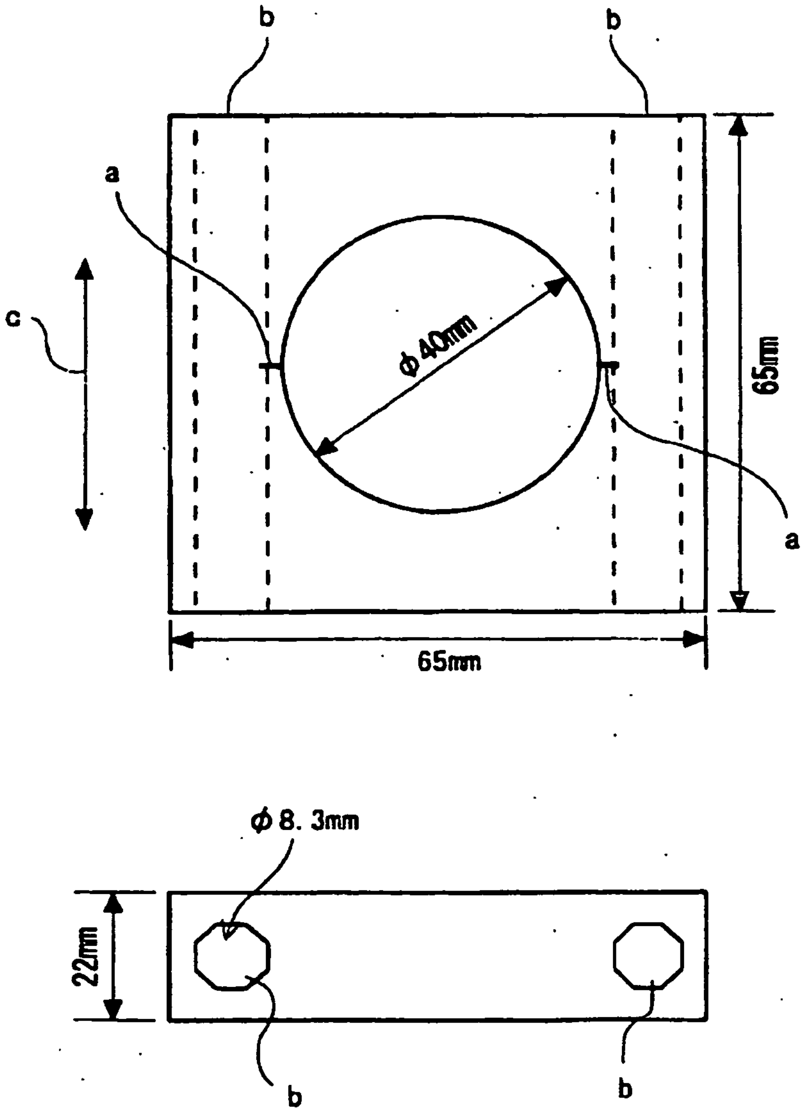


Fig.6

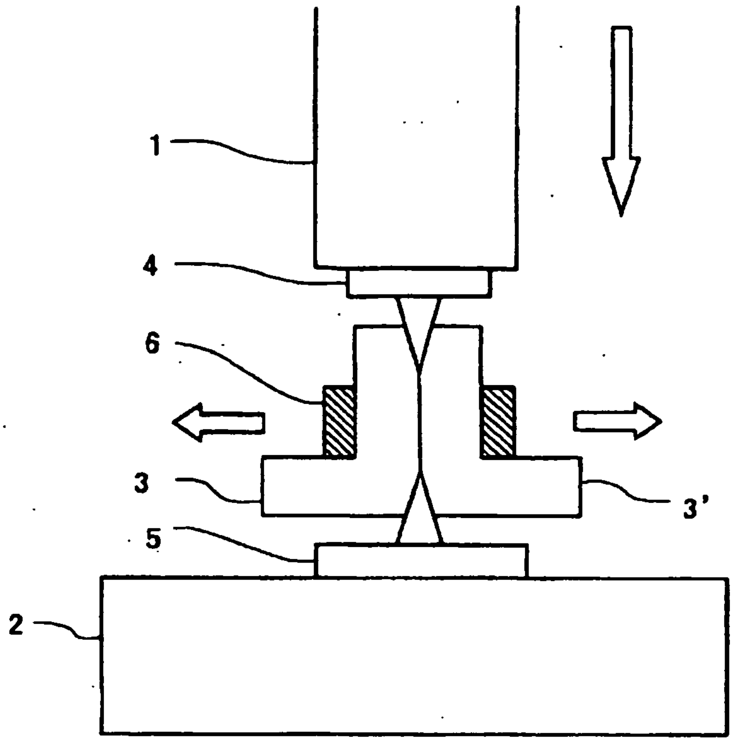
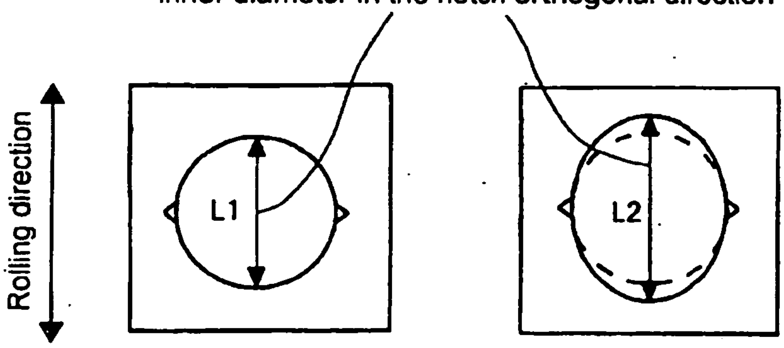

1
4
6
3
3'
5
2

Fig.7


Inner diameter in the notch orthogonal direction
Rolling direction
L1
L2
Before testing
After testing

REFERENCES CITED IN THE DESCRIPTION

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