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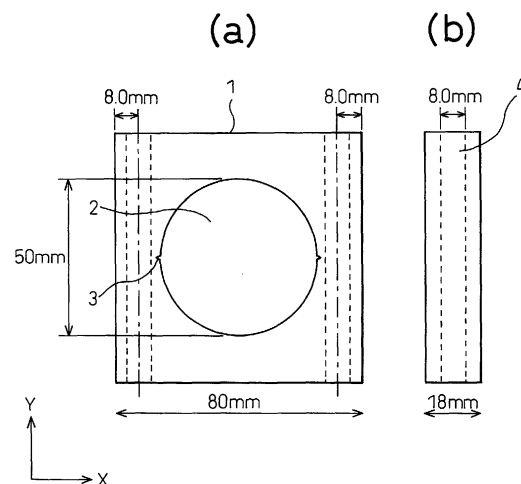
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(54) **HIGH-STRENGTH UNTEMPERED STEEL FOR FRACTURE SPLITTING AND STEEL COMPONENT FOR FRACTURE SPLITTING**

(57) High strength fracture splitting use non-heat treated steel containing, by mass%, C: 0.23 to 0.35%, Si: 0.70 to 1.30%, Mn: 0.76 to 1.17%, P: 0.040 to 0.080%, S: 0.040 to 0.118%, Cr: 0.05 to 0.20%, Al: 0.010% or less, V: 0.27 to 0.45%, and N: 0.0050 to 0.0145%, having a balance of Fe and unavoidable impurities, having values of three formulas limiting the composition of ingredients satisfying required values, ensuring hot ductility, and, when hot forged, then cooled by air cooling or air blast cooling, forming a ferrite-pearlite structure having a ferrite fraction of 60% or more, and a fracture splitting use steel part.

Fig.1



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Description

Technical Field

5 **[0001]** The present invention relates to a material for a steel part used after fracture splitting, that is, high strength fracture splitting use non-heat treated steel used after hot forging to form a steel part, then immediately applying predetermined cooling, and a fracture splitting use steel part provided with high strength and superior fracture splittability produced using that non-heat treated steel as a material.

10 Background Art

[0002] For recent forged parts for automobile engine use and forged parts for chassis's, hot forging use non-heat treated steel enabling quenching and tempering to be eliminated (hereinafter referred to as "non-heat treated steel") is being applied. Non-heat treated steel is steel designed in ingredients so that even as hot forged, then cooled by air cooling or air blast cooling, that is, even omitting the prior quenching and tempering, superior mechanical properties are realized.

[0003] As one part to which non-heat treated steel is broadly applied, there is an engine connecting rod (hereinafter referred to as a "connecting rod"). A connecting rod is consisted of a cap and rod, that is, two parts. In the past, the cap and rod were separately fabricated and bolted together. However, with this method, the mating faces of the cap and rod had to be finished to a high precision, so the processing costs rose.

[0004] For this reason, in recent years, the method has been employed of hot forging steel to an integral shape of the cap and rod, then cutting a notch at the inside of the large end, applying impact tension to split the cap and rod by fracture, realigning the fracture faces, and bolting them together.

[0005] Such a fracture split connecting rod enables the step of finishing the mating surfaces to be omitted, so not only are the costs reduced, but also the fracture faces bear part of the stress applied to the connecting rod, so the strength is superior and, accordingly, there are the merits that the bolts and body can be reduced in size.

[0006] Fracture split connecting rods are widespread in the West. There, the most general fracture splitting use non-heat treated steel is high carbon steel containing about 0.7 mass% of carbon. If using a high carbon composition, the merits are obtained that the ductility deteriorates, so the fracturing work becomes easy and the deformation at the time of fracture becomes smaller, but on the other hand there are the defects that the yield strength and the fatigue strength are inferior.

[0007] High strength low carbon non-heat treated steels overcoming the defects of conventional high carbon steel are disclosed in the patent literature.

[0008] In the hot forging use non-heat treated steels described in Patent Literature 1 and Patent Literature 2, medium carbon (C: 0.30 to 0.60 mass%) is included so as to improve the yield strength. Further, the Mn content and the N content are reduced to realize a high fractureability, that is, a small fracture deformation.

[0009] Further, steels dispersing secondary phase grains into the steel to improve the fractureability have also been proposed in numerous literature. For example, Patent Literature 3 discloses, in addition to lowering the Mn and lowering the N, dispersing TiC grains to as to obtain sufficient fracture splittability even with steel having a C content of less than 0.35%.

[0010] Steel utilizing the dispersion of TiC is also disclosed in Patent Literature 4. Patent Literature 4 discloses that at the time of hot forging, the pinning of the austenite grains by the TiC is insufficient resulting in mixed grain sizes, so after cooling, the large pearlite grains transform and that this enhances the fracture splittability.

[0011] Patent Literature 5 discloses a low ductility non-heat treated steel material superior in machineability having Ti carbosulfides or Zr carbosulfides of a maximum size of 10 μm or less and a total amount of 0.05% or more.

[0012] As means for enhancing the fractureability, the method of increasing the pearlite fraction is also common. Patent Literature 6 discloses applying ferrite-pearlite steel containing C: 0.2 to 0.5% and V: 0.05 to 0.5% and having a ferrite fraction of 20% or less to a fracture split connecting rod.

[0013] Furthermore, Patent Literature 7 discloses high strength non-heat treated steel suitable for fracture splitting having TiN inclusions in the steel of a maximum size of 5 μm or more and a density of 5/ mm^2 or more and, furthermore, having a pearlite fraction of 20% or more.

[0014] On the other hand, a method of making the area percentage of pearlite 40% or less and controlling the form of the sulfides to obtain random large surface relief fracture faces is disclosed in Patent Literature 8.

[0015] In addition, the method of adding a relatively large amount of P to suppress deformation at the time of fracture is disclosed in Patent Literature 9. Patent Literature 10 discloses making the pearlite fraction 50% or more and, when the carbon content is 0.4 to 0.5%, making P 0.05 to 0.15% is suitable.

[0016] Patent Literature 11 discloses the method of utilizing Si, V, Ti, P, and solute V to promote brittle fracture and the method of using notches to promote brittle fracture.

[0017] Patent Literature 12 discloses non-heat treated steel suitable as a material for cranking rods having a ferrite-pearlite structure of a ferrite fraction of 40% or more and, furthermore, having a ferrite hardness of a Vicker's hardness of 250 or more and a ratio of ferrite hardness and overall hardness of 0.80 or more.

5 **[0018]** Patent Literature 13 discloses a non-heat treated steel for a connecting rod improving machineability and yield strength by making $E (=2804-1549 \times C_{eq} + 8862 \times P(\%) - 23.4 \times H)$, calculated from the hardness H (HRC), P content (%), and carbon equivalent C_{eq} , 150 or less.

[0019] Patent Literature 14 discloses hot forging use non-heat treated steel enabling easy fracture separation of a forged part after hot forging having a sol-Al, N, and O contents satisfying $0.01[\text{sol-Al}\%] \leq [\text{O}\%] \leq 1.5[\text{sol-Al}\%]$, and $0.03[\text{N}\%] \leq [\text{O}\%] \leq 1.6[\text{N}\%]$.

10 **[0020]** Patent Literature 15 discloses a rolled material for a fracture splitting type connecting rod superior in fracture separability having a total of ferrite and pearlite of 95% or more, having sulfide-based inclusions of an average aspect ratio of 10.0 or less, having a $P_c (=C/(1-\alpha/100))$, C: carbon content (mass%), α : ferrite fraction (area%) of 0.41 to 0.75, and having a $V_{eq} (=V+Ti/2+Si/20)$, where V, Ti, Si are contents (mass%) of 0.18 mass% or more.

15 **[0021]** Viewing the steels for fracture split connecting rods disclosed up to now, they have a common feature of limiting the steel composition to ferrite and pearlite. However, they greatly differ in the suitable ratio of the ferrite and pearlite structures. Some make the ferrite 20% or less, while others make the pearlite 40% or less.

[0022] There are various methods for enhancing the fracture splittability. There are the methods of dispersion of Ti carbosulfides, dispersion of Ti nitrides, reduction of the Mn content, utilization of precipitation strengthening, addition of a large amount of P, and, in addition, forming notches in the connecting rods.

20
Prior Art Documents

Patent Literature

25 **[0023]**

- PLT 1: Japanese Patent Publication (A) No. 10-324954
- PLT 2: Japanese Patent Publication (A) No. 11-152546
- PLT 3: Japanese Patent Publication (A) No. 11-315340
- 30 PLT 4: Japanese Patent Publication (A) No. 2005-2367
- PLT 5: Japanese Patent Publication (A) No. 11-286746
- PLT 6: Japanese Patent Publication (A) No. 2003-193184
- PLT 7: Japanese Patent Publication (A) No. 2004-277817
- PLT 8: Japanese Patent Publication (A) No. 2003-342671
- 35 PLT 9: Japanese Patent Publication (A) No. 10-219389
- PLT 10: Japanese Patent Publication (A) No. 2002-275578
- PLT 11: Japanese Patent Publication (A) No. 9-176785
- PLT 12: Japanese Patent Publication (A) No. 2004-277840
- PLT 13: Japanese Patent Publication (A) No. 2007-119819
- 40 PLT 14: Japanese Patent Publication (A) No. 2002-256394
- PLT 15: Japanese Patent Publication (A) No. 2007-277705

Summary of Invention

45 Technical Problem

[0024] The main part covered by the present invention is a high strength connecting rod used after fracture splitting. This is provided with high strength, specifically, 850 MPa or more tensile strength and 650 MPa or more 0.2% proof stress, and realizes superior fractureability. To meet these requirements, preferably the steel is as low a carbon composition as possible and the part has a ferrite-pearlite structure.

50 **[0025]** However, in steel of a low carbon content, if trying to obtain a 850 MPa or more tensile strength, it is essential to increase the amount of alloy elements other than carbon. As a result, bainite easily forms in the hot forged part. If bainite forms, not only does the fractureability deteriorate, but also the yield strength and the yield ratio deteriorate and the mechanical properties necessary for the part can no longer be obtained.

55 **[0026]** Further, a steel material superior in fracture splittability is low in ductility not only at ordinary temperature, but also hot, but also easily is flawed or cracked at the time of production of a steel rod material and at the time of hot forging. Ease of casting and hot rolling of a steel material and hot forging of a part are extremely important requirements industrially. A steel material requires high hot ductility.

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[0027] The problem to be solved by the present invention is to provide high strength non-heat treated steel superior in fracture splittability which is superior in hot ductility and forms a stable ferrite-pearlite structure when hot forged, then cooled by air cooling or air blast cooling, and a fracture splitting use steel part.

5 Solution to Problem

[0028] The inventors engaged in in-depth experimentation and research so as to solve the above problem. As a result, they obtained the following discoveries 1) to 4).

10 1) If making the basic composition of ingredients of the steel C: 0.23 to 0.35%, Si: 0.70 to 1.30%, and, furthermore, V: 0.27 to 0.45% and making V carbonitrides precipitate and disperse in the steel, the ferrite is strengthened, the yield strength and tensile strength are improved, and the ductility deteriorates.

15 2) If making the K value defined by the following formula (1) 1.3(%) or less, when hot forging, then cooling by air cooling or air blast cooling, a ferrite-pearlite structure can be obtained.

$$K = -0.56 \times \%C - 0.07 \times \%Si + 1.3 \times \%Mn + 0.80 \times \%Cr - 1.80 \times \%P + 0.19 \times \%V - 5.6 \times \%N \dots (1)$$

20 "%element symbols" are contents of elements (%)
3) To obtain a superior fracture splittability, the ferrite fraction in the ferrite-pearlite structure should be made 60% or more. For this reason, the F value defined by the following formula (2) must be made 3.0(%) or less.

$$F = 4.3 \times \%C - 0.21 \times \%Si + 1.0 \times \%Mn + 1.4 \times \%Cr - 1.90 \times \%P + 1.8 \times \%V - 6.6 \times \%N \dots (2)$$

30 "%element symbols" are contents of elements (%)
4) To obtain a superior hot ductility, the R value defined by the following formula (3) or formula (3') must be made 35(%) or more.

$$R = 46.7 - 7.4 \times \%Si + 37.7 \times \%Mn - 349 \times \%S - 12.0 \times \%V - 174 \times \%Al \dots (3)$$

$$R = 46.7 - 7.4 \times \%Si + 37.7 \times \%Mn - 349 \times \%S - 12.0 \times \%V - 174 \times \%Al - 86.6 \times \%Pb \dots (3')$$

40 "%element symbols" are contents of elements (%)

[0029] The present invention was completed based on the above discoveries, so the gist of the present invention is as follows.

45 (1) High strength fracture splitting use non-heat treated steel characterized by containing, by mass%,
C: 0.23 to 0.35%,
Si: 0.70 to 1.30%,
50 Mn: 0.76 to 1.17%,
P: 0.040 to 0.080%,
S: 0.040 to 0.118%,
Cr: 0.05 to 0.20%,
Al: 0.010% or less,
55 V: 0.27 to 0.45%, and
N: 0.0050 to 0.0145%,
having a balance of Fe and unavoidable impurities, and

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having a K value defined by the following formula (1) of 1.3 or less, an F value defined by the following formula (2) of 3.0 or less, and an R value defined by the following formula (3) of 35 or more:

$$K = -0.56 \times \%C - 0.07 \times \%Si + 1.3 \times \%Mn + 0.80 \times \%Cr - 1.80 \times \%P + 0.19 \times \%V - 5.6 \times \%N \dots (1)$$

$$F = 4.3 \times \%C - 0.21 \times \%Si + 1.0 \times \%Mn + 1.4 \times \%Cr - 1.90 \times \%P + 1.8 \times \%V - 6.6 \times \%N \dots (2)$$

$$R = 46.7 - 7.4 \times \%Si + 37.7 \times \%Mn - 349 \times \%S - 12.0 \times \%V - 174 \times \%Al \dots (3)$$

where, %C, %Si, %Mn, %Cr, %P, %V, %N, and %S are contents in the steel (mass%), and %Al is the content as an impurity (mass%).

(2) High strength fracture splitting use non-heat treated steel as set forth in (1) characterized by further containing, by mass%, one or more of any of

Ca: 0.0005 to 0.0030%,

Zr: 0.0005 to 0.0030%,

Te: 0.0005 to 0.0030%, and

Ti: 0.005 to 0.050%.

(3) High strength fracture splitting use non-heat treated steel as set forth in (1) or (2) characterized by further containing, by mass%,

Pb: 0.010 to 0.050%

and by having an R value defined, instead of by the above formula (3), by the following formula (3') of 35 or more.

$$R = 46.7 - 7.4 \times \%Si + 37.7 \times \%Mn - 349 \times \%S - 12.0 \times \%V - 174 \times \%Al - 86.6 \times \%Pb \dots (3')$$

where, %Si, %Mn, %S, %V, and %Pb are contents in the steel (mass%) and %Al is the content as an impurity (mass%)

(4) A high strength fracture splitting use steel part produced by hot forging and cooling high strength fracture splitting use non-heat treated steel as set forth in any of the above (1) to (3), said steel part **characterized in that** the cooled steel composition is a ferrite-pearlite structure.

(5) A high strength fracture splitting use steel part as set forth in (4) **characterized in that** said steel composition has a ferrite volume fraction of 60% or more.

Advantageous Effects of Invention

[0030] The high strength fracture splitting use non-heat treated steel of the present invention is superior in hot ductility, forms a stable ferrite-pearlite structure when hot forged, then cooled by air cooling or air blast cooling, and is superior in fracture splittability. Further, a steel part produced from the high strength fracture splitting use non-heat treated steel of the present invention is high in strength, small in amount of deformation at fracture, and superior in fracture splittability and sufficiently provides the hot ductility required at the time of production.

Brief Description of Drawings

[0031]

FIG. 1 is a view showing a test piece of a shape corresponding to a large end of a connecting rod used for a fracture test. (a) shows the plane state, while (b) shows the side state.

Description of Embodiments

[0032] Below, the present invention will be explained in detail.

[0033] Non-heat treated steel for fracture splitting use has already been disclosed in numerous literature. Further, the compositions of ingredients of these steels are widely disclosed. However, in these steels, there are extremely few steels provided with all of the necessary requirements such as (a) superior hot ductility of an extent enabling industrial production, (b) formation of a ferrite-pearlite structure when hot forging, then cooling by air cooling or air blast cooling, (c) high strength, and (d) superior fracture splitting.

[0034] A ferrite-pearlite structure, compared to tempered martensite or a bainite structure, has lower ductility and impact values and has the effect of effectively suppressing deformation at the time of fracture split.

[0035] Therefore, the inventors in particular studied the formation of ferrite-pearlite structures when hot rolling, then cooling by air cooling or air blast cooling, and the composition of ingredients exhibiting a superior hot ductility and devised the optimal composition of ingredients as high strength steel for fracture split parts.

[0036] The first of the features of the steel part of the present invention is it being made of non-heat treated steel positively utilizing V precipitation strengthening. The steel is provided with a ferrite-pearlite structure. A conventional fracture split part often contains a small amount of bainite. This had become a cause of deterioration of the fracture splittability and mechanical properties, but in the present invention, this is improved and a stable quality in industrial production has been achieved.

[0037] The second of the features is the control of the ferrite volume fraction of the part made by the steel of the present invention to 60% or more, that is, an extremely large value. In steel increased in volume fraction of ferrite and greatly precipitation strengthened, the deformation at the time of fracture is small and peeling right under the fracture faces and chipping at the final fracture parts are suppressed.

[0038] The third feature of the present invention is, in addition to the quality as a fracture split part, the improvement of the defect of the "low hot ductility" common to fracture splitting use steel in general. A major problem in ordinary fracture splitting use steel is the cracks and flaws formed at the time of casting and the cracks and flaws formed in the subsequent hot working, that is, hot rolling of the steel rod material and hot rolling of the parts.

[0039] In industrial production, a particular problem arises with the cracks and flaws formed at the time of casting. Up until now, no inventions have been proposed with the objective of solving this problem. Numerous steels have been proposed for which efficient industrial production is not easy.

[0040] First, in solving the problem of stably obtaining a ferrite-pearlite structure when forming an actual part by hot forging, then immediately cooling by air cooling or air blast cooling, the inventors conducted experiments to reproduce the hot forging-cooling process for various types of steel focusing on V-containing medium carbon steel.

[0041] The experiments were conducted on 68 levels of steel having a composition of ingredients of C: 0.11 to 0.50% (mass%, same below), Si: 0.15 to 1.41%, Mn: 0.40 to 1.21%, P: 0.006 to 0.115%, S: 0.007 to 0.108%, Cr: 0.02 to 0.50%, Al: 0.001 to 0.034%, V: 0.20 to 0.45%, Ti: 0 to 0.059%, Pb: 0 to 0.260%, Ca: 0 to 0.0041%, and N: 0.0022 to 0.0141%.

[0042] The experiments were conducted using a hot working reproduction apparatus under the following conditions. The test pieces were made a diameter of 8 mm and a height of 12 mm. The test pieces were heated to 1523K, then were cooled by a 1.0K/s cooling rate, were compressed in the middle of the cooling at 1323K to a height ratio of 60%, and were further cooled by a 1.0K/s cooling rate down to room temperature.

[0043] After this, the test piece was split into two at the center line, the structure of the part at 1/4 thickness of the test piece was observed using an optical microscope, and the presence of any bainite structures was judged.

[0044] Specifically, a dilute solution of nitric acid alcohol (Nital) was used to corrode the structure which was then observed under an optical microscope at a power of 200X and measured for ratio of irregularly shaped ferrite grains.

[0045] The proeutectoid ferrite grains observed as a ferrite-pearlite structure are white and polygonal in shape, but when irregularly shaped structures which are the same white, but have fine amounts of carbides precipitated in them are discovered, they are judged as bainite. The "irregular shape" basically means a grain shape with relief shapes at the boundaries or shapes changed to pin shapes.

[0046] In the present invention, when the ratio of the bainite grains in the total number of proeutectoid ferrite grains and bainite grains is less than 3%, the composition is judged to be a ferrite-pearlite structure. If the bainite grains are less than 3%, they have almost no effect on the quality of the material.

[0047] From experience, it is known that C, Si, Mn, Cr, P, V, and N contribute to bainite transformation, so the relationship between the amounts of these elements and the bainite fraction was investigated by multiple regression analysis, whereupon it was learned that when the K value defined by the following formula (1) is 1.30(%) or less, the bainite fraction is 3% or less. For this reason, the K value was limited to 1.3 or less.

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$$K = -0.56 \times \%C - 0.07 \times \%Si + 1.3 \times \%Mn + 0.80 \times \%Cr - 1.80 \times \%P + 0.19 \%V - 5.6 \times \%N \dots (1)$$

5 where, %C, %Si, %Mn, %Cr, %P, %V, and %N are contents in the steel (mass%)

[0048] The lower limit of the K value depends on the lower limits of the different elements, so is not set.

10 [0049] Note that, in the parts covered by the present invention, it is assumed that during the cooling right after the hot forging, the average cooling rate from 1073 to 673K (value obtained by dividing temperature difference of 400K by time elapsed for temperature to fall from 1073K to 673K) is 2.0K/s or less, but to reproduce the structure and hardness of an actual part air cooled by an average cooling rate of 2.0K/s by simple heating and constant speed cooling of a hot working reproduction apparatus, making the average cooling rate after γ transformation 1.0K/s is suitable.

[0050] Next, the effects of the structure on the fractureability were studied.

15 [0051] As the material of the test piece, among the 68 levels used for finding the above K value, 30 levels in the ranges of C: 0.20 to 0.40% (mass%, same below), Cr: 0.02 to 0.20%, Al: 0.010% or less, Ti: 0 to 0.030%, and Pb: 0.10% or less were used.

[0052] These steel materials were melted in a 16 kg test furnace, cast into ingots, then hot worked to plate materials of a cross-section of 25×100 mm.

20 [0053] Furthermore, to reproduce the hot forging process, these plate-shaped materials were cut into lengths of 100 mm, heated to 1503K for 5 minutes, then cooled by blowing air at a rate of 5 m/s down to room temperature.

[0054] After cooling, a test piece 1 of a shape simulating the large end of a connecting rod shown in FIG. 1(a) was formed. At two locations facing each other at 180° of the inside, 45° V-notches 3 having a depth of 1.0 mm and tip curvature of 0.5 mm were formed. Furthermore, as shown in FIG. 1(b), a through hole 4 having a diameter of 8.0 mm was formed so that its centerline was at a position 8.0 mm from the side surface at the notched sides.

25 [0055] The test relating to fractureability was as follows. That is, the inside diameter of the test piece shown in FIG. 1 was measured, then a split die split in the vertical direction of FIG. 1 was inserted, a shim was inserted into a shim slot formed at the center of the slit die, a 200 kg weight was dropped on the wedge from a 40 mm height, and the test piece was fractured by the impact at the notched position.

30 [0056] Note that, the split die is on rail. It is structured so that one side is fixed in place, while the other side slides on the rail. The test piece is fastened to the split die by bolts so that the test piece split into two after fracturing will not detach from the split die.

35 [0057] The amount of deformation between before and after the test was made the total of the change of the inside diameter. Specifically, after fracturing, the fracture faces were aligned, reconnected, and bolted, then the test piece was measured for inside diameter, the difference from the inside diameter of the initial state measured in advance was found, and the total of the differences in the vertical and lateral directions was made the amount of deformation. It is learned that the smaller the amount of deformation of the inside diameter, the higher the fractureability.

[0058] Further, at the cross-section 5 mm away from the fracture face of the test piece, the hardness was measured and an optical microscope was used to measure the ferrite volume percentage.

40 [0059] The relationship between the difference in inside diameter and the hardness and ferrite volume percent before and after fracture of the test piece was investigated. As a result, it became clear that the difference in inside diameter before and after fracture had a large effect on the tensile strength and ferrite volume percentage.

[0060] That is, when the overall tensile strength is high and ferrite is suitably present, in particular when the ferrite volume fraction is 60% or more, it became clear that the amount of deformation at the time of impact fracture was 0.100 mm or less or sufficient small.

45 [0061] Next, 68 levels of steel the same as when finding the K value were used and the effects of the amounts of alloy elements on the ferrite volume fraction were investigated.

[0062] The test piece had a shape of a diameter of 8 mm and a height of 12 mm. This test piece heated to 1503K using a hot working reproduction apparatus, then cooled by a cooling rate of 1.0K/s, compressed in the middle of cooling at 1323K by a height ratio of 60%, and further cooled by a cooling rate of 1.0K/s to room temperature.

50 [0063] After this, the test piece was split into two at the centerline and the structure at the part of 1/4 thickness of the test piece was observed using an optical microscope to investigate the ferrite volume percentage.

[0064] From experience, it is known that C, Si, Mn, Cr, P, V, and N contribute to ferrite transformation, so the relationship between the amounts of these alloy elements and the ferrite volume fraction was found by multiple regression analysis.

55 [0065] As a result, when the F value defined by the following formula (2) is 3.0(%) or less, the result becomes 60% or more. The amount of fracture deformation was a good value equal to or less than the case of using existing non-heat treated steel or fracture splitting use containing 0.7 mass% of C as a material. From this, the F value was limited to 3.0 or less.

[0066] Note that, at the lower limit of 0.23% of the amount of C of the present invention, the amount of ferrite is at a

maximum about 75%.

$$F = 4.3 \times \%C - 0.21 \times \%Si + 1.0 \times \%Mn + 1.4 \times \%Cr - 1.90 \times \%P + 1.8 \times \%V - 6.6 \times \%N \dots (2)$$

where, %C, %Si, %Mn, %Cr, %P, %V, and %N are contents in the steel (mass%)

[0067] The lower limit of the F value depends on the lower limits of the different elements, so is not set.

[0068] Furthermore, the hot ductility right after melting and solidification, an indicator of the producibility of the steel slab, was evaluated by a hot tensile test.

[0069] The test steels were 96 levels of steel having a composition of ingredients of C: 0.11 to 0.50% (mass%, same below), Si: 0.15 to 1.41%, Mn: 0.17 to 2.46%, P: 0.006 to 0.115%, S: 0.007 to 0.108%, Cr: 0.02 to 1.00%, Al: 0.001 to 0.034%, V: 0 to 0.45%, Ti: 0 to 0.059%, Pb: 0 to 0.260%, Ca: 0 to 0.0041%, and N: 0.0022 to 0.0141%.

[0070] The test piece was made a rod shape of a diameter of 1.0 mm and a length of 100 mm with a center of the test piece covered by a quartz tube and with a thermocouple attached. This was attached to an ohmic heating apparatus provided with a tensile device and was ohmically heated while cooling the two ends by a copper water cooling zone.

[0071] Due to the current run, the center of the test piece was heated and melted. This was held for 60 seconds, then was cooled by 10K/s to constant temperatures (1473K, 1373K, and 1273K), held at each of those temperatures for 30 seconds each, then broken by tension by a strain rate of 0.005/s.

[0072] As the indicator of the hot ductility, the drawing value after breakage was employed. Steel with a small drawing value can be judged to easily crack or be flawed at the time of continuous casting.

[0073] In these tests, the drawing values at the tensile breakage temperatures of 1473K, 1373K, and 1273K were used as independent variables and the alloy elements were used as dependent variables for multiple regression, the averages of the multiple correlation coefficient of the elements in the multiple regression formula (only elements judged statistically significant) and a constant were found, and these values were used to obtain R(%) by the following formula (3) or formula (3').

$$R(\%) = 46.7 - 7.4 \times \%Si + 37.7 \times \%Mn - 349 \times \%S - 12.0 \times \%V - 174 \times \%Al \dots (3)$$

$$R(\%) = 46.7 - 7.4 \times \%Si + 37.7 \times \%Mn - 349 \times \%S - 12.0 \times \%V - 174 \times \%Al - 86.6 \times \%Pb \dots (3')$$

where, %Si, %Mn, %V, %Al, %Pb, and %S are the contents in steel (mass%).

[0074] When using continuous casting to produce a steel slab, to prevent cracks or flaws, the higher the drawing value, the better. The susceptibility to cracks and flaws is also affected by the structure of the casting machine and the casting conditions. The inventors investigated the relationship between the drawing value of various types of low hot ductility steel and the frequency of occurrence of cracks and flaws was therefore investigated.

[0075] As a result, it was learned that if the drawing value is 35% or more, the occurrence of cracks or flaws at the time of continuous casting can be sufficiently reduced. Accordingly, the R value found by the above formula (3) or formula (3') was limited to 35 or more. Note that, the upper limit of the R value is due to the amounts of the different elements, so is not particularly set.

[0076] Next, the reasons for limitation of the alloy composition of the present invention steel will be explained. Below, % means mass%.

C: 0.23 to 0.35%

[0077] C ensures the tensile strength and hardness of the part. To give good fractureability, 0.23% or more is required. On the other hand, if increasing the C, pearlite increases and the yield ratio deteriorates. Therefore, even if adjusting the alloy element to raise the tensile strength or hardness, the yield strength will not improve that much. Not only that, the fractureability and machineability will deteriorate, so the upper limit was limited to 0.35%. Further, C forms carbides with V and strengthens ferrite by precipitation strengthening. Preferably, the content is 0.28 to 0.32%.

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Si: 0.70 to 1.30%

5 **[0078]** Si is an element essential for promoting ferrite transformation and increasing the ferrite fraction. Further, Si strengthens ferrite by solution strengthening and lowers the ductility. To lower the ductility of the ferrite, 0.70% or more is necessary. However, if over 1.30%, the hot ductility deteriorates. From the viewpoint of ensuring hot ductility, 1.05% or less is preferable. More preferably, the content is 0.80 to 1.05%.

Mn: 0.76 to 1.17%

10 **[0079]** Mn is a solid-solution strengthening element and simultaneously an element promoting bainite transformation. To prevent the formation of bainite, the upper limit is made 1.17%. Further, Mn is necessary for fixing the S in the steel as a sulfide and raising the hot ductility. To stably obtain high hot ductility, the lower limit is made 0.76%. Preferably, the content is 0.80 to 1.00%.

15 P: 0.040 to 0.080%

20 **[0080]** P is an element promoting ferrite transformation and suppressing bainite transformation. To obtain the bainite transformation suppression effect, 0.040% or more is necessary. When adding this in a large amount, the hot ductility deteriorates and cracks or flaws easily form, so the upper limit is made 0.080%. From the viewpoint of ensuring the hot ductility, less than 0.065% is preferable. More preferably, the content is 0.045 to 0.062%.

S: 0.040 to 0.118%

25 **[0081]** S is an element bonding with Mn to form MnS grains and improve the machineability. To obtain a sufficient machineability, the lower limit is made 0.040%. However, if adding this in a large amount, the anisotropy of the mechanical properties becomes greater, so the upper limit is made 0.118%. Preferably, the content is 0.060 to 0.110%.

Cr: 0.05 to 0.20%

30 **[0082]** Cr, like Mn, is a solid-solution strengthening element and simultaneously is an element promoting bainite transformation. To ensure tensile strength and hardness, 0.05% or more is added. However, Cr has a higher effect of promoting bainite transformation than even Mn, so to suppress bainite, the content is limited to 0.20% or less. Preferably, the content is 0.08 to 0.16%.

35 V: 0.27 to 0.45%

40 **[0083]** V is an element forming carbonitrides to strengthen the ferrite by precipitation strengthening, improve the yield strength and tensile strength, and reduce the ductility. Further, V carbonitrides have the action of promoting ferrite transformation, so the low ductility fine ferrite increases. As a result, the breakage deformation is reduced and the peeling and other variations in fracture surfaces are also reduced.

[0084] To obtain these sufficient effects, V is limited to 0.27% or more. However, if over 0.45%, the effect becomes saturated and the cost also rises, so the upper limit is made 0.45%. Preferably, the content is 0.30 to 0.41%, more preferably 0.32 to 0.37%.

45 N: 0.0050 to 0.0145%

50 **[0085]** N is an element mainly forming V nitrides and V carbonitrides to suppress bainite transformation and promote ferrite transformation. To obtain these sufficient effects, the lower limit is made 0.0050%. If added excessively, the hot ductility deteriorates and cracks or flaws easily form, so the upper limit is made 0.0145%. Preferably, the content is 0.0055 to 0.0135%.

[0086] The present invention has the above composition of ingredients as its basic ingredients, but may further optionally contain other elements. Below, the optional elements will be explained.

[0087] One or more of Ca: 0.0005 to 0.0030%, Zr: 0.0005 to 0.0030%, Te: 0.0005 to 0.0030%, and Ti: 0.005 to 0.050%

55 **[0088]** Ca, Zr, Te, and Ti are all elements refining sulfides. The dispersion of fine sulfides in the present invention prevents the coarsening of the austenite structure right after hot forging and as a result promotes the ferrite transformation.

[0089] Further, by promoting the ferrite transformation, the bainite transformation is suppressed. To expect these effects, Ca, Zr, and Te have to be added in amounts of 0.0005% or more, while Ti has to be added in an amount of 0.005% or more.

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[0090] However, if added in large amounts, the coarse oxides and sulfides formed become causes of a drop in hot ductility and machineability, so the upper limits of Ca, Zr, and Te are made 0.0030% and the upper limit of Ti is made 0.050%.

[0091] Ti has the effect of refining sulfides and suppressing bainite transformation, but preferentially forms nitrides, so if added excessively, reduces the amount of production of V nitrides resulting in the undesirable phenomenon of the reduction in the amount of ferrite. For this reason, when adding Ti, 0.040% or less is more preferable.

Pb: 0.010 to 0.050%

[0092] Pb is added for improving the machineability. However, Pb has the effect of reducing the hot ductility, so is limited to 0.050% or less. To obtain a sufficient effect of improvement of the machineability, 0.010% or more is required.

[0093] Other unavoidably included elements will be explained next.

Al: 0.010% or less

[0094] Al, as shown by the above formula (3) and formula (3'), becomes a factor in the drop of the hot ductility, so is not positively added. Al disperses as Al oxides in the steel and causes a drop in the machineability, so not adding Al is effective for ensuring machineability. Al as an unavoidable impurity is made 0.010% or less.

Cu: 0.15% or less, Ni: 0.15% or less, Mo: 0.01% or less

[0095] Cu, Ni, and Mo are elements which can be freely included. If in fine amounts, they have no particular effect on the quality of the connecting rod, but each raises the quenchability and promotes bainite transformation. To prevent the formation of bainite structures, the Cu and Ni contained as unavoidable impurities are both preferably 0.15% or less, while Mo is preferably 0.01% or less.

[0096] Nb, similar to V, is an element having effects of precipitation strengthening and structure refinement. Part of the V can be replaced by Nb. However, Nb carbonitrides, compared with V carbonitrides, are higher in solution temperature and easily coarsen in the process of production of steel rod materials, so this is not aggressively added in the present invention.

[0097] Above, the present invention was explained focusing on a connecting rod. At the present time, fracture split technology has not spread beyond connecting rods, but the present invention can also be applied, in the same way as to connecting rods, to other parts requiring fastening by accurate dimensional precision and parts which are repeatedly detached and reattached in maintenance work along with requiring assembly precision.

Examples

[0098] Below, examples will be used to explain the present invention in detail.

[0099] Invention steels (Invention Examples 1 to 24) and comparative steels (Comparative Examples 26 to 39 and conventional material) exhibiting the compositions of ingredients shown in Table 1 were melted in a 16 kg vacuum melting furnace to form ingots. These ingots were heated to 1493K, forged to steel rods of diameters of 55 mm, then allowed to cool. These were used as evaluation materials.

Table 1

	No.	C	Si	Mn	P	S	Cr	Al	V	N	Ca	Zr	Te	Ti	Pb
I n v e x t	1	0.23	0.75	0.92	0.045	0.073	0.12	0.005	0.45	0.0084					
	2	0.33	0.80	0.78	0.042	0.045	0.16	0.005	0.27	0.0101					
	3	0.30	0.90	0.90	0.050	0.060	0.20	0.007	0.28	0.0071					
	4	0.35	0.81	0.85	0.057	0.068	0.13	0.005	0.33	0.0075					
	5	0.28	1.05	0.76	0.060	0.075	0.10	0.003	0.37	0.0060					
	6	0.25	0.70	1.17	0.053	0.070	0.05	0.009	0.29	0.0055					
	7	0.31	1.05	0.80	0.040	0.056	0.16	0.008	0.35	0.0072					
	8	0.30	0.91	1.01	0.064	0.085	0.08	0.008	0.37	0.0050					
	9	0.33	0.82	0.79	0.052	0.040	0.12	0.009	0.30	0.0141					
	10	0.30	0.82	1.00	0.047	0.110	0.12	0.006	0.31	0.0088					
	11	0.29	1.28	0.83	0.055	0.055	0.10	0.010	0.27	0.0101					
	12	0.35	0.96	0.81	0.079	0.075	0.10	0.004	0.28	0.0112					
	13	0.31	0.84	0.85	0.055	0.045	0.10	0.006	0.30	0.0076	0.0010				
	14	0.34	0.80	0.86	0.056	0.090	0.07	0.004	0.30	0.0140		0.0022			
	15	0.34	0.80	0.77	0.060	0.070	0.12	0.009	0.28	0.0111			0.0012		
	16	0.30	0.85	0.80	0.044	0.080	0.14	0.008	0.30	0.0090				0.032	
	17	0.30	0.83	0.98	0.045	0.074	0.12	0.005	0.41	0.0135	0.0026	0.0009			
	18	0.28	0.99	0.95	0.045	0.086	0.09	0.004	0.35	0.0142		0.0027	0.0018		
	19	0.33	0.85	0.79	0.066	0.055	0.12	0.001	0.27	0.0075	0.0009			0.025	
	20	0.32	1.03	1.10	0.062	0.074	0.08	0.004	0.35	0.0092	0.0017		0.0015		
	21	0.33	0.87	0.82	0.049	0.071	0.09	0.004	0.32	0.0075	0.0013	0.0007	0.0012		
	22	0.34	1.04	0.76	0.060	0.074	0.12	0.003	0.30	0.0055	0.0006		0.0025		
	23	0.33	1.02	0.80	0.047	0.060	0.13	0.010	0.28	0.0135	0.0020		0.0011		0.035
	24	0.32	1.05	0.77	0.055	0.045	0.13	0.007	0.28	0.0099		0.0018			0.047
	Conv. mat. (C70S6)	0.68	0.16	0.49	0.009	0.064	0.12	0.003	0.03	0.0012					

(continued)

	No.	C	Si	Mn	P	S	Cr	Al	V	N	Ca	Zr	Te	Ti	Pb
C o m p o s i t i o n s	26	0.20	0.50	1.04	0.053	0.083	0.19	0.009	0.45	0.0052					
	27	0.31	0.82	1.36	0.044	0.065	0.08	0.010	0.39	0.0120					
	28	0.53	0.67	0.82	0.054	0.093	0.10	0.010	0.21	0.0055					
	29	0.30	1.50	0.99	0.062	0.151	0.09	0.007	0.20	0.0130					
	30	0.32	0.82	0.85	0.151	0.098	0.20	0.007	0.36	0.0074					
	31	0.28	0.85	0.80	0.055	0.075	0.14	0.044	0.29	0.0223					
	32	0.23	0.65	1.15	0.041	0.045	0.52	0.005	0.31	0.0020					
	33	0.28	0.74	0.77	0.063	0.043	0.07	0.002	0.31	0.0072	0.0052				
	34	0.35	0.98	0.79	0.042	0.045	0.05	0.008	0.38	0.0134		0.0055			
	35	0.29	1.02	0.88	0.055	0.056	0.10	0.008	0.41	0.0066			0.0070		
	36	0.30	1.01	0.89	0.055	0.055	0.10	0.006	0.36	0.0060	0.0040	0.0012			
	37	0.29	0.98	0.85	0.057	0.055	0.11	0.004	0.37	0.0073	0.0016	0.0021	0.0052		
	38	0.25	0.99	0.90	0.063	0.088	0.09	0.004	0.28	0.0111					0.145
39	0.27	1.01	0.80	0.062	0.111	0.20	0.042	0.32	0.0050						

[0100] First, the hot ductility right after melting and solidifying the material was evaluated by a hot tensile test. The test piece was made a rod shape of a diameter of 1.0 mm and a length of 100 mm, the center of the test piece was covered by a quartz tube, and a thermocouple was attached.

5 [0101] This was attached to an ohmic heating device provided with a tensile device, was ohmically heated to melt the center of the test piece while cooling the two ends by a copper water cooling zone, was held there for 60 seconds, then was cooled by 10K/s to 1273K to solidify, was held at 1273K for 30 seconds, was broken by tension by a tensile rate of 0.005 mm/s, and was measured for the drawing value after breakage.

[0102] Further, to investigate the structure, mechanical characteristics, and fractureability of a connecting rod using a steel rod material, a test piece corresponding to a forged connecting rod was fabricated by hot forging.

10 [0103] Specifically, a steel rod material of a diameter of 55 mm was heated to 1503K, then forged vertically to the length direction of the steel rod to reduce the thickness to 20 mm, then was cooled by air blast cooling to room temperature. During the cooling, the average cooling rate from 1073K to 673K was 1.7K/s.

[0104] From the cooled forged material, (1) a tensile test piece and (2) a fracture test piece of a shape corresponding to the large end of a connecting rod were formed. The shape and dimensions of the fracture test piece of the shape

15 corresponding to the large end of a connecting rod are shown in FIG. 1.
[0105] As shown in FIG. 1(a), the test piece 1 is an 80 mmx80 mm, thickness 18 mm plate shape at the center of which a hole 2 of a diameter 50 mm is formed. On the inside surface of the diameter 50 mm hole, 45° V-notches 3 of a depth of 1.0 mm and a front end rate of curvature of 0.5 mm were formed at two locations facing each other across 180° in a direction vertical to the length direction of the steel rod material before forging.

20 [0106] Furthermore, as shown in FIG. 1(b), a through hole 4 of a diameter 8.0 mm was formed so that its center line became a position 8.0 mm from the side surface of the notched side.

[0107] The test apparatus is consisted of a split die and a falling weight tester. The split die is consisted of a rectangular steel material on which is formed a cylinder split into two along the center line with one end fixed in place and the other end movable on a rail. At the mating surfaces of the two half cylinders, a shim hole is formed.

25 [0108] At the time of a fracture test, the test piece is fit in this split die, a shim is inserted, and the assembly is placed under a falling weight. The falling weight has a weight of 200 kg and is designed to fall along a guide.

[0109] When falling the falling weight, the shim is driven in and the test piece is broken into two by tension. Note that, to prevent the test piece from flying from the split die at the time of fracture, the test piece is fastened at its surroundings so as to be pressed against the split die.

30 [0110] In the examples, the test piece was fractured by a falling weight height of 100 mm, the fractured pieces of the test piece were aligned and bolted, and the changes in inside diameter in the fracture direction and direction vertical to the fracture direction were measured.

[0111] Further, for the cross-section 5 mm from the fracture face, an optical microscope was used to measure the ferrite volume percentage and the same method as the above method was used to observe the microstructure and judge

35 the presence of any bainite structures.
[0112] That is, the structure corroded by a dilute solution of nitric acid alcohol (Nital) was observed under an optical microscope at a power of 200X, then the number of white irregularly shaped grains with fine amounts of precipitated carbides were counted as bainite grains.

[0113] A ratio of less than 3% of bainite grains in the total number of proeutectoid ferrite grains and bainite grains was judged as no bainite structures and defined as ferrite-pearlite.

40 [0114] Table 2 shows the K value, F value, and R value and also the drawing value at the time of a hot tensile test, the presence of bainite in a material reproducing a forged connecting rod, the results of a tensile test at ordinary temperature, and the amount of deformation after a fracture test (total of amounts of change of inside diameter in XY directions).

Table 2

	No.	K value	F value	R value	Bainite	Ferrite frac. (%)	Drawing (%)	0.2% YS (MPa)	TS (MPa)	X-dir. deform. (μm)	Y-dr. deform. (μm)	Deform. (μm)
I n v e x t	1	1.07	2.6	44	No	68	45	759	954	43	36	79
	2	0.82	2.6	50	No	72	54	713	885	52	47	99
	3	1.02	2.6	48	No	68	48	737	918	50	43	93
	4	0.87	2.8	44	No	65	44	789	981	42	33	75
	5	0.77	2.4	36	No	71	37	750	940	35	32	67
	6	1.30	2.6	56	No	70	55	710	881	53	47	100
	7	0.88	2.6	44	No	66	47	770	958	42	36	78
	8	1.07	2.7	43	No	65	47	819	1001	39	30	69
	9	0.77	2.6	51	No	68	46	706	890	51	46	97
	10	1.10	2.7	35	No	64	40	749	925	36	31	67
	11	0.80	2.3	44	No	73	41	736	903	47	40	87
	12	0.72	2.5	40	No	69	40	756	925	42	33	75
	13	0.87	2.5	52	No	67	55	723	908	53	42	95
	14	0.81	2.6	37	No	68	37	749	947	38	30	68
	15	0.73	2.5	40	No	67	39	716	882	43	40	83
	16	0.85	2.5	38	No	72	37	724	884	43	34	77
	17	1.07	2.8	46	No	67	43	795	998	43	33	76
	18	0.99	2.5	40	No	68	36	736	928	39	37	76
	19	0.77	2.5	48	No	68	52	693	865	52	47	99
	20	1.15	2.8	50	No	66	49	794	988	45	40	85
	21	0.82	2.6	42	No	70	38	777	954	42	33	75
	22	0.74	2.6	38	No	71	40	759	940	38	31	69
	23	0.78	2.5	40	No	71	41	734	898	44	36	80

(continued)

	No.	K value	F value	R value	Bainite	Ferrite frac. (%)	Drawing (%)	0.2% YS (MPa)	TS (MPa)	X-dir. deform. (μm)	Y-dr. deform. (μm)	Deform. (μm)
	24	0.75	2.4	44		70	40	736	929	42	40	82
	Oonv.mat. (C70S6)	0.32	3.6	41	No	12	38	622	995	995	71	71
C o m p . e x .	26	1.32	2.7	47	Yes	68	39	723	918	143	122	265
	27	1.53	3.2	63	Yes	55	50	844	1056	169	151	320
	28	0.71	3.3	36	No	15	34	678	967	94	83	177
	29	0.94	2.2	17	No	77	15	720	905	21	9	30
	30	0.78	2.6	33	No	70	27	748	955	109	105	214
	31	0.77	2.3	34	No	72	33	709	892	40	36	76
	32	1.71	3.2	65	Yes	57	60	704	895	150	134	284
	33	0.75	2.3	51	No	74	33	692	874	62	4G	108
	34	0.72	2.7	48	No	69	32	786	1017	35	31	66
	35	0.93	2.6	47	No	66	29	771	994	39	31	70
	36	0.93	2.6	48	No	67	30	745	966	45	40	85
	37	0.89	2.6	47	No	68	26	727	944	45	41	86
38	0.91	2.2	26	No	78	23	657	840	102	81	183	
39	0.90	2.5	21	No	74	15	688	883	116	94	210	

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5 [0115] Nos. 1 to 24 are invention examples. In each case, no bainite structure was formed, the ferrite fraction was 61% or more, and the drawing value at a hot tensile test was a good 37% or more. Further, the tensile strength at the ordinary temperature tensile test and the 0.2% yield strength were respectively 865 MPa or more and 693 MPa or more. The 850 MPa or more tensile strength and the 650 MPa or more 0.2% yield strength aimed at by the present invention are realized.

[0116] As opposed to this, the conventional steel C70S6 has a large C content, so the tensile strength (TS) is a high 995 MPa, but the 0.2% yield strength is a low 622 MPa.

10 [0117] In the comparative steels of Nos. 26 to 39, in the large K value Nos. 26, 27, and 32, the bainite structure transforms and the amount of deformation at the fracture test becomes larger. Further, Nos. 27, 28, and 32 have large F values, low ferrite fractions, and again large amounts of fracture deformation.

[0118] Nos. 29, 30, 31, 38, and 39 are all low in R value and have drawing values in a hot tensile test of less than 35%, so production of an industrial steel material is difficult. Nos. 33 to 37 are large in R value, but have Ca, Zr, and/or Te added in large amounts, so the drawing value at the time of a hot tensile test is low.

15 Industrial Applicability

20 [0119] As explained above, the high strength fracture splitting use non-heat treated steel of the present invention is superior in hot ductility, becomes a stable ferrite-pearlite structure when hot forging, then air cooling or air blast cooling, and is superior in fracture splittability. Further, the steel part produced from the high strength fracture splitting use non-heat treated steel of the present invention is high in strength, small in amount of deformation at the time of fracture, and has a superior fracture splittability and further sufficiently provides the hot ductility required at the time of production. Accordingly, the present invention is high in industrial applicability.

25 Reference Signs List

[0120]

- 30 1 test piece
2 hole
3 V notch
4 through hole

35 Claims

1. High strength fracture splitting use non-heat treated steel **characterized by** containing, by mass%,
C: 0.23 to 0.35%,
Si: 0.70 to 1.30%,
Mn: 0.76 to 1.17%,
40 P: 0.040 to 0.080%,
S: 0.040 to 0.118%,
Cr: 0.05 to 0.20%,
Al: 0.010% or less,
V: 0.27 to 0.45%, and
45 N: 0.0050 to 0.0145%, having a balance of Fe and unavoidable impurities, and
having a K value defined by the following formula (1) of 1.3 or less, an F value defined by the following formula (2)
of 3.0 or less, and an R value defined by the following formula (3) of 35 or more:

50
$$K = -0.56 \times \%C - 0.07 \times \%Si + 1.3 \times \%Mn + 0.80 \times \%Cr - 1.80 \times \%P + 0.19 \%V - 5.6 \times \%N \dots (1)$$

55
$$F = 4.3 \times \%C - 0.21 \times \%Si + 1.0 \times \%Mn + 1.4 \times \%Cr - 1.90 \times \%P + 1.8 \%V - 6.6 \times \%N \dots (2)$$

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$$R=46.7-7.4\times\%Si+37.7\times\%Mn-349\times\%S-12.0\times\%V-174\times\%Al\cdots(3)$$

5 where, %C, %Si, %Mn, %Cr, %P, %V, %N, and %S are contents in the steel (mass%), and %Al is the content as an impurity (mass%).

2. High strength fracture splitting use non-heat treated steel as set forth in claim 1 **characterized by** further containing, by mass%, one or more of any of

Ca: 0.0005 to 0.0030%,

10 Zr: 0.0005 to 0.0030%,

Te: 0.0005 to 0.0030%, and

Ti: 0.005 to 0.050%.

3. High strength fracture splitting use non-heat treated steel as set forth in claim 1 or 2 **characterized by** further containing, by mass%,

15 Pb: 0.010 to 0.050%

and by having an R value defined, instead of by the above formula (3), by the following formula (3') of 35 or more.

20
$$R=46.7-7.4\times\%Si+37.7\times\%Mn-349\times\%S-12.0\times\%V-174\times\%Al-$$

$$86.6\times\%Pb\cdots(3')$$

25 where, %Si, %Mn, %S, %V, and %Pb are contents in the steel (mass%) and %Al is the content as an impurity (mass%)

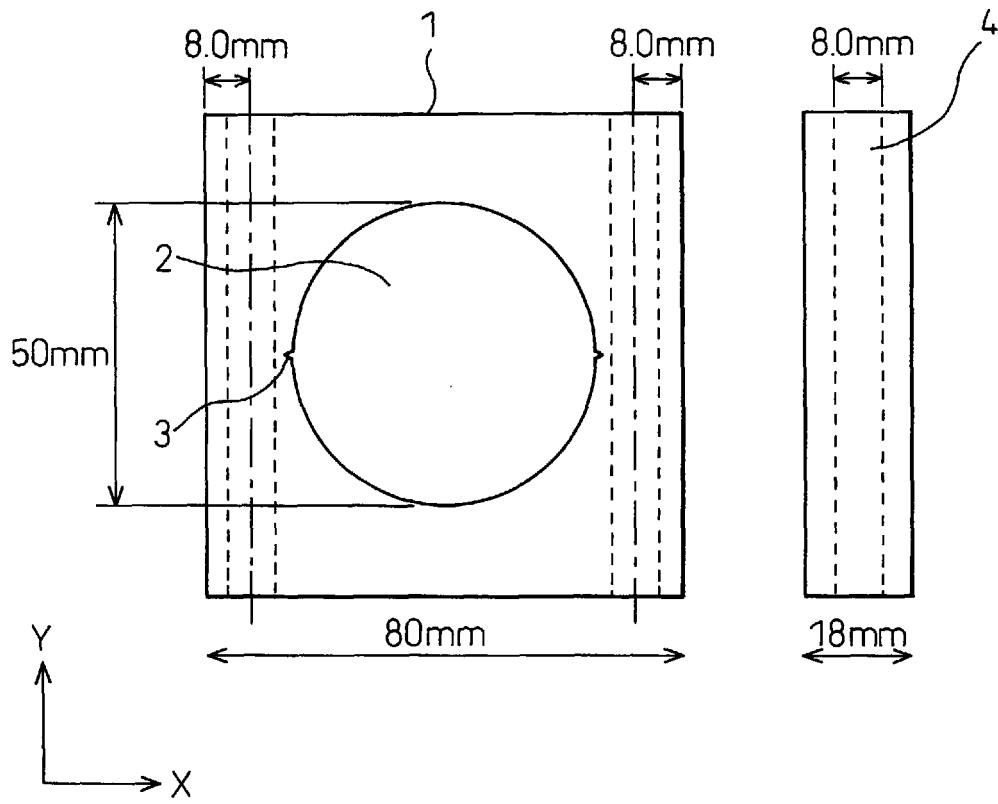
4. A high strength fracture splitting use steel part produced by hot forging and cooling high strength fracture splitting use non-heat treated steel as set forth in any of claims 1 to 3, said steel part **characterized in that** the cooled steel composition is a ferrite-pearlite structure.

5. A high strength fracture splitting use steel part as set forth in claim 4 **characterized in that** said steel composition has a ferrite volume fraction of 60% or more.

Fig.1

(a)

(b)



INTERNATIONAL SEARCH REPORT

International application No.
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<p>A. CLASSIFICATION OF SUBJECT MATTER C22C38/00(2006.01)i, C22C38/38(2006.01)i, C22C38/60(2006.01)i</p> <p>According to International Patent Classification (IPC) or to both national classification and IPC</p>																				
<p>B. FIELDS SEARCHED</p> <p>Minimum documentation searched (classification system followed by classification symbols) C22C1/00-49/14</p> <p>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</p> <p>Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)</p>																				
<p>C. DOCUMENTS CONSIDERED TO BE RELEVANT</p> <table border="1"> <thead> <tr> <th>Category*</th> <th>Citation of document, with indication, where appropriate, of the relevant passages</th> <th>Relevant to claim No.</th> </tr> </thead> <tbody> <tr> <td>A</td> <td>JP 9-176785 A (Sumitomo Metal Industries, Ltd.), 08 July 1997 (08.07.1997), entire text (Family: none)</td> <td>1-5</td> </tr> <tr> <td>A</td> <td>JP 2007-277705 A (Kobe Steel, Ltd.), 25 October 2007 (25.10.2007), entire text & US 2009/0047169 A1 & EP 2000553 A1 & WO 2007/108365 A1</td> <td>1-5</td> </tr> <tr> <td>A</td> <td>JP 2006-206934 A (Daido Steel Co., Ltd.), 10 August 2006 (10.08.2006), entire text (Family: none)</td> <td>1-5</td> </tr> </tbody> </table> <p><input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.</p> <p>* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family</p> <table border="1"> <tr> <td>Date of the actual completion of the international search 26 October, 2009 (26.10.09)</td> <td>Date of mailing of the international search report 02 November, 2009 (02.11.09)</td> </tr> <tr> <td>Name and mailing address of the ISA/ Japanese Patent Office</td> <td>Authorized officer</td> </tr> <tr> <td>Facsimile No.</td> <td>Telephone No.</td> </tr> </table>			Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.	A	JP 9-176785 A (Sumitomo Metal Industries, Ltd.), 08 July 1997 (08.07.1997), entire text (Family: none)	1-5	A	JP 2007-277705 A (Kobe Steel, Ltd.), 25 October 2007 (25.10.2007), entire text & US 2009/0047169 A1 & EP 2000553 A1 & WO 2007/108365 A1	1-5	A	JP 2006-206934 A (Daido Steel Co., Ltd.), 10 August 2006 (10.08.2006), entire text (Family: none)	1-5	Date of the actual completion of the international search 26 October, 2009 (26.10.09)	Date of mailing of the international search report 02 November, 2009 (02.11.09)	Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer	Facsimile No.	Telephone No.
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REFERENCES CITED IN THE DESCRIPTION

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