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(72) Inventor: **The designation of the inventor has not yet been filed**

(74) Representative: **Müller-Boré & Partner
Patentanwälte
Grafinger Strasse 2
81671 München (DE)**

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(71) Applicant: **Kabushiki Kaisha Kobe Seiko Sho
Chuo-ku
Kobe-shi
Hyogo 651-8585 (JP)**

(54) **STEEL FOR FRACTURE SPLIT CONNECTING RODS**

(57) The present invention provides a steel for a fracture splitting type connecting rod, in which: the steel contains C: 0.25 - 0.5% (in mass %, the same is applied hereunder), Si: 0.01 - 2.0%, Mn: 0.50 - 2.0%, P: 0.015 - 0.080%, S: 0.01 - 0.2%, V: 0.02 - 0.20%, Cr: 0.05 - 1.0%, Ti: 0.01 - 0.10%, and N: 0.01% or less; an f-value represented by the expression shown below is in the range of 0.003 to 0.04; and the average aspect ratio of sulfide

system inclusions is 15 or less,

$$f = [Ti] - [N] \times 48/14$$

(in the expression, [Ti] and [N] represent the contents (mass %) of Ti and N in a steel, respectively).

EP 2 216 423 A1

Description

Technical Field

5 **[0001]** The present invention relates to a steel favorably used for producing a connecting rod (hereunder abbreviated as a con'rod occasionally) used as a component in an automobile engine or the like.

Background Art

10 **[0002]** An internal-combustion engine such as a gasoline engine or a diesel engine uses a con'rod as a component for connecting a piston to a crankshaft, transferring the reciprocating motion of the piston to the crankshaft, and converting the reciprocating motion to the rotary motion of the crankshaft. The con'rod is a component having a nearly-round through-hole to attach itself to a crankshaft and is configured so that the through-hole portion may be separated (divided) into two nearly-semicircular components in order to facilitate assembly and detachment at maintenance. In the separated

15 **[0003]** Such a con'rod can be produced, for example, by hot-forging a con'rod main body and a con'rod cap individually and thereafter applying cutting to the mating faces. On this occasion, knock pin processing may be applied in some cases in order to avoid deviation if need arises. If such processing is applied however, arising problems are that the yield quantity of the material deteriorates and the cost increases because many processes are required.

20 **[0004]** In view of the problems, adopted is a method of assembling a con'rod and a crankshaft by: hot-forging the con'rod integrally; applying machining (through-hole forming (drilling), bolt hole forming, and the like for attaching the con'rod to the crankshaft); thereafter applying fracture splitting process to the con'rod in the cold so that the through-hole portion may be divided into two nearly-semicircular components; and finally interposing the crankshaft, fitting the fracture surfaces, and fastening them with bolts. By this method, it comes to be unnecessary to apply cutting process

25 for forming mating faces to the fracture surfaces.
[0005] Meanwhile, with regard to a steel for a con'rod, demands for the improvement of machinability are increasing. In general however, machinability and fracture splitting performance are hardly compatible. A possible measure to improve machinability is to reduce the content of alloys and lower the hardness of a steel but, if the content of alloys is reduced, the ductility of the steel rises and the fracture splitting performance deteriorates. They are in the relationship of trade-off and are hardly compatible.

30 **[0006]** As steels for a con'rod excellent in fracture splitting performance, steels disclosed in Patent Documents 1 to 3 are known for example. Patent Document 1 proposes to advance brittle fracture by controlling the contents of Si, V, P, N, Al, Ti, Nb, N, B, and others, Patent Document 2 proposes to advance brittle fracture by controlling the contents of Si, V, P, and others, and Patent Document 3 proposes to advance brittle fracture by controlling the contents of Al, N, and others. Further Patent Documents 1 to 3 describe that brittle fracture can be advanced by adding Ti. Such a steel for a con'rod however is poor in machinability. In the case of Patent Document 1 for example, in the examples, a C content is more than 0.5% and alloy elements such as V and Cr are used excessively. Otherwise, in the case where contents of C and others are restricted, fracture splitting performance is secured inversely by using Ti in excess of 0.10%. Meanwhile, in the cases of Patent Documents 2 and 3 too, in the examples, Ti is used in excess of 0.10% and the machinability is poor.

Patent Document 1: Japanese Patent No. 3235442

Patent Document 2: Japanese Patent No. 3416868

Patent Document 3: Japanese Patent No. 3416869

Disclosure of the Invention

Problem to be Solved by the Invention

50 **[0007]** The present invention has been established in view of the above circumstances and an object thereof is to provide a steel for a fracture splitting type con'rod that allows fracture splitting performance and machinability to be compatible.

Means for Solving the Problem

55 **[0008]** In a steel containing C by 0.25 to 0.5%, the fracture splitting performance deteriorates extremely unless an alloy element such as Ti is added (refer to the case of 0.002% Ti in Fig. 1). Addition of an alloy element is effective in enhancing the brittleness of a steel and thus enhancing the fracture splitting performance (refer to the case of 0.125%

Ti in Fig. 1). If Ti is added abundantly however, machinability deteriorates. From the viewpoint of conventional technologies, fracture splitting performance and machinability are in the relationship of trade-off and no concrete measures for securing both of them have been shown.

[0009] However, as a result of the research earnestly studied by the present inventors in order to solve the above problems, the present inventors: have found that, when a Ti content is coordinated from the viewpoint of effective Ti (Ti not forming nitride), fracture splitting performance is enhanced rapidly by a very small amount of effective Ti and the effect is saturated immediately thereafter, in contrast machinability lowers gently and the machinability scarcely lowers when an effective Ti content (an f-value) is very small (refer to Fig. 2), and consequently both the fracture splitting performance and the machinability can be compatible by controlling a Ti content from the viewpoint of an effective Ti content (an f-value) (refer to Fig. 1); and have completed the present invention.

[0010] That is, a steel for a fracture splitting type connecting rod according to the present invention is **characterized in that**: the steel contains C: 0.25 - 0.5% (in mass %, the same is applied hereunder), Si: 0.01 - 2.0%, Mn: 0.50 - 2.0%, P: 0.015 - 0.080%, S: 0.01 - 0.2%, V: 0.02 - 0.20%, Cr: 0.05 - 1.0%, Ti: 0.01 - 0.10%, and N: 0.01% or less, with the remainder consisting of iron and inevitable impurities; an f-value represented by the expression (1) shown below is in the range of 0.003 to 0.04; and, in a longitudinal section at a position of D/4 (D is the thickness or the diameter of the steel) from the steel surface, the number of sulfide system inclusions 1 μm or more in width is 100 to 4,000 pieces per 1 mm^2 , and the average aspect ratio (length/width) of the sulfide system inclusions 1 μm or more in width is 15 or less,

$$f = [\text{Ti}] - [\text{N}] \times 48/14 \quad (1),$$

(in the expression, [Ti] and [N] represent the contents (mass %) of Ti and N in a steel, respectively).

[0011] The steel may further contain one or more kinds of Zr: 0.15% or less, Ca: 0.005% or less, Mg: 0.005% or less, Te: 0.1% or less, REM: 0.3% or less, Al: 0.05% or less, Nb: 0.05% or less, Cu: 1.0% or less, Ni: 1.0% or less, Mo: 1.0% or less, and Bi: 0.1% or less. Here, when Ca is contained, it is recommended to control Al to 0.01% or less.

[0012] In a steel according to the present invention, preferably, (a) Ti is 0.08% or less and (b) V is 0.10% or less.

Effect of the Invention

[0013] In the present invention, since the contents of Ti, N, effective Ti (an f-value), and others are controlled appropriately in a steel containing C by 0.25 to 0.5%, it is possible to enhance both the fracture splitting performance and the machinability of the steel for a con'rod.

Brief Description of the Drawings

[0014]

Fig. 1 is a graph showing the relationship between fracture splitting performance and machinability when an effective Ti content (an f-value) is changed.

Fig. 2 is a graph showing the relationship between an effective Ti content (an f-value) and fracture splitting performance or machinability.

In Fig. 3, Fig. 3(a) is a schematic top view of a test piece used in fracture splitting performance test and Fig. 3(b) is a schematic side view of the test piece.

Fig. 4 is a schematic view of an apparatus used for explaining the method of fracture splitting test.

Fig. 5 is a schematic top view showing a test piece before and after fracture splitting test.

Explanations of Reference Symbols

[0015]

- 1 Press
- 2 Support table
- 3a, 3b Holder
- 4, 5 Wedge
- 6 Test piece

Best Mode for Carrying Out the Invention

[0016] With regard to a steel according to the present invention, firstly chemical components of the steel are explained. The chemical components of a steel according to the present invention are as follows.

C: 0.25 - 0.5%

[0017] is an element necessary for securing strength and enhancing fracture splitting performance. Consequently, the lower limit of a C content is set at 0.25%. A C content is preferably 0.30% or more and yet preferably 0.35% or more. If a C content is excessive however, machinability deteriorates. Consequently, a C content is set at 0.5% or less. A C content is preferably 0.48% or less and yet preferably 0.45% or less.

Si: 0.01 - 2.0%

[0018] Si is useful as a deoxidizing element when steel is melted and refined. A Si content required for sufficiently exhibiting the effect is preferably 0.01% or more, yet preferably 0.05% or more, and still yet preferably 0.10% or more. If a Si content is excessive however, machinability and hot workability deteriorate. Consequently, a Si content is set at 2.0% or lower. A Si content is preferably 1% or less and yet preferably 0.7% or less.

Mn: 0.50 - 2.0%

[0019] Mn is an element that functions as a deoxidizing and desulfurizing element during melting and refining and prevents cracking during casting. Further, Mn forms sulfide system inclusions (for example, MnS) by combining with S, exhibits notch effect during fracture splitting, and improves fracture splitting performance. In order to sufficiently exhibit the effects, a Mn content is set at 0.50% or more. A Mn content is preferably 0.70% or more and yet preferably 0.90% or more. If a Mn content is excessive however, bainite is generated in a metallographic structure and machinability and fracture splitting performance deteriorate. Consequently, a Mn content is set at 2.0% or less. A Mn content is preferably 1.8% or less and yet preferably 1.5% or less.

P: 0.015 - 0.080%

[0020] P is an element effective in improving fracture splitting performance since P segregates at grain boundaries and lowers toughness and ductility. Consequently, in order to sufficiently exhibit the effects, a P content is set at 0.015% or more. A P content is preferably 0.020% or more and yet preferably 0.030% or more. If a P content is excessive however, the hot workability of a steel deteriorates. Consequently, a P content is set at 0.080% or less. A P content is preferably 0.070% or less and yet preferably 0.060% or less.

S: 0.01 - 0.2%

[0021] S is an element that forms sulfide system inclusions (for example, MnS), improves fracture splitting performance by exhibiting notch effect during fracture splitting, and improves machinability. In order to sufficiently exhibit the effects, a S content is set at 0.01% or more. A S content is preferably 0.020% or more and yet preferably 0.030% or more. If a S content is excessive however, hot workability deteriorates. Consequently, a S content is set at 0.2% or less. A S content is preferably 0.1% or less and yet preferably 0.07% or less.

V: 0.02 - 0.20%

[0022] V is an element effective in securing the strength of a steel and improving the fracture splitting performance. A V content required for sufficiently exhibiting the effects is preferably 0.02% or more and yet preferably 0.05% or more. If a V content is excessive however, the effects are saturated and the excessive addition causes machinability to deteriorate and the cost to increase. Consequently, a V content is set at 0.20% or less. A V content is preferably 0.19% or less and yet preferably 0.17% or less.

[0023] With regard to a V content, a best V content is 0.10% or less. Even if a V content is 0.10% or less, sufficient fracture splitting performance can be secured and, by not adding V excessively, it is possible to secure sufficient machinability even when a machinability improvement element such as Ca that prevents machinability from deteriorating is not added. A V content is preferably 0.08% or less and yet preferably 0.06% or less.

Cr: 0.05 - 1.0%

[0024] Cr is an element contributing to the improvement of strength such as yield strength and fatigue strength. A Cr content required for sufficiently exhibiting the effect is preferably 0.05% or more, yet preferably 0.10% or more, and still yet preferably 0.13% or more. If a Cr content is excessive however, the machinability of a steel deteriorates. Consequently, a Cr content is set at 1.0% or less. A Cr content is preferably 0.90% or less and yet preferably 0.70% or less.

Ti: 0.01 - 0.10%

[0025] Ti is an element important for improving the fracture splitting performance of a steel. In order to sufficiently exhibiting the effect, a Ti content is set at 0.01% or more. A Ti content is preferably 0.018% or more and yet preferably 0.020% or more. If a Ti content is increased however, the machinability of a steel deteriorates. By increasing an effective Ti content (an f-value) as it will be stated later, with the addition of a small amount of Ti, the fracture splitting performance improves rapidly and then the fracture splitting performance does not improve any more even when Ti is added further. Consequently, it is desirable to reduce a Ti content to the utmost limit as long as an after-mentioned effective Ti content (an f-value) is secured. In view of the circumstances, a Ti content is set at 0.10% or less. A Ti content is preferably 0.08% or less, yet preferably 0.07% or less, and still yet preferably 0.06% or less.

N: 0.01% or less

[0026] In the present invention, while a Ti content is reduced in order to improve machinability, it is attempted to effectively improve also fracture splitting performance by making use of a small amount of Ti. By restricting a N content in a steel, it is possible to control the generation of TiN and make use of the small amount of Ti. Consequently, a N content is set at 0.01% or less. A N content is preferably 0.009% or less and yet preferably 0.007% or less. Here, the lower limit of a N content is not particularly limited but a N content may be 0.002% or more.

[0027] The basic components of a steel for a con'rod according to the present invention are as described above and the remainder substantially consists of iron. However, it should be acceptable that the steel includes impurities brought in inevitably due to the situation of raw materials, other materials, and production facilities. Further, a steel for a con'rod according to the present invention may arbitrarily contain following elements if needed.

[0028] That is, at least one kind selected from the group consisting of

Zr: 0.15% or less,

Ca: 0.005% or less,

Mg: 0.005% or less,

Te: 0.1% or less, and

REM: 0.3% or less.

Zr, Ca, Mg, Te and REM are elements useful for spheroidizing sulfide system inclusions (for example, MnS) and thus enhancing fracture splitting performance and may be contained in a steel when needed. Since the increase of Mn tends to cause the fracture splitting performance to deteriorate in particular, it is recommended to add Zr, Ca, Mg, Te or REM in order to avoid the influence to the utmost. In order to sufficiently exhibit the effects, a Zr content is preferably 0.01% or more and yet preferably 0.05% or more, a Ca content is preferably 0.0001% or more and yet preferably 0.001% or more, a Mg content is preferably 0.0001% or more and yet preferably 0.001% or more, a Te content is preferably 0.0001% or more and yet preferably 0.001% or more, and a REM content is preferably 0.0001% or more and yet preferably 0.001% or more.

[0029] If those elements are contained excessively however, the effects are saturated and the cost is caused to increase. Further if a Zr content is excessive, machinability deteriorates. Meanwhile, if a Ca content, a Mg content, and a Te content are excessive, oxide system inclusions increase and the fracture strength of a steel deteriorates. Consequently, when those elements are contained, the upper limits are set as stated above. A Zr content is preferably 0.13% or less (yet preferably 0.12% or less), a Ca content is preferably 0.004% or less (yet preferably 0.003% or less), a Mg content is preferably 0.004% or less (yet preferably 0.003% or less), a Te content is preferably 0.05% or less (yet preferably 0.03% or less), and a REM content is preferably 0.1% or less (yet preferably 0.05% or less). Here, Zr, Ca, Mg, Te and REM may be added individually or in combination.

[0030] Then, at least either one of

Al: 0.05% or less, or

Nb: 0.05% or less.

Al and Nb are elements useful for deoxidizing and crystal grain refining and contribute to the enhancement of strength. In order to sufficiently exhibit the effects, an Al content is preferably more than 0.01% and yet preferably 0.02% or more, and a Nb content is preferably 0.01% or more and yet preferably 0.02% or more. If those elements are added excessively however, the effects are saturated and hence the upper limits are set as stated above. An Al content is preferably 0.04%

or less (yet preferably 0.035% or less) and an Nb content is preferably 0.045% or less (yet preferably 0.040% or less). Here, in the present invention, Ca may be added to a steel in some cases as stated above. When Ca is added, a nozzle is likely to clog. When Ca is added therefore, it is desirable to control an Al content to preferably 0.01% or less and yet preferably 0.007% or less.

[0031] Then, at least one kind selected from the group consisting of

Cu: 1.0% or less,

Ni: 1.0% or less, and

Mo: 1.0% or less.

Cu, Ni, and Mo are elements contributing to the improvement of the strength of a steel and may be contained in the steel if needed. In order to sufficiently exhibit the effect, a Cu content is preferably 0.01% or more and yet preferably 0.05% or more, a Ni content is preferably 0.01% or more and yet preferably 0.1% or more, and a Mo content is preferably 0.01% or more and yet preferably 0.1% or more. If a Cu content is excessive however, marks are generated on a steel surface during production. Meanwhile, if a Ni content is excessive, the effect is saturated and the excessive addition causes the cost to increase. Moreover, if a Mo content is excessive, the machinability of a steel deteriorates. Consequently, when those elements are contained, the upper limits are set as stated above. A Cu content is preferably 0.5% or less, a Ni content is preferably 0.5% or less, and a Mo content is preferably 0.7% or less.

Bi: 0.1% or less

[0032] Bi is an element contributing to the improvement of machinability. A Bi content required for sufficiently exhibiting the effect is preferably 0.001% or more and yet preferably 0.01% or more. The effect is saturated if a Bi content is excessive however, and hence the upper limit is set as stated above. A Bi content is preferably 0.08% or less.

[0033] A feature of the present invention lies in the fact that an effective Ti content (an f-value) is appropriately controlled while steel components are drawn up in the aforementioned ranges. An effective Ti content means a content of Ti obtained by subtracting a content of TiN from a content of Ti in a steel and is referred to as an f-value occasionally in the present description. When fracture splitting performance is coordinated from the viewpoint of an effective Ti content, the fracture splitting performance advances rapidly by a very small amount of effective Ti and the effect is saturated immediately thereafter. In contrast, machinability lowers gently and the machinability scarcely lowers when an effective Ti content (an f-value) is very small. Consequently, both the fracture splitting performance and the machinability can be improved by using Ti of a quantity enough to secure an effective Ti content (an f-value) necessary for rapidly increasing the fracture splitting performance in the requisite minimum.

[0034] An effective Ti content (an f-value) is given by the following expression (1). An effective Ti content (an f-value) required for surely securing fracture splitting performance is 0.003 or more, preferably 0.005 or more, and yet preferably 0.008 or more. If an effective Ti content (an f-value) increases however, the quantity of added Ti increases and machinability is likely to deteriorate. Consequently, an effective Ti content (an f-value) is preferably 0.04 or less, yet preferably 0.02 or less, and still yet preferably 0.015 or less.

$$f = [Ti] - [N] \times 48/14 \quad (1),$$

(in the expression, [Ti] and [N] represent the contents (mass %) of Ti and N in a steel, respectively)

[0035] In a best embodiment, fracture splitting performance is secured by surely satisfying the aforementioned lower limit of an effective Ti content (an f-value) and, on top of that, the upper limit of the effective Ti content (the f-value) and the upper limit of the Ti content in a steel are reduced to the utmost. By so doing, it is possible to improve machinability to the utmost limit while fracture splitting performance is surely secured. When an effective Ti content (an f-value) and a Ti content in a steel are reduced to the utmost, the effective Ti content (the f-value) is 0.015 or less and the Ti content is 0.06% or less in a steel.

[0036] Further, in a steel for a con'rod according to the present invention, it is necessary to reduce the aspect ratio of sulfide system inclusions (for example, MnS). The sulfide system inclusions are elongated by rolling and hot forging in the directions of the rolling and the forging. When the elongated sulfide system inclusions exist in the longitudinal direction (elongated in the direction perpendicular to a fracture splitting face) at the time of the fracture splitting of a steel, the sulfide system inclusions peel off from a metal matrix and stress relaxation occurs in accordance with the progression of cracks. As a result, brittle fracture is hindered, toughness and ductility are enhanced, and fracture splitting performance is caused to deteriorate. In contrast, when an aspect ratio is reduced and sulfide system inclusions are spheroidized by inhibiting the sulfide system inclusions from being elongated, stress increases at the tips of cracks generated around the sulfide system inclusions and brittle fracture advances in the event of fracture splitting in the longitudinal direction. As a result, the degree of plastic deformation can be lowered and the fracture splitting performance of a steel improves.

Further, the effect of the spheroidization of the sulfide system inclusions on the improvement of the fracture splitting performance is exhibited when the widths of the sulfide system inclusions are 1 μm or more. If the widths of the sulfide system inclusions are excessively narrow, the sulfide system inclusions themselves break and the brittle fracture of a steel cannot advance.

[0037] The size and the shape of sulfide system inclusions necessary for exhibiting the fracture splitting performance improving effect are quantitatively represented as follows. That is, in a steel according to the present invention, in a longitudinal section at a position of $D/4$ (D is the thickness or the diameter of the steel) from the steel surface, the number of sulfide system inclusions 1 μm or more in width is 100 or more pieces per 1 mm^2 , and the arithmetic average of the aspect ratios (length/width) (the average aspect ratio) of the sulfide system inclusions 1 μm or more in width is 15 or less.

[0038] An average aspect ratio is preferably 10 or less, yet preferably 8 or less, and still yet preferably 6 or less. It is desirable that an average aspect ratio is as close to one as possible. The lower limit of an average aspect ratio is not particularly limited but an average aspect ratio may be 2 or more (or 3 or more).

[0039] The number of sulfide system inclusions 1 μm or more in width is preferably 300 or more pieces and yet preferably 400 or more pieces per 1 mm^2 . If the number of sulfide system inclusions increases however, defects such as cracks tend to be generated during rolling and hot forging. Consequently, the number of sulfide system inclusions 1 μm or more in width is set at 4,000 or less pieces per 1 mm^2 . It is recommended to control the number of sulfide system inclusions 1 μm or more in width to preferably 3,000 or less pieces and yet preferably 2,500 or less pieces per 1 mm^2 .

[0040] Here, "sulfide system inclusions" mainly means MnS in the present invention but includes other sulfide and complex sulfide. The width, the average aspect ratio (length/width), and the number of pieces of sulfide system inclusions are the values obtained by observing a visual field of 1 mm^2 with an optical microscope at a magnification of 1,000 in a longitudinal section at a position of $D/4$ (D is the thickness or the diameter of a steel) from a steel surface.

[0041] Here, the size and the shape of sulfide system inclusions can be controlled in prescribed ranges by appropriately setting rolling conditions in proportion to the contents of Mn, S, and added inclusion spheroidizing elements (Zr, Ca, Mg, Te, REM, and other elements). With regard to the rolling conditions, it is recommended to select the rolling start temperature from the range of 1,000°C or higher and the rolling end temperature from the range of 850°C or higher. As the rolling start temperature and the rolling end temperature are raised, the aspect ratio of sulfide system inclusions is likely to reduce and a prescribed value is likely to be satisfied. In addition, since sulfide system inclusions are likely to precipitate by using Ti precipitates such as TiC and TiN as nuclei, the sulfide system inclusions having small aspect ratios precipitate in large numbers when a steel contains Ti.

Examples

[0042] The present invention is hereunder explained more specifically in reference to examples but is not limited by the examples below. Further, it is surely possible to arbitrarily modify the present invention within the range conforming to aforementioned and after-mentioned gist and the modifications are all included in the technological scope of the present invention.

Test example 1

[0043] Steels having the chemical compositions shown in Table 1 are melted by an ordinary melting and refining method, cast, slabbed, and thereafter rolled at a start temperature of 1,050°C and an end temperature of 900°C, and thereby bar steels of 50 mm in diameter are obtained.

Properties of the obtained bar steels are investigated in the following manner.

(1) Sulfide system inclusions

[0044] In a longitudinal section at a position of $D/4$ (D is a diameter) from a bar steel surface, a visual field of 1 mm^2 is observed with an optical microscope (1,000 magnifications) and the number of sulfide system inclusions 1 μm or more in width is counted. Further, the aspect ratios of the sulfide system inclusions 1 μm or more in width are measured and the arithmetic average is obtained.

(2) Fracture splitting performance (dimension change)

[0045] Each of the bar steels obtained in the test example is cut into an appropriate length, heated to a temperature of 1,200°C, flattened to a thickness of 25 mm by forging, and thereafter air-cooled. The obtained flat plate is cut and a test piece shown in Fig. 3 is obtained. In Fig. 3, Fig. 3(a) shows the top view of a test piece and Fig. 3(b) shows the side view of a test piece, and the symbol a represents notches, the symbol b represents bolt holes, and the symbol c is the arrow showing the rolling direction. The test piece has a tabular shape of 65 mm x 65 mm x 22 mm in thickness and a

EP 2 216 423 A1

cylindrical hole 43 mm in diameter is bored in the center. Notches a (R = 0.2 mm, 0.5 mm in depth) are formed at the ends of the hole in the center. Further, bolt holes b (8.3 mm in diameter) are formed in the test piece in the rolling direction.

[0046] As shown in Fig. 4, holders 3a and 3b are inserted into the center hole of a test piece 6, they are set in a press test apparatus (1,600 t press), fracture splitting is applied to the test piece 6 at a press speed of 270 mm/s. Here, the fracture speed of the test piece is about 150 mm/s by calculation because the wedge angle of wedges 4 and 5 is 30°. Then as shown in Fig. 5, the difference of the hole diameter (L2 - L1) between before and after the fracture splitting is measured as the dimension change and the case where the dimension change is 0.15 mm or less is evaluated as being excellent in fracture splitting performance. Here, the criterion of 0.15 mm or less dimension change is identical to the criterion stipulated in C70S6 of the DIN standards used in Europe.

(3) Machinability (tool service life)

[0047] Milling is applied to the cut plane of a bar steel obtained in the test example, thereafter drilling is applied to the milling plane under the following conditions, and the distance (the total length) of the drilling until a tool breaks or is damaged by melting is measured;

Cutting tool: SKH51 (φ10 straight drill),

Cutting speed: 30 m/min,

Feed: 0.15 mm/rev.,

Drilling depth: 30 mm,

Lubrication state: Dry, and

Drilling position: D/4 (D is the diameter of a bar steel).

[0048] Tool service life is evaluated by a relative value obtained from the drilling distance L of each bar steel by using the drilling distance L_{A1} of the steel type A1 in Table 1 as the standard.

$$\text{Tool service life} = L / L_{A1}$$

[0049] The results are shown in Table 1 and Figs. 1 and 2.

[0050]

[Table 1]

Steel type	Composition (mass %, the remainder consists of iron and inevitable impurities)											Effective Ti content (f-value)	Sulfide system inclusions		Dimension change (mm)	Tool service life (relative value)
	C	Si	Mn	P	S	V	Cr	Ti	N	Al	Added component		Aspect ratio	Piece/mm ²		
A1	0.40	0.25	1.04	0.043	0.043	0.160	0.10	0.002	0.0106	-	Ca:0.0035	-0.034	3.8	206	0.203	1.0
A2	0.40	0.24	1.04	0.045	0.041	0.157	0.10	0.030	0.0100	-	Ca:0.0024	-0.004	3.3	216	0.257	1.1
A3	0.41	0.25	1.07	0.048	0.059	0.164	0.10	0.023	0.0045	-	Ca:0.0012	0.008	8.8	142	0.046	0.6
A4	0.39	0.25	1.08	0.047	0.050	0.168	0.10	0.033	0.0054	-	Ca:0.0026	0.014	2.7	287	0.033	0.8
A5	0.40	0.25	1.07	0.049	0.043	0.165	0.10	0.052	0.0049	-	Ca:0.0026	0.035	2.3	291	0.032	0.5
A6	0.39	0.24	1.05	0.052	0.042	0.159	0.10	0.125	0.0063	-	Ca:0.0024	0.103	2.1	307	0.026	0.1
Al: 0.01% or less is an inevitable content and expressed by the symbol "-"																

EP 2 216 423 A1

[0051] As it is obvious from Table 1 and Figs. 1 and 2, by reducing the quantity of added Ti while an effective Ti content (an f-value) is secured, it is possible to improve both fracture splitting performance and machinability.

Test example 2

[0052] Test example 2 is carried out in the same way as Test example 1 except that steels of the chemical compositions shown in Tables 2 and 3 are used in Test example 2. The tool service life in each of the groups B to H and J is shown by a relative value obtained by rating the tool service life of the steel type to which Ti is not added as 1.

[0053] The results are shown in Tables 4 to 7. Here, in Table 7, the tool service life of the steel type A1 obtained by rating the tool service life of steel type J1 as 1 is shown together so as to be able to compare the tool service life with the tool service life of A group steels having a relatively large V content of about 0.160%.

[0054]

[Table 2]

Steel type	Composition (mass %, the remainder consists of iron and inevitable impurities)											Effective Ti content (f-value)
	C	Si	Mn	P	S	V	Cr	Ti	N	Al	Added component	
B1	0.42	0.21	0.95	0.030	0.053	0.195	0.91	-	0.0048	-	Ca:0.0025	-0.016
B2	0.42	0.17	0.97	0.020	0.049	0.189	0.90	0.010	0.0048	-	Ca:0.0021	-0.006
B3	0.42	0.16	0.96	0.024	0.052	0.188	0.89	0.018	0.0055	-	Ca:0.0013	-0.001
B4	0.44	0.17	0.97	0.020	0.051	0.194	0.90	0.031	0.0052	-	Ca:0.0013	0.013
B5	0.43	0.16	0.97	0.020	0.046	0.187	0.90	0.045	0.0052	-	Ca:0.0015	0.027
B6	0.43	0.15	0.98	0.022	0.053	0.191	0.91	0.115	0.0062	-	Ca: 0.0018	0.094
B7	0.44	0.16	1.01	0.025	0.055	0.188	0.90	0.047	0.0051	-	Ca : 0.0025, Bi:0.05	0.030
C1	0.42	0.25	1.50	0.030	0.051	0.122	0.25	-	0.0054	0.017	-	-0.019
C2	0.40	0.25	1.48	0.034	0.052	0.051	0.25	0.034	0.0049	0.029	Ca: 0.0025	0.017
C3	0.39	0.25	1.51	0.036	0.055	0.057	0.25	0.029	0.0047	0.025	REM:0.005	0.013
C4	0.40	0.25	1.32	0.044	0.105	0.166	0.10	0.031	0.0051	-	Ca:0.0022	0.014
D1	0.39	0.24	0.59	0.051	0.054	0.245	0.10	-	0.0051	0.029	-	-0.017
D2	0.41	0.26	0.63	0.053	0.050	0.141	0.10	0.046	0.0043	-	Ca:0.0022	0.031
E1	0.41	0.23	1.02	0.045	0.053	0.120	0.13	-	0.0084	0.031	Cu:0.20, Ni:0.30	-0.029
E2	0.40	0.25	1.07	0.048	0.050	0.047	0.13	0.038	0.0043	-	Ca:0.0021, Cu:0.18, Ni:0.31	0.023
E3	0.40	0.26	1.05	0.051	0.052	0.045	0.13	0.041	0.0041	-	Ca:0.0025, Mo:0.52	0.027
F1	0.35	0.23	1.26	0.090	0.060	0.185	0.10	-	0.0098	-	Ca:0.0013, Mg:0.0026, Te:0.005	-0.034
F2	0.34	0.20	1.19	0.065	0.060	0.102	0.10	0.050	0.0098	-	Ca:0.0015, Mg:0.0021, Te:0.006	0.016
Al: 0.01% or less is an inevitable content and expressed by the symbol "-"												

[0055]

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[Table 3]

Steel type	Composition (mass %, the remainder consists of iron and inevitable impurities)											Effective Ti content (f-value)
	C	Si	Mn	P	S	V	Cr	Ti	N	Al	Added component	
G1	0.47	0.65	0.51	0.082	0.042	0.124	0.14	-	0.0039	0.033	Zr:0.12	-0.013
G2	0.47	0.63	0.50	0.047	0.040	0.050	0.14	0.047	0.0036	0.035	Zr:0.115	0.035
G3	0.45	0.65	0.53	0.048	0.043	0.053	0.15	0.049	0.0039	0.012	Zr:0.112, Nb:0.045	0.036
G4	0.46	0.65	0.51	0.048	0.039	0.055	0.15	0.051	0.0043	0.016	Te:0.012, Nb:0.034	0.036
H1	0.33	0.24	1.19	0.052	0.050	0.121	0.30	-	0.0103	-	-	-0.035
H2	0.31	0.25	1.22	0.047	0.053	0.123	0.30	0.035	0.0061	-	-	0.014
11	0.71	0.24	0.49	0.010	0.057	-	0.10	-	0.0055	0.025	Ca:0.0006	-0.019
12	0.42	0.19	2.05	0.012	0.015	-	0.15	-	0.0072	0.032	-	-0.025
13	0.38	0.13	1.57	0.027	0.230	-	0.13 -		0.0101	0.031	-	-0.035
14	0.39	0.26	0.73	0.018	0.012	-	1.43	-	0.0143	0.024	-	-0.049
15	0.20	0.25	1.10	0.032	0.047	0.124	0.20	0.025	0.0047	-	Ca:0.0020	0.009
J1	0.41	0.26	1.10	0.012	0.050	0.054	0.28	-	0.0102	0.028	-	-0.035
J2	0.41	0.24	0.98	0.013	0.049	0.097	0.21	-	0.0102	0.031	-	-0.035
J3	0.38	0.25	0.94	0.048	0.059	0.059	0.28	0.038	0.0043	0.025	-	0.023
J4	0.39	0.25	1.05	0.055	0.054	0.053	0.27	0.042	0.0048	0.020	-	0.026
J5	0.39	0.26	1.03	0.051	0.056	0.098	0.19	0.041	0.0041	0.019	-	0.027
J6	0.37	0.25	1.02	0.053	0.054	0.069	0.28	0.044	0.0051	0.019	-	0.027
J7	0.38	0.25	1.04	0.032	0.060	0.071	0.27	0.041	0.0052	0.023	-	0.023
J8	0.39	0.25	1.02	0.042	0.048	0.055	0.25	0.044	0.0044	-	-	0.029
J9	0.38	0.26	1.00	0.051	0.055	0.092	0.21	0.040	0.0042	-	-	0.026
J10	0.39	0.25	1.00	0.039	0.052	0.074	0.25	0.038	0.0039	-	-	0.025
Al: 0.01% or less is an inevitable content and expressed by the symbol "-."												

[0056]

[Table 4]

Steel type	Effective Ti content (f-value)	Sulfide system inclusions		Cracking during forging	Dimension change (mm)	Tool service life (relative value)
		Aspect ratio	Piece/mm ²			
B1	-0.016	6.5	160	Nil	0.170	1.0
B2	-0.006	8.6	127	Nil	0.115	1.2
B3	-0.001	8.9	120	Nil	0.122	1.4
B4	0.013	3.9	225	Nil	0.037	0.5
B5	0.027	2.7	264	Nil	0.046	0.6
B6	0.094	2.2	395	Nil	0.028	0.1
B7	0.030	2.2	365	Nil	0.037	0.8
C1	-0.019	19.2	84	Nil	0.280	1.0
C2	0.017	2.8	297	Nil	0.075	8.2
C3	0.013	3.5	268	Nil	0.037	9.4
C4	0.014	1.8	819	Nil	0.022	14.9
D1	-0.017	19.2	83	Nil	0.076	1.0
D2	0.031	2.4	313	Nil	0.053	3.1

[0057]

[Table 5]

Steel type	Effective Ti content (f-value)	Sulfide system inclusions		Cracking during forging	Dimension change (mm)	Tool service life (relative value)
		Aspect ratio	Piece/mm ²			
E1	-0.029	20.2	85	Nil	0.144	1.0
E2	0.023	2.9	283	Nil	0.055	4.5
E3	0.027	2.5	334	Nil	0.050	3.1
F1	-0.034	3.3	275	Present	-	1.0
F2	0.016	1.2	646	Nil	0.049	12.7
G1	-0.013	2.9	226	Present	-	1.0
G2	0.035	2.6	358	Nil	0.011	6.6
G3	0.036	3.1	228	Nil	0.042	10.1
G4	0.036	1.6	365	Nil	0.010	7.1
H1	-0.035	20.6	113	Nil	0.311	1.0
H2	0.014	11.8	381	Nil	0.113	1.0

[0058]

[Table 6]

Steel type	Effective Ti content (f-value)	Sulfide system inclusions		Cracking during forging	Dimension change (mm)
		Aspect ratio	Piece/mm ²		
I1	-0.019	9.5	127	Nil	0.140

(continued)

Steel type	Effective Ti content (f-value)	Sulfide system inclusions		Cracking during forging	Dimension change (mm)
		Aspect ratio	Piece/mm ²		
I2	-0.025	30.4	56	Nil	0.353
I3	-0.035	20.7	432	Present	-
I4	-0.049	26.0	56	Nil	0.804
I5	0.009	4.0	191	Nil	0.187

[0059]

[Table 7]

Steel type	Effective Ti content (f-value)	Sulfide system inclusions		Cracking during forging	Dimension change (mm)	Tool service life (relative value)
		Aspect ratio	Piece/mm ²			
J1	-0.035	20.7	83	Nil	0.409	1.0
J2	-0.035	20.5	83	Nil	0.326	0.9
J3	0.023	10.8	119	Nil	0.050	3.3
J4	0.026	11.1	112	Nil	0.076	1.7
J5	0.027	11.0	112	Nil	0.026	1.0
J6	0.027	10.5	117	Nil	0.065	2.6
J7	0.023	10.0	122	Nil	0.064	2.3
J8	0.029	12.0	102	Nil	0.105	2.1
J9	0.026	11.6	109	Nil	0.054	1.7
J10	0.025	12.7	106	Nil	0.082	1.6
A1	-0.034	3.8	206	Nil	0.203	0.3

[0060] In each of the cases of the steel types B4, B5, B7, C2 to C4, D2, E2, E3, F2, G2 to G4, and H2 in which the components of C, Si, Mn, and the like and the effective Ti contents (the f-values) are appropriately controlled, the dimension change is 0.15 mm or less after fracture splitting, the fracture splitting performance is excellent, and the tool service life is also excellent. Further, in each of the cases of the steel types J3 to J10 containing V of 0.10% or less that is one of the best modes in the present invention, good fracture splitting performance is obtained and the tool service life is excellent even though a machinability improvement element such as Ca is not contained.

Test example 3

[0061] Test example 3 is carried out in the same way as Test example 1 except that the steel type H2 shown in Table 2 is used and the rolling start temperature and the rolling end temperature are set as shown in Table 8 below in Test example 3.

[0062] The results are shown in Table 8.

[0063]

[Table 8]

No	Rolling start temperature (°C)	Rolling end temperature (°C)	Sulfide system inclusions		Dimension change (mm)	Tool service life (relative value)
			Aspect ratio	Number (piece/mm ²)		
1	950	800	17.9	236	0.157	0.8
2	1050	900	11.8	381	0.113	1.0

(continued)

No	Rolling start temperature (°C)	Rolling end temperature (°C)	Sulfide system inclusions		Dimension change (mm)	Tool service life (relative value)
			Aspect ratio	Number (piece/mm ²)		
3	1250	1050	8.9	578	0.090	0.9

[0064] As it is obvious from Table 8, as the rolling start temperature and the rolling end temperature are raised, the aspect ratio of sulfide system inclusions can be reduced.

Claims

1. A steel for a fracture splitting type connecting rod, containing
C: 0.25 - 0.5% (in mass %, the same is applied hereunder),
Si: 0.01 - 2.0%,
Mn: 0.50 - 2.0%,
P: 0.015 - 0.080%,
S: 0.01 - 0.2%,
V: 0.02 - 0.20%,
Cr: 0.05 - 1.0%,
Ti: 0.01 - 0.10%, and
N: 0.01% or less,
with the remainder consisting of iron and inevitable impurities,
wherein an f-value represented by the expression (1) shown below is in the range of 0.003 to 0.04; and
in a longitudinal section at a position of D/4 (D is the thickness or the diameter of the steel) from the steel surface,
the number of sulfide system inclusions 1 μm or more in width is 100 to 4,000 pieces per 1 mm², and the average aspect ratio (length/width) of the sulfide system inclusions 1 μm or more in width is 15 or less,

$$f = [Ti] - [N] \times 48/14 \quad (1),$$

(in the expression, [Ti] and [N] represent the contents (mass %) of Ti and N in a steel, respectively).

2. A steel for a fracture splitting type connecting rod according to Claim 1, wherein Ti is 0.08% or less.
3. A steel for a fracture splitting type connecting rod according to Claim 1, wherein V is 0.10% or less.
4. A steel for a fracture splitting type connecting rod according to Claim 1, further containing at least one kind selected from the group consisting of
Zr: 0.15% or less,
Ca: 0.005% or less,
Mg: 0.005% or less,
Te: 0.1% or less, and
REM: 0.3% or less.
5. A steel for a fracture splitting type connecting rod according to Claim 1, further containing at least either one of Al:
0.05% or less, or
Nb: 0.05% or less.
6. A steel for a fracture splitting type connecting rod according to Claim 1, further containing at least one kind selected from the group consisting of
Cu: 1.0% or less,
Ni: 1.0% or less, and
Mo: 1.0% or less.

7. A steel for a fracture splitting type connecting rod according to Claim 1, further containing Bi: 0.1% or less.

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FIG. 1

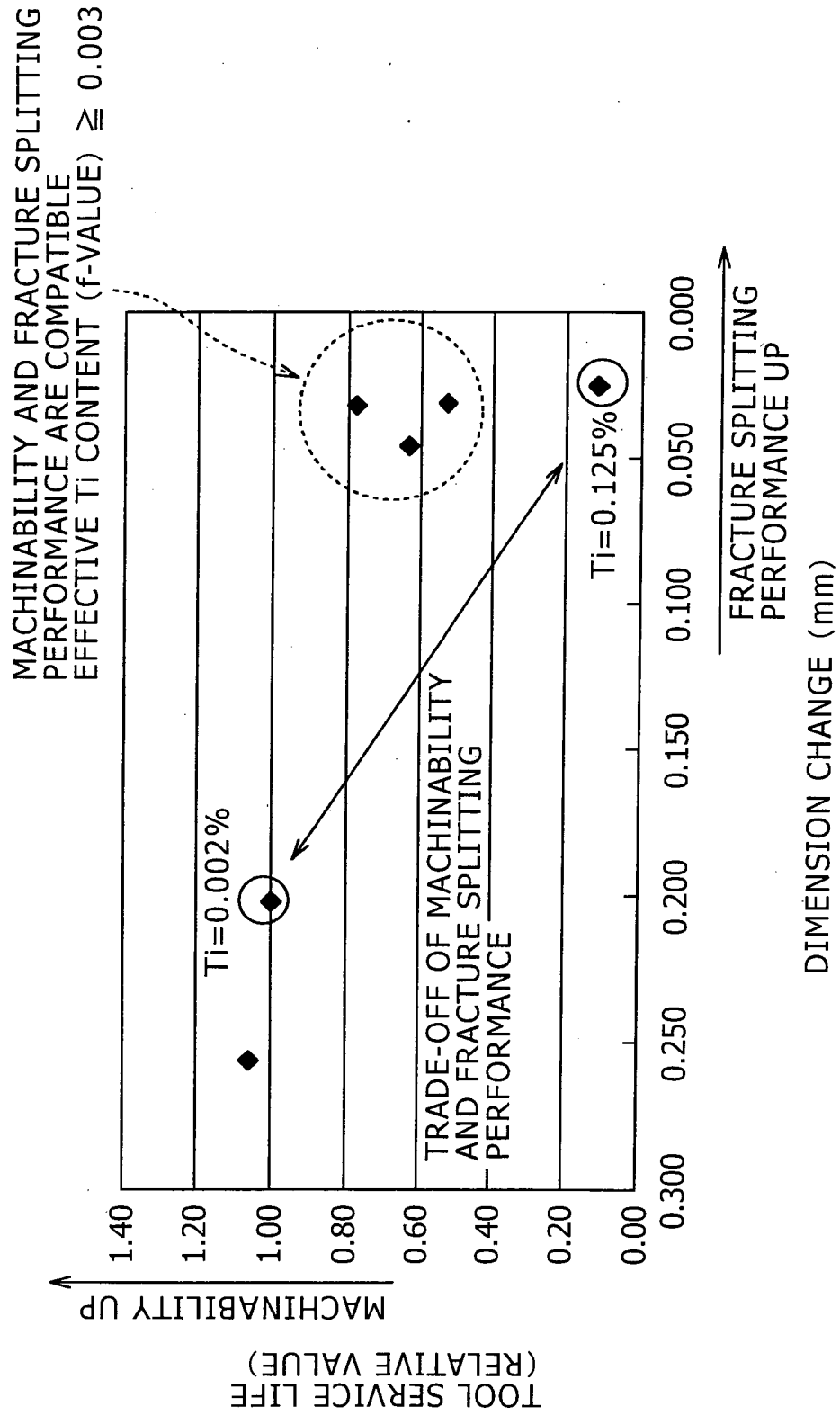


FIG. 2

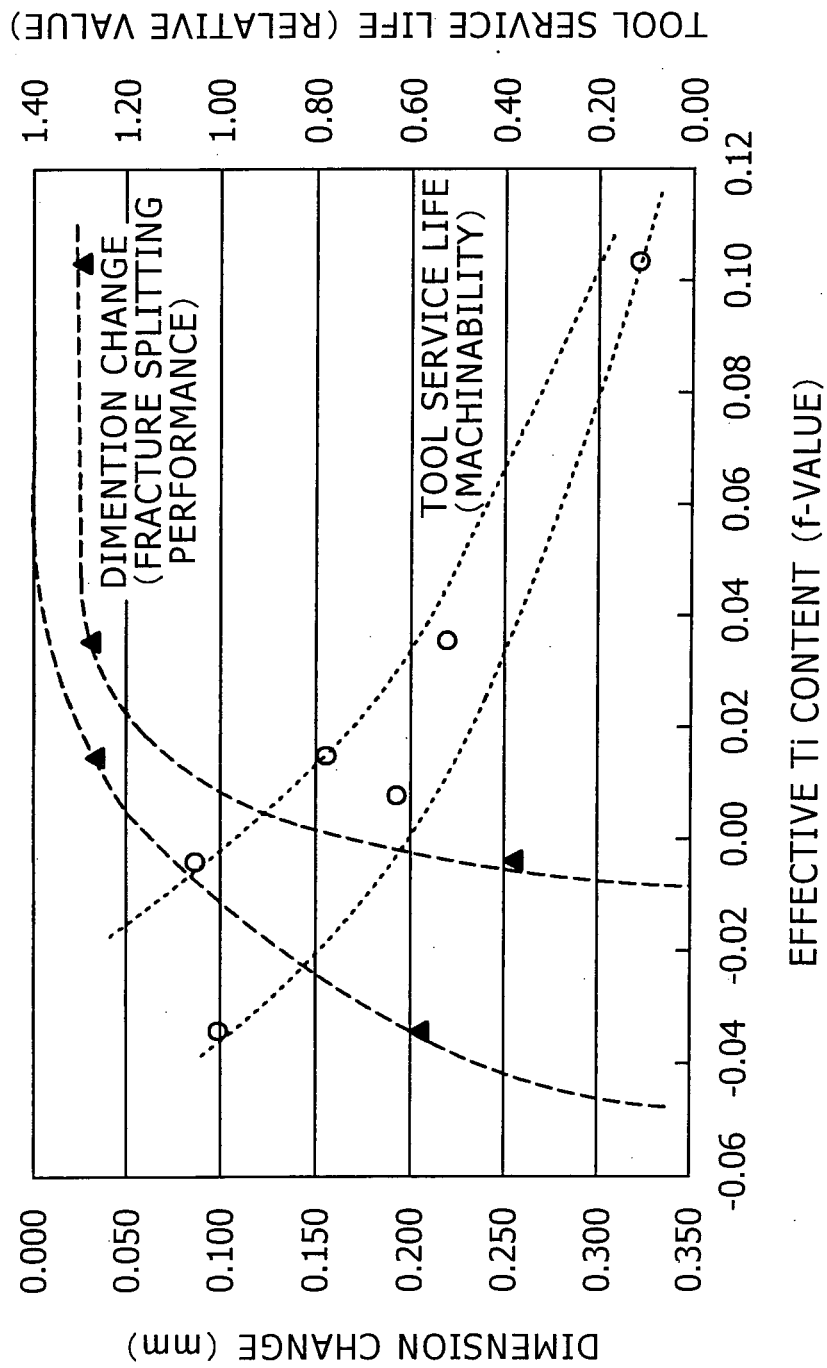


FIG. 3

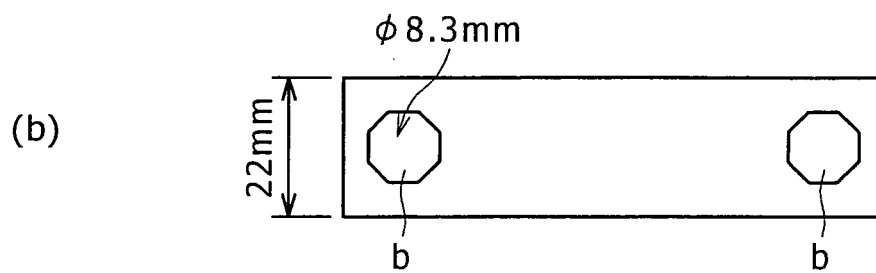
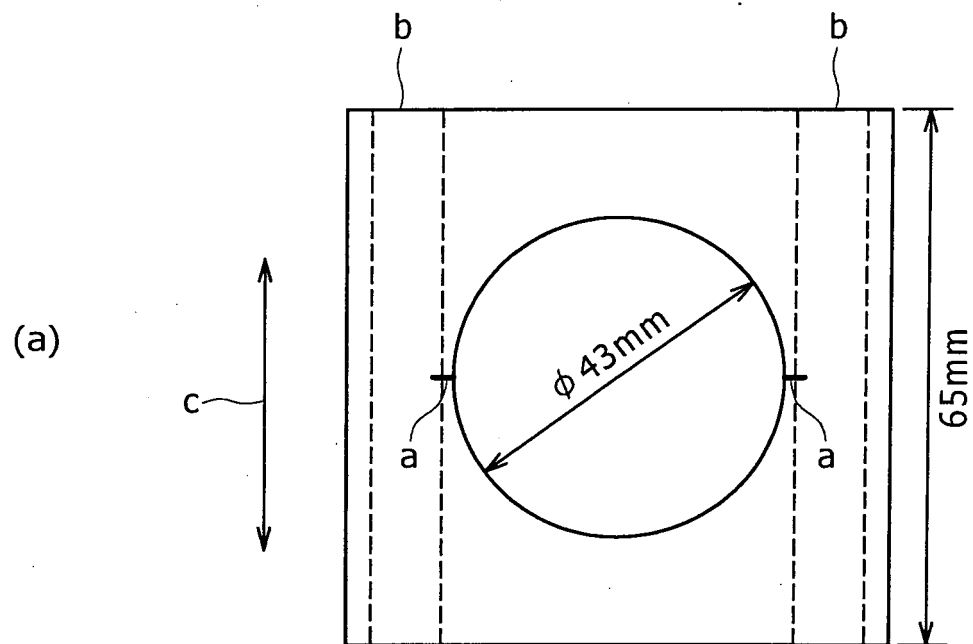


FIG. 4

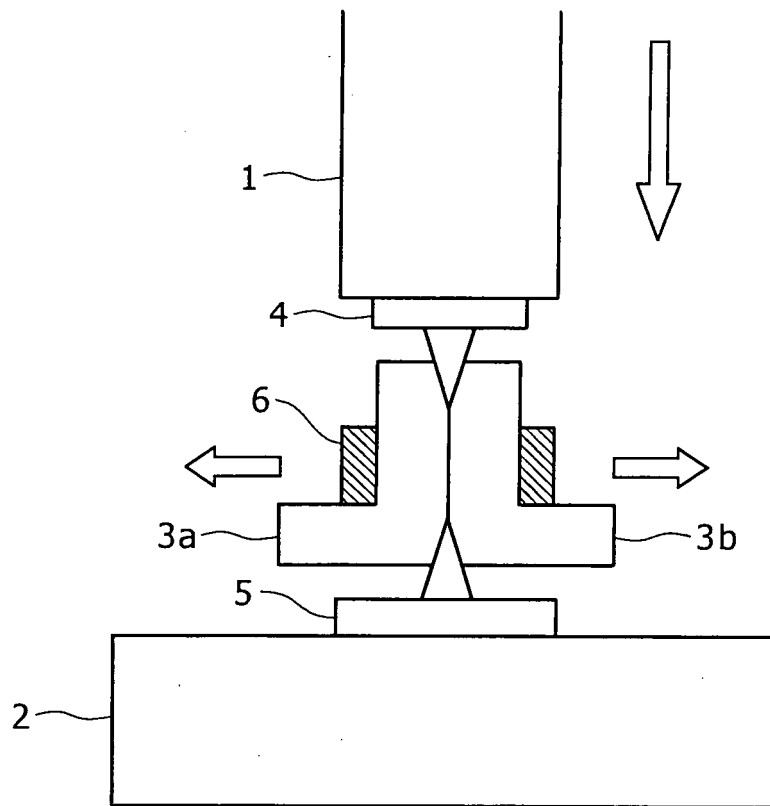
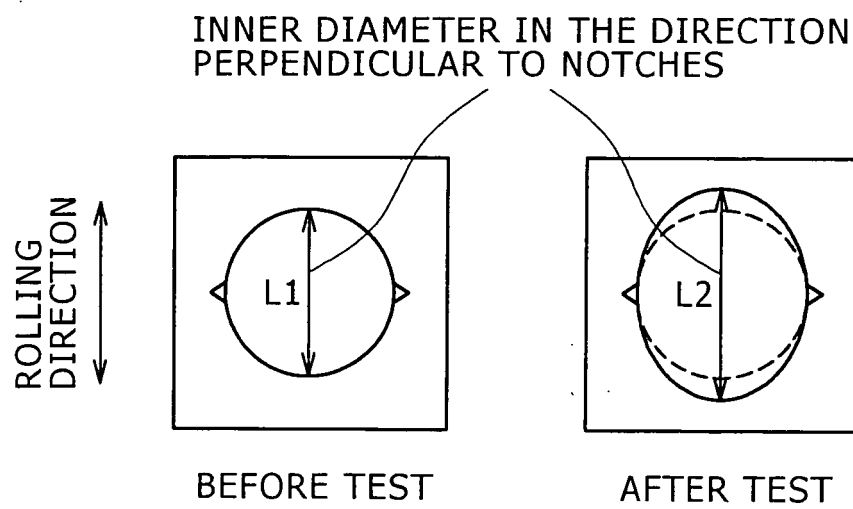


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2008/071702

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C22C38/38(2006.01)i, C22C38/58(2006.01)i

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)

C22C1/00-49/14

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

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2009
Kokai Jitsuyo Shinan Koho	1971-2009	Toroku Jitsuyo Shinan Koho	1994-2009

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 11-236643 A (Sumitomo Metal Industries, Ltd.), 31 August, 1999 (31.08.99), Claims; Par. Nos. [0001], [0018] to [0033]; table 2; Par. No. [0041] (Family: none)	1-7
A	JP 2000-345298 A (Sumitomo Metal Industries, Ltd.), 12 December, 2000 (12.12.00), Claims; Par. Nos. [0001], [0018] to [0033]; table 2; Par. No. [0041] (Family: none)	1-7

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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Date of the actual completion of the international search
14 January, 2009 (14.01.09)Date of mailing of the international search report
27 January, 2009 (27.01.09)Name and mailing address of the ISA/
Japanese Patent Office

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2008/071702

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2007-277705 A (Kobe Steel, Ltd.), 25 October, 2007 (25.10.07), Claims; Par. No. [0048]; tables 2, 4; Par. No. [0073]; table 5 & WO 2007/108365 A1	1-7
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REFERENCES CITED IN THE DESCRIPTION

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- JP 3416869 B [0006]