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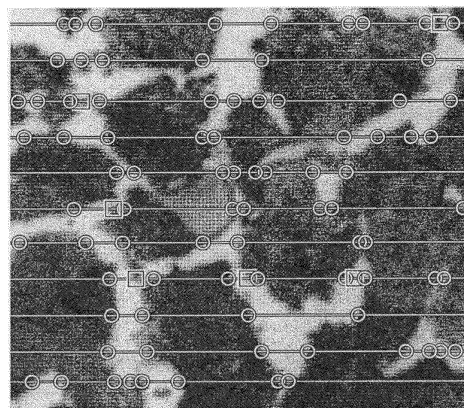
(54) **STEEL FOR MECHANICAL STRUCTURES WHICH HAS EXCELLENT MACHINABILITY**

(57) A steel for mechanical structures has a mixed texture which is composed of a hard phase comprising at least one texture selected from pearlite, bainite and martensite and a ferrite phase, wherein the average equivalent circle diameter of ferrite grains is 7 μm or less and the (ferrite grain) - (ferrite grain) connection rate (X)

which is expressed by formula (1) is 0.15 or less. (1):
[(Ferrite grain) - (ferrite grain) connection rate (X)] = [the number (A) of (ferrite grain) - (ferrite grain) boundary surfaces] / [the number (B) of (ferrite grain) - (hard phase) boundary surfaces]

FIG. 2A

(FERRITE GRAIN)-(FERRITE GRAIN) CONNECTION RATE $X \leq 0.15$



WHITE PART: FERRITE GRAIN, GRAY-BLACK PART: HARD PHASE
□ : (FERRITE GRAIN)-(FERRITE GRAIN) BOUNDARY
○ OUTLINED WHITE PART: (FERRITE GRAIN)-(HARD PHASE) BOUNDARY

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Description

Technical Field

5 **[0001]** The invention relates to a steel for use in machine-construction, to be used in manufacturing various machine-construction parts, including an automotive part, and a construction machinery part, etc. and in particular, to a steel for use in machine-construction, having excellent machinability such that a machined cut-surface roughness can be reduced.

Background Art

10 **[0002]** In general, the various parts for use in machine-construction, such as an automotive part, and a construction machinery part, etc., are each finished in a final shape by applying forging, and so forth to a steel for use in machine-construction to be followed by a cutting operation. At the time of applying the cutting operation, a steel for use in machine-construction, exhibiting excellent machinability, is required from the viewpoint of part accuracy and manufacturing efficiency. With respect to a steel material for use in a forming tool, in particular, requirements for machined cut-surface roughness have become severe, so that there is a demand for a steel for use in machine-construction, capable of securing the machined cut-surface roughness, smaller in size. If the machined cut-surface roughness becomes larger (more rough), this will raise needs for applying further finishing to a surface state by grinding, and so forth, thereby creating a problem in that a manufacturing process becomes complicated.

20 **[0003]** With respect to the steel for use in machine-construction, exhibiting excellent machinability, there have thus far been proposed a variety of techniques. For example, in Patent Literature 1, there is shown one of these techniques, indicating that if the content of an element, such as C, Mn, P, S, Pb, O, Si, Al, etc., in a leaded free-cutting steel, low in respect of carbon and sulfur, is specified, while specifying an average size of an MnS based inclusion, and a proportion of a sulfide not bonded with an oxide, this will enable machinability to be improved. Furthermore, excellent machined cut-surface roughness can also be obtained.

25 **[0004]** With this technique, lead (Pb), as a useful element for improvement of machinability, is contained in the basic components. Lead is well known as the element for use in improving machinability, however, harmful effects of Pb on the human body and environments are pointed out, and it is lately required to exhibit excellent machinability without addition of Pb.

30 **[0005]** Under such circumstances described as above, progress has since been made in the development of a technique capable of exhibiting excellent machinability without positive addition of Pb. For example, in Patent Literature 2, there is disclosed that excellent machinability equivalent to that of a Pb-added steel can be obtained by composite addition of S, Te, and Ca. Further, it is disclosed that machinability can be further improved by addition of Bi or a rare-earth element (REM) in the case of this technique.

35 **[0006]** Unfortunately, since a machinability-enhancing element (a free-cutting element), such as Te, Bi, and REM, etc., is expensive, and an increase in manufacturing cost will pose a problem.

40 **[0007]** On the other hand, in Patent Literature 3, there is proposed a free-cutting steel for use in machine-construction, exhibiting the respective characteristics of the mechanical property of a steel material, and the chip-segmentation property thereof by causing a predetermined content of Mg to be contained under the presence of a sulfide-based inclusion. With this technique, Mg is added in order to control the sulfide-based inclusion to be kept in a predetermined shape and dispersed state. However, Mg being a strong deoxidizing element in addition to Mg being susceptible to evaporation because of a low boiling point, the steel in its oxide form is susceptible to be separated from a molten steel. For this reason, a yield becomes low, thereby resulting in a situation where an increase in cost is unavoidable.

45 Citation List

Patent Literature

[0008]

50 Patent Literature 1: Japanese Unexamined Patent Application Publication No. S 62 (1987)-23970
 Patent Literature 2: Japanese Unexamined Patent Application Publication No. 2004-292929
 Patent Literature 3: Japanese Unexamined Patent Application Publication No. 2002-69569

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Summary of Invention

Technical Problem

5 **[0009]** The present invention has been developed under such circumstances described as above, and it is an object of the invention to provide a steel for use in machine-construction, capable of exhibiting excellent machinability, in spite of a normal chemical composition thereof, without use of Pb having harmful effects on the human body, and an expensive free-cutting element, the steel being excellent in machined cut-surface roughness, in particular.

10 Solution to Problem

[0010] According to the present invention which can achieve the above object, a steel for use in machine-construction has a mixed microstructure including a hard phase composed of at least one species selected from the group consisting of pearlite, bainite, and martensite, and a ferrite phase. The gist of the present invention lies in that an average equivalent circle diameter of ferrite grains is 7 μm or less, and a [(ferrite grain) - (ferrite grain) connection rate X], as expressed by an equation (1) described hereunder, is 0.15 or less provided that [(ferrite grain) - (ferrite grain) connection rate X] = [the number (A) of [(ferrite grain) - (ferrite grain) interface surfaces]] / [the number (B) of [(ferrite grain) - (hard phase) interface surfaces]] ... (1), and [the number (A) of [(ferrite grain) - (ferrite grain) interface surfaces]], in the equation, indicates the number of intersection points between a straight line and [the (ferrite grain) - (ferrite grain) interfaces], at the time of drawing a predetermined straight line across a photograph taken by use of a scanning electron microscope, whereas the number (B) of [(ferrite grain) - (hard phase) interface surfaces] indicates the number of intersection points between the straight line and the [(ferrite grain) - (hard phase) interfaces], at the time of drawing a predetermined straight line in the same way as described above.

[0011] By "average equivalent circle diameter" is meant an average value of the respective diameters of ferrite crystal grains (equivalent circle diameters) if the ferrite crystal grain is converted into a circle equivalent thereto in area.

[0012] With respect to the chemical component composition of the steel for use in machine-construction, according to the present invention, there is no particular limitation thereto in the case of a steel for use in machine-construction, however, a preferable chemical component composition may include C: 0.2 to 1.2% (mass %, the same applies to chemical component composition hereinafter), Si: 0.05 to 0.5%, Mn: 0.2 to 1.8%, P: 0.03% or less (excluding 0%), and S: 0.03% or less (excluding 0%), the balance being iron and unavoidable impurities.

[0013] The preferable chemical component composition may further include at least one species of element selected from the group consisting of Cr: 0.5% or less (excluding 0%), Cu: 0.5% or less (excluding 0%), Ni: 0.5% or less (excluding 0%), and Mo: 0.5% or less (excluding 0%), as necessary, which is effective, and the characteristics of the steel for use in machine-construction are further improved depending on the species of the element contained.

[0014] According to the invention, there is provided a method for improving the machined-surface characteristics, and a steel product whose machined-surface characteristics is improved can be obtained by cutting the steel for use in machine-construction, described as above.

[0015] According to the invention, there is provided a method for manufacturing a forming tool, having excellent surface characteristics, whereby the forming tool can be efficiently manufactured by cutting the steel for use in machine-construction, according to the invention, without application of a finish processing, such as grinding, etc., thereto.

Advantageous Effects of Invention

[0016] With the present invention, it is possible to realize a steel for use in machine-construction, having a mixed microstructure including a hard phase composed of at least one species selected from the group consisting of pearlite, bainite, and martensite and a ferrite phase, by specifying that an average equivalent circle diameter of ferrite grains is 7 μm or less, and a [(ferrite grain) - (ferrite grain) connection rate X] is expressed by a prescribed relational expression, thereby enabling the steel to exhibit superior machinability, and excellent machined cut-surface roughness, in particular.

50 Brief Description of Drawings

[0017]

Fig. 1A is a schematic diagram for depicting a relationship between the microstructure of a steel material and the machined cut-surface roughness thereof, being a view showing the initial state of a cutting operation.

Fig. 1B is a schematic diagram for depicting a relationship between the microstructure of the steel material and the machined cut-surface roughness thereof, being a view showing a state of the cutting operation, halfway through thereof.

Fig. 1C is a schematic diagram for depicting a relationship between the microstructure of the steel material and the machined cut-surface roughness thereof, being a view showing a state of the cutting operation, after the completion thereof.

Fig. 2A is a drawing-substitute photograph, showing a procedure for finding a [(ferrite grain)-(ferrite grain) connection rate X], being a view showing the case of $X \leq 0.15$.

Fig. 2B is a drawing-substitute photograph, showing a procedure for finding a [(ferrite grain)-(ferrite grain) connection rate X], being a view showing the case of $X \geq 0.15$.

Description of Embodiments

[0018] In order to realize a steel for use in machine-construction, capable of obtaining excellent machined cut-surface roughness, in spite of a normal chemical composition thereof, the inventor of the present invention, et al, have continued studies on a relation of the steel with a metal microstructure thereof, in particular. As a result, they have come up with an idea that one of the causes of deterioration in the machined cut-surface roughness at the time of a cutting operation is the presence of phases differing in hardness from each other, in a mixed state, inside a microstructure. This state is described hereunder with reference to the drawings.

[0019] Figs. 1A through 1C each are a schematic diagram for depicting a relationship between the microstructure of a steel material and the machined cut-surface roughness thereof. In the figure, reference numeral 1 denotes a ferrite phase, and reference numeral 2 denotes a hard phase (a hard phase composed of at least one species selected from the group consisting of pearlite, bainite, and martensite), respectively. The steel material is of a mixed-microstructure construction, in which these phases are present in a mixed state. In the figure, a portion of the steel material, on the upper side thereof, indicates the upper surface of the steel material to be cut. At the time of a cutting operation, the ferrite phase 1 that is soft in the mixed-microstructure construction undergoes deformation as if pushed out by the hard phase 2, as shown in Fig. 1A. Subsequently, the ferrite phase 1, in a such state as to be pushed out, is removed by a cutting edge (the tip) of a tool, as shown in Fig. 1B. On a surface (a worked surface) where the cutting edge of the tool has passed through, the ferrite phase 1 is deformed in such a way as to be retracted, by the agency of elastic recovery of the hard phase 2, as shown in Fig. 1C, so that a recess 3 occurs to the ferrite phase 1 on the worked surface, and thereby the worked the surface roughness of the steel material will undergo deterioration due to the presence of this recess.

[0020] The inventor of the present invention, et al, have proceeded to make further studies on the requirements for obtaining excellent machined cut-surface roughness, on the basis of the idea described as above. As a result, they have found out that if the average equivalent circle diameter of the ferrite grains is set in a predetermined range, and each portion where the ferrite grains are connected to each other is reduced in number, this will enable the steel for use in machine-construction, capable of obtaining excellent machined cut-surface roughness to be realized, whereupon the present invention has been completed.

[0021] Respective requirements specified by the present invention are described hereunder.

[0022] In order to inhibit formation of the recess on the worked surface, it is necessary to cause the soft ferrite phases to be finely dispersed. With the microstructure in which the ferrite phases are finely dispersed, the individual phases become smaller in size, and therefore, the volume of one soft phase, when pushed out by a phase that is harder (the hard phase), will be smaller, and the recess occurring on the worked surface, as well, will be smaller. As a result, there is developed a state in which minute asperities are dispersed, thereby improving the worked surface roughness.

[0023] In order to cause soft ferrite phases to be in a finely dispersed state, it is necessary to render the size of a ferrite grain (the grain size) as small as possible. With the steel for use in machine-construction, according to the invention, in order to ensure a desired dispersed-state of ferrites, the size (the grain size) of a ferrite grain need be $7 \mu\text{m}$ or less in terms of the average equivalent circle diameter. Further, the average equivalent circle diameter of the ferrites (the ferrite grains) is preferably $6 \mu\text{m}$ or less, and more preferably $5 \mu\text{m}$ or less. Still further, a preferable lower limit of the average equivalent circle diameter of the ferrites (the ferrite grains) is not less than $2 \mu\text{m}$.

[0024] However, just to specify only the size of the ferrite grain is insufficient to attain the object of the present invention. The reason for this is because there is a possibility of occurrence of a phenomenon in which the ferrite grains, each thereof being small in grain size, are connected to each other. If such a phenomenon described as above occurs, a plurality of the ferrite grains are gathered together to thereby indicate a state as if those ferrite grains behave as a large chunk of aggregated ferrite grains, so that the ferrite grains grouped together, as a whole, will be pushed out by the phase (the hard phase) harder than the ferrite phase. This state appears as if there had occurred a phenomenon equivalent to the phenomenon in which a ferrite grain large in grain size exists (the phenomenon causing deterioration in the machined cut-surface roughness).

[0025] In contrast, in the case where the ferrite grain small in grain size is surrounded by the hard phases, the volume of the ferrite phase, pushed out at a site of the ferrite grain, is reduced, thereby causing the recess formed after the cutting operation to be miniaturized, so that the worked surface roughness is rendered excellent. Further, in the strict

sense, the pearlite indicates a microstructure having a construction in which ferrite and cementite sheet-like in shape are alternately, and lamellarly arranged, however, such a microstructure as described above is en bloc referred to as "pearlite" herein. Further, the ferrite as the target of the present invention is a phase appearing white in a scanning electron microscope image upon nital etching being applied thereto, by disregarding the lamellar ferrite in the pearlite.

[0026] With the present invention, in order to determine whether or not the ferrite grain small in grain size exists in such a state as to be surrounded by the hard phases, a concept referred to as a [(ferrite grain) - (ferrite grain) connection rate X] is specified to be used for assessment. The [(ferrite grain) - (ferrite grain) connection rate X] is expressed by the following equation (1).

$$\text{[(ferrite grain) - (ferrite grain) connection rate X]} = [\text{the number (A) of [(ferrite grain) - (ferrite grain) interface surfaces]}] / [\text{the number (B) of [(ferrite grain) - (hard phase) interface surfaces]}] \dots (1)$$

[0027] At the time of drawing a predetermined straight line across a photograph taken by use of a scanning electron microscope, [the number (A) of (ferrite grain) - (ferrite grain) interface surfaces], in the equation, indicates the number of intersection points between the straight line and [the (ferrite grain) - (ferrite grain) interface surfaces], whereas the number (B) of [(ferrite grain) - (hard phase) interface surfaces] indicates the number of intersection points between the straight line and the [(ferrite grain) - (hard phase) interface surfaces], at the time of drawing a predetermined straight line in the same way as described above.

[0028] A procedure for finding the [(ferrite grain) - (ferrite grain) connection rate X] is described hereunder with reference to the drawings. First, a metal microstructure is portrayed and subsequently, a microstructure observation is made by use of the scanning electron microscope (SEM). Horizontal line-segments are drawn across an observation surface at regular intervals of 5 μm such that the total length (lengths in total) of the horizontal line-segments is not less than 1000 μm , as shown in each of Figs. 2A, 2B, (the drawing-substitute photographs), to thereby find the number of the intersection points (surrounded by $\square$) between each of the line-segments and an interface between the ferrite grains adjacent to each other, and the number of the intersection points [a part surrounded by $\bigcirc$ (white outlined)], that is, the number (B) of the [(ferrite grain) - (hard phase) interfaces], respectively. Subsequently, [the (ferrite grain) - (ferrite grain) connection rate X] is calculated on the basis of the equation (1). An observation area at the time of conducting an observation is preferably not less than 40,000 μm^2 from the viewpoint of ensuring higher accuracy. Further, the total length (lengths in total) of the line-segments horizontally drawn at the equal intervals is preferably not less than 1000 μm for the same reason described as above.

[0029] If the value of the [(ferrite grain) - (ferrite grain) connection rate X], specified as above, is small, this indicates that a region where the ferrite grains successively exist is less in number, in other words, this indicates that the ferrite grains do not successively exist, and each of the ferrite grains is surrounded by a hard phase to be thereby isolated from each other so as to be in a dispersed state. Conversely, if the value of the [(ferrite grain) - (ferrite grain) connection rate X], is large, this indicates that the region where the ferrite grains successively exist is more in number, in other words, the ferrite grains are susceptible to form a large aggregated phase.

[0030] Fig. 2A shows a working example in which the [(ferrite grain) - (ferrite grain) connection rate X] was 0.15 or less, and Fig. 2B shows a working example in which the [(ferrite grain) - (ferrite grain) connection rate X] exceeded 0.15.

[0031] In order to obtain excellent worked-surface roughness, the [(ferrite grain) - (ferrite grain) connection rate X] need be 0.15 or less. The [(ferrite grain) - (ferrite grain) connection rate X] is preferably 0.13 or less, and more preferably 0.10 or less.

[0032] With the steel for use in machine-construction, according to the present invention, the object of the invention is attained by satisfying the requirements described as above, and there is no limitation to a ferrite area percentage (a ferrite-area fraction of the microstructure as a whole), however, an area % on the order of 30 through 80 is preferable from the viewpoint of an increase in ductility due to an increase in the ferrite area percentage, an increase in tool abrasion, due to an increase in the hardness of the steel material, caused by lowering of the ferrite area percentage, and so forth. The area % on the order of 40 through 70 is more preferable.

[0033] The invention has been developed assuming that a steel in use is the steel for use in machine-construction, and as for the steel grade thereof, a steel grade of a normal chemical component composition, for use in machine-construction may be used. With respect to elements including C, Si, Mn, P, and S, it is recommendable to adjust the content of each of the elements so as to fall within an appropriate range. The respective appropriate ranges of these chemical components, and reasons for setting these ranges, from such a point of view, are described as follows.

(C: 0.2 to 1.2%)

[0034] C is an element effective for securing the strength of a steel component manufactured from the steel for use in machine-construction. If a C-content is excessively low, it will be difficult to adjust a steel material such that the [(ferrite grain) - (ferrite grain) connection rate X] falls within the specified range, whereas if the C-content is excessively high, hardness will become excessively high, thereby deteriorating machinability (for example, a tool life). For this reason, the C-content is preferably set to not less than 0.2% (more preferably not less than 0.25%), and 1.2% or less (more preferably, 1.1% or less).

(Si: 0.05 to 0.5%)

[0035] Si, as a deoxidizing element, is contained in the steel for use in machine-construction, for the purpose of increasing the strength of a steel component, due to solid solution hardening, and if an Si content is less than 0.05%, such an advantageous effect as described cannot be effectively exhibited, whereas if Si in excess of 0.5% is contained, this will cause hardness to excessively rise, thereby deteriorating machinability (for example, the tool life). Further, a more preferable lower limit of the Si content is not less than 0.1%, while a more preferable upper limit thereof is 0.4% or less.

(Mn: 0.2 to 1.8%)

[0036] Mn is effective as a deoxidizing and desulfurizing element, in molten steel, while being an element effective for enhancing hardenability to thereby increase the strength of a steel component. If an Mn content is less than 0.2%, these effects cannot be exhibited, whereas if Mn in excess of 1.8% is contained, this will cause hardness to excessively rise, thereby deteriorating cold workability. Further, a more preferable lower limit of the Mn content is not less than 0.3%, and a more preferable upper limit thereof is 1.5% or less.

(P: 0.03% or less) (excluding 0%)

[0037] P is an element unavoidably contained in steel to be segregated at a ferrite grain boundary, thereby deteriorating cold workability. Accordingly, P is preferably lowered as much as possible, however, an attempt to cause extreme reduction in P-content will invite an increase in steel-making cost, so that it is difficult to lower the P-content down to 0% from a manufacturing point of view. Therefore, the P-content is preferably set to 0.03% or less (excluding 0%). An upper limit of the P-content is more preferably 0.025% or less.

(S: 0.03% or less) (excluding 0%)

[0038] S is an element unavoidably contained in steel, as in the case of P, being a detrimental element that exists in steel, in the form of MnS, thereby deteriorating cold workability, so that it is necessary to reduce S as much as possible. An S content is preferably 0.03% or less from such a point of view, (more preferably 0.025% or less). However, S being an unavoidably contained impurity, it is industrially difficult to reduce the S-content to 0%.

[0039] The basic component composition of the steel for use in machine-construction, according to the present invention, is as described above, and the balance is practically iron. Further, by "practically iron" is meant unavoidable impurities (for example, Al, N, O, H, etc.), other than P and S, besides components (for example, Sb, Zn, etc.), each thereof being in a trace amount, permissible to the extent that the characteristics of the steel according to the present invention is not interfered with, other than iron, can be contained. Still further, the following selective components may be contained as necessary in the steel for use in machine-construction, according to the invention. In the case where these components are contained, the reasons for limiting respective component ranges are given as follows.

[0040] (At least one species selected from the group consisting of (Cr: 0.5% or less (excluding 0%), Cu: 0.5% or less (excluding 0%), Ni: 0.5% or less (excluding 0%), and Mo: 0.5% or less (excluding 0%))

[0041] Any element selected from the group consisting of Cr, Cu, Ni, and Mo is an element effective in increasing the strength of a final product by causing the hardenability of a steel material, and if necessary, one species of these elements is singly contained or not less than two species thereof are contained. However, if these elements each is excessive in content, the strength will become excessively high, thereby causing deterioration in cold workability, and therefore, the preferable upper limit described as above was set for the respective elements. A more preferable upper limit for any one of these elements is 0.45% or less (still more preferably, 0.40% or less). Still further, as the content of any one of these elements increases, so does the effect thereof, however, a preferable lower limit of the content of any one among those elements is not less than 0.015% (more preferably, not less than 0.020%).

[0042] At the time of manufacturing the steel for use in machine-construction, according to the present invention, a steel satisfying the component composition described as above is subjected to hot rolling under normal conditions to

be turned into a hot-rolled steel-plate material. Subsequently, the hot-rolled steel-plate material is heated up to a temperature in a range of 800 to 950°C, and it need only be sufficient to cool the hot-rolled steel-plate material to 500°C or lower at an average cooling rate of not less than 2°C/sec after holding the same at that temperature for around 10 to 25 min (holding time). Further, the manufacturing conditions may be changed halfway through an operation provided that

(Heating temperature: 800 to 950°C)

[0043] In order to control the [(ferrite grain) - (ferrite grain) connection rate X] at 0.15 or less, it is necessary to control a heating temperature (a heating temperature after the hot rolling) in the range of 800 to 950°C. If the heating temperature at this point in time exceeds 950°C, the total area of an austenite grain boundary, per unit volume, will decrease due to coarsening of an austenite grain size at the time of heating, thereby causing ferrite grains to be precipitated from the austenite grain boundary to approach each other, so that it will become difficult to cause the ferrite grains to be isolated from each other. Further, if the heating temperature is less than 800°C, the ferrite grains existing in the hot-rolled steel-plate material prior to the heat treatment will not be fully transformed into the austenite phase, so that it will become difficult to control the [(ferrite grain) - (ferrite grain) connection rate X] at 0.15 or less. A more preferable lower limit of the heating temperature is not lower than 820°C (more preferably, not lower than 850°C), and a more preferable upper limit thereof is not higher than 930°C (more preferably, not higher than 900°C).

(Holding time in the heating temperature range: 10 to 25 min)

[0044] Holding time in the heating temperature range is a factor having an influence exerted on the [(ferrite grain) - (ferrite grain) connection rate X]. If the holding time at this point in time is less than 10 min, a transformation from a ferrite phase before the heat treatment to an austenite phase will not satisfactorily proceed, resulting in a state where the ferrite phase is left out in the microstructure. Further, if the holding time exceeds 25 min, an austenite grain will undergo coarsening, and the total area of the austenite grain boundary, per unit volume, decreases, so that the ferrite grains, precipitated from the austenite grain boundary, approach each other, thereby rendering it difficult for the respective ferrite grains to be isolated from each other. A more preferable lower limit of the holding time is not less than 15 min, and a more preferable upper limit thereof is 20 min or less.

(Cooling until 500°C or lower at an average cooling rate of not less than 2°C after heated holding)

[0045] If an average cooling rate until 500°C or lower (a cooling-stop temperature) is less than 2°C/sec, this will render it impossible for the average grain size of ferrites to be 7 μm or less. There is the need for the average cooling rate being at not less than 2°C/sec from such a point of view, described as above. The average cooling rate is more preferably not less than 5°C/sec, and still more preferably not less than 7°C/sec. Further, with respect to the cooling at this point in time, a cooling form capable of varying the cooling rate may be adopted provided that variation is made within the range where the average cooling rate is not less than 2°C/sec.

(Cooling-stop temperature: 500°C or lower)

[0046] The cooling-stop temperature is preferably 500°C or lower. If the cooling-stop temperature is higher than 500°C, the ferrite grain size will become susceptible to coarsen, thereby rendering it difficult for the average grain size of the ferrite grains to be at 7 μm or less. On the other hand, if the cooling-stop temperature is lower, no influence will be exerted on the microstructure of the material. Therefore, normal cooling (standing to cool) is applied after completion of cooling until 500°C or lower, and lowering of temperature, down to room temperature, will suffice.

[0047] The steel for use in machine-construction, according to the invention, excellent in machinability, is thus obtained, and a steel product with improved machined-surface characteristics (the worked-surface roughness) can be manufactured by applying a cutting operation to the steel for use in machine-construction. Further, since excellent machined-surface characteristics can be obtained by applying a cutting operation to the steel for use in machine-construction, according to the invention, the steel for use in machine-construction as it is can be used as a forming tool without applying a finish-machining, such as grinding, etc., thereto.

[0048] The invention is more specifically described below with reference to examples of the invention, however, it is to be pointed out that the invention be not limited by the examples described below and that various changes and modifications may be obviously possible in the invention without departing from the spirit and scope thereof, those changes and modifications being incorporated in the technical range of the invention.

Examples

[0049] A hot-rolled steel material (a steel-plate material (plate thickness: 30 mm) was prepared by hot rolling under a normal hot-rolling condition, using each of steel grades A through D, having respective chemical component compositions shown in Table 1 given below. In Table 1, the steel grade A is an S55C equivalent steel (JISG 4051), the steel grade B is an S60C equivalent steel (JISG 4051), the steel grade C is an S50C equivalent steel (JISG 4051), and the steel grade D is an S45C equivalent steel (JISG 4051).

[Table 1]

Steel grade	Chemical component composition *(mass%)				
	C	Si	Mn	P	S
A	0.55	0.26	0.74	0.010	0.0024
B	0.60	0.22	0.76	0.018	0.0092
C	0.50	0.17	0.78	0.019	0.013
D	0.45	0.18	0.72	0.014	0.020
* Balance: iron and unavoidable impurities, other than P and S					

[0050] Respective examples were prepared under manufacturing conditions (heating temperature, holding time, an average cooling rate after heating, and a cooling method), shown in Table 2 below, using the hot-rolled steel material obtained as above (Test Nos. 1 through 7). A steel of the steel grade A under Test No. 1 is the test sample obtained by heating the hot-rolled steel material of the S55C equivalent steel (the steel grade A) up to 850°C to be held at that temperature for 20 min to be subsequently air cooled (at an average cooling rate: 3°C/sec) without air cooling by blowing with the use of a blower. A steel of the steel grade B under Test No. 2 is the test sample obtained by heating the hot-rolled steel material of the S60C equivalent steel (the steel grade B) up to 850°C to be held at that temperature for 20 min to be subsequently furnace cooled (at an average cooling rate: 0.8°C/sec). A steel of the steel grade C under Test No. 3 is the test sample obtained by heating the hot-rolled steel material of the S50C equivalent steel (the steel grade C) up to 900°C to be held at that temperature for 20 min to be subsequently air cooled (at an average cooling rate: 6°C/sec) by blowing with the use of a blower. A steel of the steel grade A under Test No. 4 is the test sample obtained by heating the hot-rolled steel material of the S55C equivalent steel (the steel grade A) up to 850°C to be held at that temperature for 20 min to be subsequently air cooled (at an average cooling rate: 6°C/sec) by blowing with the use of a blower, being further held for 1.5 min at a point in time, when the temperature dropped to 750°C to be thereafter air cooled (the average cooling rate: 6°C/sec), while blowing air to the hot-rolled steel material again with the use of the blower. A steel of the steel grade A under Test No. 5 is the test sample obtained by heating the hot-rolled steel material of the S55C equivalent steel (the steel grade A) up to 850°C to be held at that temperature for 20 min to be subsequently furnace cooled (at the average cooling rate: 0.8°C/sec). A steel of the steel grade A under Test No. 6 is the test sample obtained without heating the hot-rolled steel material of the S55C equivalent steel (the steel grade A). A steel of the steel grade D under Test No. 7 is the test sample obtained by heating the hot-rolled steel material of the S45C equivalent steel (the steel grade D) up to 700°C to be held at that temperature for 30 min to be subsequently air cooled (at the average cooling rate: 3°C/sec) without air cooling by blowing with the use of a blower. With respect to any of the test samples, the cooling-stop temperature was set to 500°C or lower.

[Table 2]

Test No.	Steel grade	Manufacturing condition			
		Heating temperature (°C)	Holding time (min)	Average cooling rate (°C/sec)	Cooling method
1	A	850	20	3	Air cooled
2	B	850	20	0.8	Furnace cooled
3	C	900	20	6	Air cooled (blowing)

(continued)

Test No.	Steel grade	Manufacturing condition			
		Heating temperature (°C)	Holding time (min)	Average cooling rate (°C/sec)	Cooling method
4	A	(1)850	20	6	Air cooled (blowing)
		(2)750	1.5	6	Air cooled (blowing)
5	A	850	20	0.8	Furnace cooled
6	A	-	-	-	-
7	D	700	30	3	Air cooled

[0051] With respect to each of the test samples (Test Nos. 1 through 7), as obtained, a measurement was made on the average equivalent circle diameter of ferrites, and a [(ferrite grain)-(ferrite grain) connection rate X], by the following method.

(Measurement on the average equivalent circle diameter of ferrites)

[0052] The test samples each were specularly polished to be subsequently corroded by use of a 3% nital solution to thereby expose a metal microstructure, and subsequently, a microstructure observation was made on five visual fields, in a region of approximately 170 μm x 230 μm , by use of a scanning electron microscope (SEM) up to 400x magnification, to take a photograph of the five visual fields. Based on these photographs, a white part was determined as a ferrite grain from a contrast in an image to be marked, whereupon an equivalent circle diameter of a ferrite grain was found by an image analysis, thereby having found an average value of the respective equivalent circle diameters, in the five visual fields.

(Measurement on a [(ferrite grain)-(ferrite grain) connection rate X])

[0053] The working examples each were specularly polished to be corroded with the use of the 3% nital solution to expose a metal microstructure, and subsequently, a microstructure observation was made in a region of 40000 μm^2 in area, using a scanning electron microscope (SEM) up to 400x magnification, having thereby taken a photograph of the region. Thereafter, horizontal lines were drawn at regular intervals across a photograph of the microstructure such that the total length (lengths in total) of horizontal line-segments is not less than 1000 μm , having thereby found a [(ferrite grain)-(ferrite grain) connection rate X] according to the procedure described in the foregoing.

[0054] Still further, with respect to the respective test samples, a cutting test was conducted under conditions shown in Table 3 depicted below, having thereby assessed the machined cut-surface roughness of each of the test samples, after the cutting operation. In this case, a cutting test was conducted by means of two-dimensional cutting (planing), using a machining center. The machined cut-surface roughness, serving as a criterion for decision on machinability, was measured by moving a stylus in a direction parallel with the cutting direction, with the use of a contact-needle roughness meter. As to the criterion for decision on machinability, if the machined cut-surface roughness was less than 0.10 μm , in terms of calculated average roughness Ra, the surface characteristic was assessed as excellent. In this connection, two-dimensional cutting was adopted in the cutting test although a more-complex three-dimensional cutting was expected in the case of a normal cutting. However, since the three-dimensional cutting can be regarded as the case of integration of two-dimensional cuttings, the effect of the three-dimensional cutting can be estimated on the basis of data obtained from the two-dimensional cutting.

[Table 3]

Processing style	Two-dimensional cutting (planing)
Tool in use	Protrusion-cutting process tool, Tool width: 6 mm, Face angle: 10°, P-grade cemented carbide tip (non coat) without tip-breaker
Cutting depth	5 μm
Cutting rate	1 m / min

(continued)

Processing style	Two-dimensional cutting (planing)
Cutting type	Wet cutting (water-soluble cutting oil)
Cutting direction	Direction perpendicular to the rolling direction (L direction)

[0055] These results, as summarized, are shown in Table 4 depicted below.

[Table 4]

Test No.	Steel grade	(Ferrite grain) - (Ferrite grain) connection rate X (-)	Ferrite average equivalent circle diameter (μm)	Machined cut-surface roughness (Ra) (μm)
1	A	0.09	5.6	0.03
2	B	0.10	9.7	0.12
3	C	0.12	5.1	0.05
4	A	0.12	6.6	0.08
5	A	0.13	8.3	0.11
6	A	0.18	6.9	0.12
7	D	0.26	4.9	0.14

[0056] On the basis of the result, described as above, observation can be made as follows. It is evident that the example, as the object of each of Test Nos. 1, 3, and 4, is an example satisfying all the requirements of the [(ferrite grain)-(ferrite grain) connection rate X] and the average equivalent circle diameter of ferrite, specified by the present invention, and the machined cut-surface roughness (Ra) thereof indicates an excellent value. Further, it is evident that the example as the object of Test No. 1, in particular, is an example in which the heating temperature and the holding time are at a more preferable value, respectively, and the [(ferrite grain)-(ferrite grain) connection rate X] as well is at a more preferable value, thus having the most superior surface characteristics.

[0057] In contrast, the example as the object of each of Test Nos. 2, and 5 through 7 is an example failing to satisfy any of the requirements specified by the present invention. With any of those examples, the machined cut-surface roughness was found large in value. More specifically, the examples under Test No.2, and Test No. 5, respectively, represent an example in which the average cooling rate was at 0.8°C/sec, and the average equivalent circle diameter of ferrites was found large, and the machined cut-surface roughness (Ra) as well was found large.

[0058] The working example as the object of Test No. 6 is an example in which the heat treatment was not applied after the hot rolling, the [(ferrite grain)-(ferrite grain) connection rate X] of the ferrite grain was found large, and the machined cut-surface roughness (Ra) as well was found large. The example as the object of Test No. 7 is an example in which the heating temperature was low, the [(ferrite grain)-(ferrite grain) connection rate X] of the ferrite grain was found large, and the machined cut-surface roughness (Ra) as well was found large.

[0059] Although the present invention has been described in detail, while referring to specific embodiments, it is believed obvious to those skilled in the art that variation and modification may be made in the invention without departing from the spirit and scope thereof.

[0060] This application is based on Japanese Patent Application dated August 22, 2013 (Japanese Patent Application No. 2013 - 172-546) which is incorporated herein by reference.

Industrial Applicability

[0061] The steel for use in machine-construction, according to the invention, is useful for various parts for use in machine-construction, including an automotive part and a construction machinery part, etc., and this steel for use in machine-construction is also suitable for application to a forming tool, in particular, because of excellent machinability.

List of Reference Signs

[0062]

- 1: ferrite phase
- 2: hard phase
- 3: recess

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Claims

1. A steel for use in machine-construction, having a mixed microstructure comprising:

10 a hard phase composed of at least one species selected from the group consisting of pearlite, bainite, and martensite; and
 a ferrite phase,
 wherein an average equivalent circle diameter of ferrite grains is 7 μm or less, and a [(ferrite grain) - (ferrite grain) connection rate X], as expressed by an equation (1) described hereunder, is 0.15 or less, provided that
 15 [(ferrite grain) - (ferrite grain) connection rate X] = [the number (A) of [(ferrite grain) - (ferrite grain) interface surfaces]] / [the number (B) of (ferrite grain) - (hard phase) interface surfaces] represents the equation (1), and
 at the time of drawing a predetermined straight line across a photograph taken by use of a scanning electron microscope, [the number (A) of [(ferrite grain) - (ferrite grain) interface surfaces]], in the equation, indicates the
 number of intersection points between the straight line and [the (ferrite grain) - (ferrite grain) interface surfaces],
 20 whereas [the number (B) of [(ferrite grain) - (hard phase) interface surfaces]] indicates the number of intersection points between the straight line and the [(ferrite grain) - (hard phase) interface surfaces], at the time of drawing a
 predetermined straight line in the same way as described above.

2. The steel for use in machine-construction, according to claim 1, comprising:

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C: 0.2 to 1.2% (mass %, the same applies to chemical component composition hereinafter);

Si: 0.05 to 0.5%;

Mn: 0.2 to 1.8%;

P: 0.03% or less (excluding 0%); and

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S: 0.03% or less (excluding 0%), the balance being iron and unavoidable impurities.

3. The steel for use in machine-construction, according to claim 2, further comprising at least one species of element selected from the group consisting of Cr: 0.5% or less (excluding 0%), Cu: 0.5% or less (excluding 0%), Ni: 0.5% or less (excluding 0%), and Mo: 0.5% or less (excluding 0%), as other elements.

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4. A method for improving machined-surface characteristics of a machined cut-surface of the steel for use in machine-construction, according to any of claims 1 to 3.

5. A method for manufacturing a forming tool to be used in cutting of the steel for use in machine-construction, according to any of claims 1 to 3.

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FIG. 1A

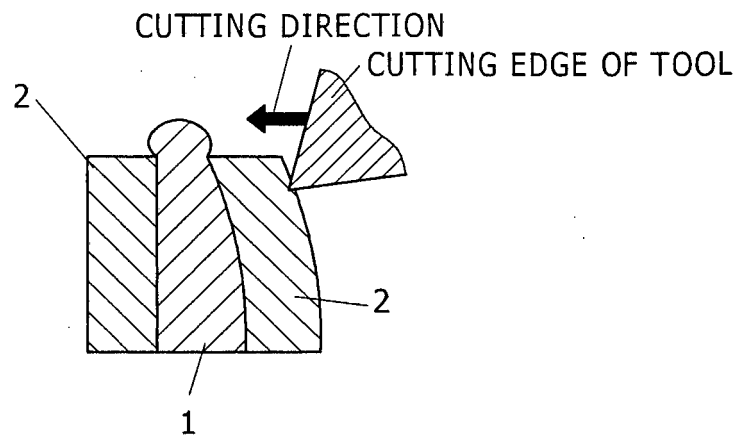


FIG. 1B

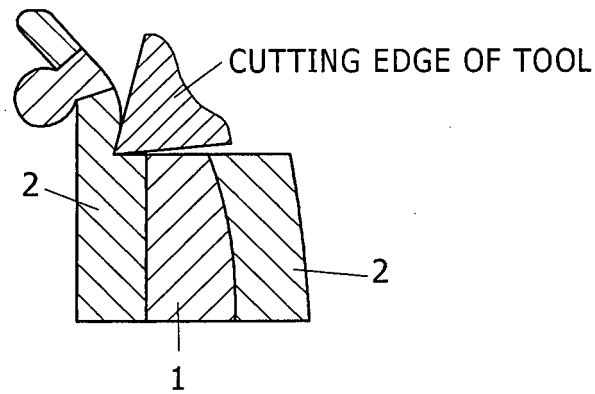


FIG. 1C

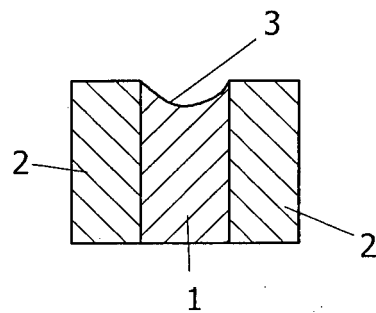
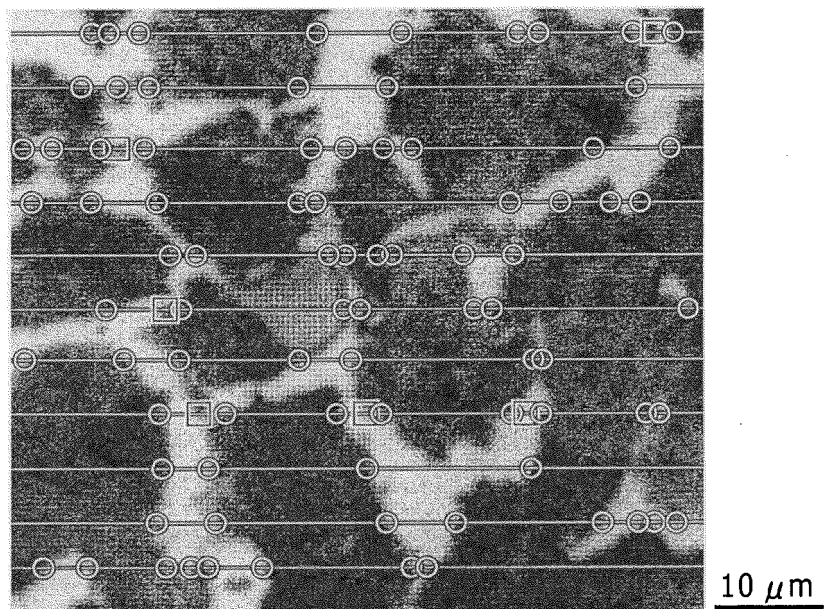


FIG. 2A

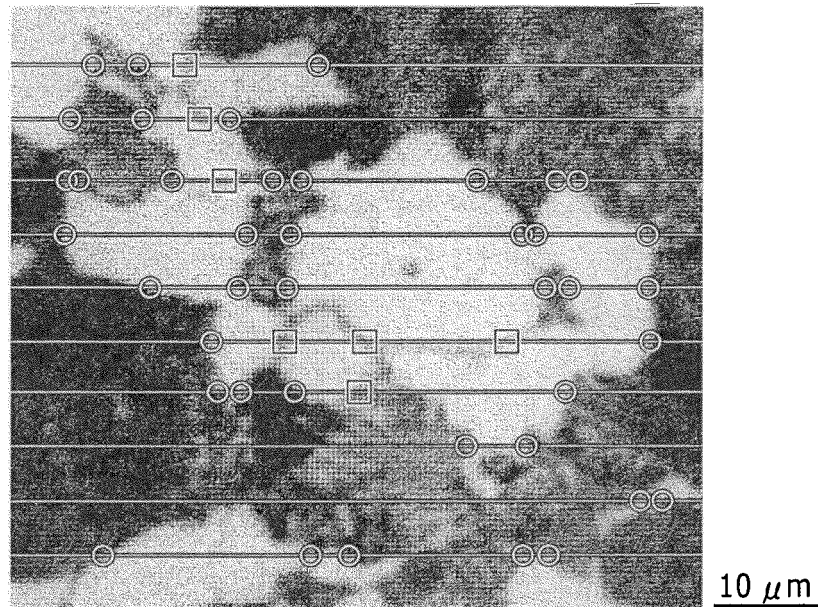
(FERRITE GRAIN)-(FERRITE GRAIN) CONNECTION RATE $X \leq 0.15$



WHITE PART: FERRITE GRAIN, GRAY-BLACK PART: HARD PHASE
 □ : (FERRITE GRAIN)-(FERRITE GRAIN) BOUNDARY
 ○ OUTLINED WHITE PART: (FERRITE GRAIN)-(HARD PHASE) BOUNDARY

FIG. 2B

(FERRITE GRAIN)-(FERRITE GRAIN) CONNECTION RATE $X > 0.15$



WHITE PART: FERRITE GRAIN, GRAY-BLACK PART: HARD PHASE
□ : (FERRITE GRAIN)-(FERRITE GRAIN) BOUNDARY
○ OUTLINED WHITE PART: (FERRITE GRAIN)-(HARD PHASE) BOUNDARY

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/071081

A. CLASSIFICATION OF SUBJECT MATTER

C22C38/00(2006.01)i, C21D6/00(2006.01)i, C21D8/02(2006.01)i, C22C38/04
(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)
C22C38/00, C21D6/00, C21D8/02, C22C38/04, C22C38/58

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 1996-2014
Kokai Jitsuyo Shinan Koho 1971-2014 Toroku Jitsuyo Shinan Koho 1994-2014

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.
X A	JP 9-324212 A (Kawasaki Steel Corp.), 16 December 1997 (16.12.1997), claims; 0001, 0018 to 0028; tables 1, 4 (Family: none)	1-3 4, 5
X A	JP 8-283838 A (Nippon Steel Corp.), 29 October 1996 (29.10.1996), claims; 0045; tables 1, 2 (Family: none)	1-3 4, 5
Y A	JP 2013-1928 A (Kobe Steel, Ltd.), 07 January 2013 (07.01.2013), claims; 0001, 0022, 0023, 0031, 0035 (Family: none)	1, 4 2, 3, 5

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

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"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

Date of the actual completion of the international search
14 October, 2014 (14.10.14)

Date of mailing of the international search report
04 November, 2014 (04.11.14)

Name and mailing address of the ISA/
Japanese Patent Office

Authorized officer

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Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2014/071081

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 11-236644 A (Nippon Steel Corp.), 31 August 1999 (31.08.1999), claims; 0001, 0012, 0024, 0040; table 2 (Family: none)	1, 4 2, 3, 5
A	JP 2008-255398 A (Kobe Steel, Ltd.), 23 October 2008 (23.10.2008), tables 1 to 4 & US 2008/0156403 A1 & EP 1939309 A1	1-5

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REFERENCES CITED IN THE DESCRIPTION

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- JP S62198723970 A [0008]
- JP 2004292929 A [0008]
- JP 2002069569 A [0008]
- JP 2013172546 A [0060]