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# (54) HOT-WORKING TOOL STEEL HAVING EXCELLENT STIFFNESS AND HIGH-TEMPERATURE STRENGTH AND METHOD FOR PRODUCTION THEREOF

(57) Disclosed is a hot-working tool steel having improved toughness and high-temperature strength. Also disclosed is a method for producing the hot-working tool steel. The hot-working tool steel comprises the following components (by mass): C: 0.34-0.40%, Si: 0.3-0.5%, Mn: 0.45-0.75%, Ni: 0-0.5% (exclusive), Cr: 4.9-5.5%, (Mo+1/2W): 2.5-2.9% (provided that Mo and W are contained singly or in combination), and V: 0.5-0.7%, with the remainder being Fe and unavoidable impurities. Preferably, the cross-sectional structure of the hot-working tool steel upon quenching contains a granular structure and an acicular structure, wherein the granular structure (A%) accounts for 45 area% or less, the acicular structure (B%) accounts for 40 area% or less, and the remaining austenite (C%) accounts for 5 to 20 volume%.; Also disclosed is a method for producing a hot-working tool steel, which comprises tempering the above-mentioned hot-working tool steel so that a value X determined by the following relational expression between a tempered hardness (HRC) and the percentages of the tissues becomes 40 or greater.

$$X = [-0.36(HRC)-1.47(A\%)-1.67\times(B\%)+6.55\times(C\%)+72.91]$$

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FIG.1

## Description

### TECHNICAL FIELD

**[0001]** The invention relates to a hot-working tool steel having improved toughness and high-temperature strength, which is suitable for many kinds of hot-working tools such as press dies, forging dies, die-casting dies, and extruding tools, and a method for producing the hot-working tool steel.

### BACKGROUND ART

**[0002]** Since a hot-working tool contacts a high-temperature workpiece or a hard workpiece during use, it is required to have both strength and toughness to be resistant to thermal fatigue and impact. Therefore, in the field of hot-working tool, an alloy tool steel, such as SKD 61 of JIS steel grade, has been conventionally employed. Recently, the workpiece is processed at higher temperature due to shortening of the production time of the product by using the hot-working tool and to work an intricate shaped product. The hot-working tool, such as a die, has become larger in order to work simultaneously a plurality of products. Therefore, the material for hot-working tool is required to ensure a further improved high-temperature strength and a toughness even in the interior of a large-size tool.

**[0003]** In order to improve the toughness and high-temperature strength of the alloy tool steel, approached have been proposed for improving the high-temperature strength while maintaining the toughness by defining the range of chemical composition (see Patent Document 1) and a for improving the high-temperature strength and toughness by specifying the quantity of residual carbide (see Patent Document 2).

PATENT DOCUMENT 1: JP-A-02-179848
PATENT DOCUMENT 2: JP-A-2000-328196

### DISCLOSURE OF THE INVENTION

### PROBLEMS TO BE SOLVED BY THE INVENTION

**[0004]** In the method in Patent Document 1, while the toughness level cannot be evaluated since specific disclosure of the values are absent, however, the limitation of the range of the composition is insufficient to provide both toughness and high-temperature strength at a sufficiently high level, judging from the result of study conducted by the inventor. In the method in Patent Document 2 as well, it is insufficient to define only the quantity of the residual carbide for controlling the toughness and high-temperature strength at a high level, since the toughness and high-temperature strength are affected greatly by the structure, such as martensite or bainite structure, after quenching.

**[0005]** An object of the invention is to provide a hot-working tool steel surely having improved toughness and high-temperature strength and a method for production thereof.

### MEANS FOR SOLVING THE PROBLEMS

**[0006]** As a result of earnest studies, the inventors found that the structure after quenching exerts a great influence on the toughness and high-temperature strength, and identified a structure after quenching that is suitable for providing both of excellent toughness and high-temperature strength. The inventors found that there exists a very narrow preferred composition range where the suitable structure after quenching can be obtained by controlling the each element so as to be in an optimum range, and finally arrived at the invention.

**[0007]** The invention provides a hot-working tool steel having excellent toughness and high-temperature strength, consisting essentially of, by mass percent, 0.34 to 0.40% of carbon, 0.3 to 0.5% of Si, 0.45 to 0.75% of Mn, 0 to less than 0.5% of Ni, 4.9 to 5.5% of Cr, total amount of Mo and half of tungsten (Mo+1/2W) of 2.5 to 2.9% wherein Mo and W may be contained singly or in combination, and 0.5 to 0.7% of V, the balance being Fe and unavoidable impurities. The hot-working tool steel according to the invention may be tempered to have a hardness of not lower than 40HRC. Especially, the steel has an effect of providing both of excellent toughness and high-temperature strength in a high hardness of not lower than 43HRC, particularly not lower than 45HRC. The steel preferably has a hardness of not higher than 49HRC.

**[0008]** For the hot-working tool steel according to the invention, preferably, one or more kinds of elements of C, Si, Mn, Ni, Cr, Mo, W and V constituting this steel meet the conditions of the following narrow composition ranges. Needless to say, it is desirable that all elements meet the conditions.
C: 0.35 to 0.39%
Si: 0.35 to 0.45%

Mn: 0.5 to 0.7%
Ni: 0.01 to 0.3%
Cr: 5.0 to 5.4%
(Mo+1/2W): 2.6 to 2.8%, Mo and W being contained singly or in combination
V: 0.55 to 0.65%

**[0009]** The invention also provides the hot-working tool steel having the above-described composition, and the cross-sectional structure thereof after quenching contains a granular structure and an acicular structure, wherein the area percentage of the granular structure (A%) is not more than 45%; the area percentage of the acicular structure (B%) is not more than 40%; and the volume percentage of retained austenite (C%) is 5 to 20%.

**[0010]** Furthermore, the invention provides a method of production of a hot-working tool steel having excellent toughness and high-temperature strength, wherein the hot-working tool steel is tempered so that a value X determined by the following relational expression between tempered hardness (HRC) and the percentages of the structures is not less than 40. The tempered hardness is set at 40 to 49HRC, preferably 43 to 49HRC, and further preferably 45 to 49HRC.

$$X = [-0.36\times(HRC)-1.47\times(A\%)-1.67\times(B\%)+6.55\times(C\%)+72.91]$$

ADVANTAGES OF THE INVENTION

**[0011]** According to the invention, both of the toughness and high-temperature strength of a hot-working tool steel can be provided at a very high level. This effect is achieved to the maximum when the steel is tempered so as to have hardness of not lower than 40HRC, for example, not lower than 43HRC, more preferably not lower than 45HRC, and still further preferably not lower than 46HRC. Therefore, the invention provides a technique that is effective for practical use of a hot-working tool steel capable of being applied to many kinds of high-temperature applications and environments.

BEST MODE FOR CARRYING OUT THE INVENTION

**[0012]** As described above, one important aspect of the invention is to define the contents of elements controlled in the optimum range. Specifically, the aspect of the invention is to find the existence of a narrow composition range which is capable of providing both toughness and high-temperature strength at a high level even by any quenching method, for example, in addition to a quench cooling rate in a wide range in the conventional production method, by controlling the contents of elements into a limited range, further desirably, by recognizing the later-described quenched structure. That is to say, for the basic elements, while the conventional balance of C-Cr content relationship is kept, it is important to optimally control other carbide forming elements such as Mo, W and V which mutually relate to the C-Cr content and to control Si and Ni which exert a great influence to the properties as a result of the control of these basic elements. Hereunder, the reason for component limitation constituted by the narrow composition range of the steel in accordance with the invention is described.

**[0013]** Carbon (C) is an essential and important element for hot-working tool steel, some of which solid-solute in a matrix to provide strength and some of which form carbide to enhance wear resistance and seizure resistance. Also, in the case where carbon is an interstitial atom forming a solid solution, and is added together with a substitutional atom having a high affinity with carbon, such as Cr, is expected an I (interstitial atom) - S (substitutional atom) effect, that is an effect that carbon acts as drag resistance of solute atom to enhance strength. However, if the carbon content is not more than 0.34 mass%, hardness and wear resistance sufficient for a tool element cannot be secured. On the other hand, since the excessive addition of carbon leads to a decrease in toughness and hot strength, the upper limit of carbon content is defined to be 0.40 mass%. The carbon content is preferably 0.35 to 0.39%, further preferably 0.36 to 0.38%.

**[0014]** Silicon (Si) is a deoxidizing agent in the steel making process and is also an element for enhancing the machinability. To achieve these effects, not less than 0.3 mass% of Si should be added. If the addition is too much, however, the later-described acicular structure develops, thereby decreasing the toughness. Also, much addition of Si restrains the precipitation of cementite-based carbide in the bainite structure at quenching so that the precipitation, coagulation, and coarsening of alloy carbide during tempering are promoted indirectly, thereby decreasing the high-temperature strength. Therefore, the Si content is limited to not more than 0.5 mass%, preferably 0.35 to 0.45%.

**[0015]** Manganese (Mn) has effects of enhancing the hardenability and restraining the production of ferrite to obtain a proper quenched/tempered hardness. If Mn is present in the structure as a nonmetallic inclusion MnS, it has a great effect of improving the machinability. To achieve these effects, not less than 0.45 mass% of Mn is added. If the addition is too much, the viscosity of matrix is increased, thereby decreasing the machinability. Therefore, the Mn content is limited to not more than 0.75 mass%, preferably 0.5 to 0.7%.

**[0016]** Nickel (Ni) is an element for restraining the production of ferrite. Also, Ni is an additional element that is important for providing excellent hardenability together with C, Cr, Mn, Mo, W, etc., achieving an effect of restraining the production of the later-described acicular structure even in the case where the cooling rate of quenching is low, forming a structure mainly composed of martensite, and preventing the toughness from decreasing. Furthermore, Ni has an effect of improving toughness essentially in the matrix. Therefore, for example, not less than 0.01% of Ni is preferably added. It is most important in the invention to regulate strictly the upper limit of Ni, even if Ni is added. If the Ni content is too high, the viscosity of matrix is increased, so that the machinability is decreased and the high-temperature strength is decreased. Also, the later-described granular structure develops, thereby decreasing the toughness. Therefore, the Ni content is limited to not more than 0.5 mass%. Preferably, the Ni content is regulated to not more than 0.3 mass%.

**[0017]** Chromium (Cr) is an element having effects of enhancing the hardenability and of strengthening the matrix and improving the wear resistance by forming carbide, and also is an element essential for the hot-working tool steel according to the invention, which contributes to the improvement in resistance to softening in temper and high-temperature strength. To achieve these effects, not less than 4.9 mass% of Cr should be added. However, since the excessive addition of Cr leads to a decrease in hardenability and high-temperature strength, the upper limit of Cr content is 5.5 mass%. The Cr content is preferably 5.0 to 5.4%, further preferably 5.1 to 5.3%.

**[0018]** Molybdenum (Mo) and tungsten (W) can be added singly or in combination to enhance the hardenability, to provide strength by precipitating fine carbide by means of tempering, and to improve the softening resistance. Since W has an atomic weight about two times that of Mo, the content can be specified by Mo+1/2W (naturally, either one may be added, or both of the two may be added). To achieve the above-mentioned effects, not less than 2.5 mass% of (Mo+1/2W) should be added. Since the excessive addition thereof leads to a decrease in machinability and a decrease in toughness caused by the development of the later-described acicular structure, the content of (Mo+1/2W) is not more than 2.9 mass%. Preferably, the content of (Mo+1/2W) is 2.6 to 2.8%.

**[0019]** Vanadium (V) forms carbide having effects of strengthening the matrix and improving the wear resistance. Also, it enhances the resistance to softening in temper and restrains the coarsening of crystal grains. It also contributes to the improvement in toughness. To achieve these effects, not less than 0.5 mass% of V should be added. Since the excessive addition of V leads to a decrease in machinability and toughness, the content of V is not more than 0.7 mass%. Preferably, the content of V is 0.55 to 0.65%.

**[0020]** The main elements that possibly remain as unavoidable impurities are P, S, Co, Cu, Al, Ca, Mg, O, N, and the like. In order to attain the effects of the invention to the maximum, it is desirable that the contents of these elements be as low as possible. On the other hand, for the purpose of achieving additional effects such as the mode control of inclusion and the improvement in mechanical properties or manufacturing efficiency, a minute amount of these elements can be also contained and/or added. In this case, it can be thought that if the contents, by mass percent, of these elements are P≤0.03%, S≤0.01%, Co≤0.05%, Cu≤0.25%, Al≤0.025%, Ca≤0.01%, Mg≤0.01%, 0≤0.01%, and N≤0.03%, these elements do not exert an especially large influence on the basic properties of the hot-working tool steel according to the invention. Therefore, the above-mentioned ranges are allowable, and the above-mentioned percentages are preferred upper limits.

**[0021]** In addition to the importance of the above-described composition, the invention preferably define a feature from an approach in term of the structure. Specifically, by studying the "structural factors" having an influence on the mechanical properties of alloy tool steel, the optimum structure is also defined in addition to the optimum composition range, which is the very narrow range of the invention. That is to say, the hot-working tool steel in accordance with the invention having the above-described composition contains a granular structure and an acicular structure each having the following area percentage in the cross-sectional structure after quenched.
granular structure (A%): not more than 45 area%;
acicular structure (B%): not more than 40 area%
retained austenite (C%): 5 to 20 volume%

**[0022]** First, a "quenched structure" means a structure mainly composed of martensite and/or bainite, which is obtained by cooling from an austenite temperature region, as is defined ordinarily. The quenched structure of the invention is essentially composed of the above-mentioned martensite and/or bainite and a small amount of retained austenite, and each of the above-mentioned granular structure and acicular structure is composed of a part of the martensite and/or bainite. The granular structure and acicular structure defined in the quenched structure according to the invention is different from those specified by the definition of feather-like bainite (upper bainite) and needle-like bainite (lower bainite), which are used for ordinary classification of bainite.

**[0023]** That is to say, the granular structure according to the invention is a structure in which many fine carbides grow in several directions in the structure. In the cross-sectional structure of the steel, the granular structure according to the invention takes a "granular shape" on the whole as shown in its name. Since the granular structure is produced even at a cooling rate as high as air-cooling rate of a small sample of about 10 mm cubic, it is still more difficult to reduce the granular structure when a practical steel ingot is quenched. However, if the granular structure occupies most of the structure, the toughness decreases. In the invention, therefore, the area percentage of the granular structure in the quenched structure is defined to be preferably not more than 45%, further preferably not more than 40%, and still further preferably not more than 30%.

**[0024]** Next, the acicular structure of the invention is a structure in which many long carbides as compared with those in the granular structure, grow in the structure in a direction. In the cross-sectional structure, the acicular structure according to the invention takes a "needle shape". Although this acicular structure is generated at a cooling rate lower than the cooling rate at which the granular structure begins to be generated, it is still difficult to reduce the acicular structure when a practical steel ingot is quenched. However, if the acicular structure occupies most of the structure, the toughness deteriorates greatly. In the invention, therefore, the area percentage of the acicular structure in the quenched structure is defined to be preferably not more than 40%, further preferably not more than 25%.

**[0025]** The granular structure and the acicular structure of the invention can be distinguished and quantitatively determined by visual observation of its cross section by utilizing the difference in shape. Specifically, in any structure cross section, both the structures having poor corrosion resistance as compared with the martensite matrix in which no carbide is precipitated are corroded preferentially by for example, the selective potentiostatic etching by electrolytic dissolution method (SPEED method). Fig. 1 is a micrograph obtained by observing the corroded surface by using a scanning electron microscope (magnification of . 5000). As shown in Figs. 2 and 3 as supplementary schematic views, the granular structure and the acicular structure of the invention can be distinguished and quantitatively determined. In this case, in the invention, it is sufficient to observe any three fields in which the structures each having the maximum length of about 0.5 μm or longer to determine the effect. Fig. 1 shows one field of example steel 6 of the invention described in example 3 later, having 27 area% of the granular structure and 30 area% of the acicular structure. Fig. 4 shows one field of view of conventional steel 31 described in example 3 later, having 44 area% of the granular structure and 16 area% of the acicular structure.

**[0026]** Also, in the quenched structure configuration of the invention, retained austenite is important. Retained austenite is a structure preferably to be reduced since it deteriorates the strength properties. In the invention, however, a proper amount of the retained austenite contributes to improve toughness. Therefore, in the invention, the volume percentage of retained austenite in the quenched structure is preferably 5 to 20%, further preferably not less than 10%. A quantitative analysis of the retained austenite can be performed by an ordinary method, for example, by volume percentage measurement utilizing diffracted intensity obtained by the X-ray diffractometry using e.g. an electropolished sample.

**[0027]** In the method for producing the hot-working tool steel according to the invention, the above-described requirements for composition and quenched structure are met, and then a target hardness in tempering of the next process is determined, and then tempering is performed such that X in the following relational expression is not less than 40. Thereby, a hot-working tool steel having excellent toughness is produced.

$$X = [-0.36\times(HRC)-1.47\times(A\%)-1.67\times(B\%)+6.55\times(C\%)+72.91]$$

where
A%: area percentage of granular structure
B%: area percentage of acicular structure
C%: volume percentage of retained austenite.

**[0028]** The above expression clarifies specific influence parameters as a result of a study on the influence of quenched structure and tempered hardness on the toughness after tempering. For securing the toughness after tempering, the reduction in granular structure and acicular structure is effective. Of these two structures, the reduction in acicular structure having a larger negative coefficient in the expression is especially effective. On the other hand, it is found that a proper amount of retained austenite acts advantageously to secure the toughness because the retained austenite has a large positive coefficient in the expression. The target hardness may be set, for example, at not less than 40HRC that effectuates the hot-working tool steel. However, the hot-working tool steel meeting the requirements for composition and quenched structure configuration of the invention will secure a sufficient toughness, even if the target hardness is higher, for example, 43HRC or more, or 45HRC or more. However, the tempered hardness is preferably kept to not more than 49HRC in order to maintain a remarkable toughness.

EXAMPLE 1

**[0029]** Table 1 gives chemical compositions of steels of the invention, comparative steels, and conventional steels. The comparative steels have a chemical compositions deviating from the limited narrow composition range of the invention. The conventional steels are hot-working tool steels generally used at present, which naturally have chemical compositions out of the composition range of the invention.

**[0030]**

[Table 1]

| | | | | | | | | | | (Mass%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample | C | Si | Mn | S | Ni | Cr | Mo | W | V | Fe ※ |
| Steel of the invention 1 | 0.360 | 0.42 | 0.60 | 0.0024 | 0.09 | 5.15 | 2.70 | <0.01 | 0.60 | Balance |
| Steel of the invention 2 | 0.400 | 0.40 | 0.56 | 0.0021 | <0.01 | 5.10 | 2.70 | <0.01 | 0.60 | Balance |
| Steel of the invention 3 | 0.380 | 0.31 | 0.58 | 0.0023 | <0.01 | 5.13 | 2.72 | <0.01 | 0.60 | Balance |
| Steel of the invention 4 | 0.382 | 0.40 | 0.53 | 0.0024 | <0.01 | 5.19 | 2.71 | <0.01 | 0.60 | Balance |
| Steel of the invention 5 | 0.385 | 0.40 | 0.73 | 0.0024 | <0.01 | 5.15 | 2.69 | <0.01 | 0.59 | Balance |
| Steel of the invention 6 | 0.374 | 0.40 | 0.59 | 0.0022 | <0.01 | 5.19 | 2.68 | <0.01 | 0.58 | Balance |
| Steel of the invention 7 | 0.374 | 0.39 | 0.59 | 0.0021 | 0.30 | 5.20 | 2.69 | <0.01 | 0.57 | Balance |
| Steel of the invention 8 | 0.380 | 0.41 | 0.63 | 0.0020 | <0.01 | 5.03 | 2.70 | <0.01 | 0.59 | Balance |
| Steel of the invention 9 | 0.367 | 0.41 | 0.56 | 0.0025 | <0.01 | 5.41 | 2.68 | <0.01 | 0.59 | Balance |
| Steel of the invention 10 | 0.372 | 0.41 | 0.59 | 0.0023 | <0.01 | 5.24 | 2.59 | <0.01 | 0.59 | Balance |
| Steel of the invention 11 | 0.380 | 0.40 | 0.59 | 0.0023 | 0.11 | 5.18 | 2.78 | <0.01 | 0.59 | Balance |
| Steel of the invention 12 | 0.380 | 0.40 | 0.59 | 0.0022 | 0.03 | 5.15 | 2.73 | <0.01 | 0.50 | Balance |
| Steel of the invention 13 | 0.380 | 0.41 | 0.62 | 0.0022 | 0.02 | 5.20 | 2.72 | <0.01 | 0.70 | Balance |
| Comparative steel 21 | 0.370 | 0.39 | 0.60 | 0.0020 | 0.01 | 5.18 | 2.40 | <0.01 | 0.59 | Balance |
| Comparative steel 22 | 0.380 | 0.41 | 0.61 | 0.0019 | 0.62 | 5.07 | 2.45 | <0.01 | 0.59 | Balance |
| Comparative steel 23 | 0.380 | 0.40 | 0.65 | 0.0020 | 0.60 | 5.15 | 2.69 | <0.01 | 0.58 | Balance |
| Comparative steel 24 | 0.379 | 0.60 | 0.59 | 0.0019 | 0.01 | 5.13 | 2.39 | <0.01 | 0.59 | Balance |
| Comparative steel 25 | 0.381 | 0.60 | 0.60 | 0.0018 | 0.30 | 5.15 | 2.39 | <0.01 | 0.60 | Balance |
| Comparative steel 26 | 0.379 | 0.59 | 0.62 | 0.0019 | 0.60 | 5.11 | 2.40 | <0.01 | 0.61 | Balance |
| Comparative steel 27 | 0.380 | 0.51 | 0.64 | 0.0024 | 0.01 | 5.15 | 2.72 | <0.01 | 0.60 | Balance |
| Convention steel 31 | 0.344 | 0.29 | 0.58 | 0.0021 | <0.01 | 5.10 | 2.40 | <0.01 | 0.57 | Balance |
| Convention steel 32 | 0.372 | 0.06 | 0.74 | 0.0023 | 0.01 | 5.35 | 3.01 | <0.01 | 0.75 | Balance |
| ※ including impurities | | | | | | | | | | |

**[0031]** For the steels of the invention, comparative steels, and conventional steels, steels having a thickness of 30 mm and a width of 60 mm were produced as followed. Steel ingots were produced by melting by 10 kg in a vacuum induction furnace and then homogenized by heat treatment at 1250°C for five hours. They were then hot forged at 1150°C. After annealed at 860°C, they were quenched from 1030°C. The quenching was performed by cooling in pressurized gas. Here, the time required for cooling the steel from the quenching temperature (1030°C) to an intermediate temperature (525°C) between the quenching temperature and room temperature (20°C) is defined as a "half cooling time". For example, when 10 minutes is required for cooling from 1030°C to 525°C, "half cooling" is expressed to be 10 minutes. Some steels were cooled for about three minutes in half cooling time as "rapid cooling", and some were cooled for about 40 minutes in half cooling time as a part in which the cooling rate is low, such as the central part of a large-size steel. Subsequently, the steels were tempered at various temperatures so as to have a hardness of 46HRC.

**[0032]** From each of steels of the invention, comparative steels, and conventional steels in Table 1 which are manufactured as described above, a 2-mm U-notch Charpy impact test piece was manufactured so that the longitudinal direction of the test piece is taken in the width direction of forged steel and the notch direction of the test piece is taken in the longitudinal direction of the steel (that is, it is cut out in the T direction). By using this 2-mm U-notch Charpy impact test piece, Charpy impact test was carried out at room temperature. The test results are given in Table 2. In the case where the Charpy impact test is carried out by using the test piece that is cut out in the T direction and tempered so as to have a relatively high hardness of 46HRC, the impact value is easily decreased by the influence of forged structure.

Therefore, if an impact value exceeding 34 (J/cm$^2$) is obtained, it can be said that the steel has an excellent toughness. In particular, if an impact value exceeding 40 (J/cm$^2$) is obtained, the toughness of steel is very excellent.

**[0033]**

[Table 2]

| Sample | 2-mm U-notch Charpy impact value (J/cm$^2$) | |
|---|---|---|
| | quenching with half cooling time of 3 min. | quenching with half cooling time of 40 min. |
| Steel of the invention 1 | 49.8 | 37.5 |
| Steel of the invention 2 | 52.5 | 36.2 |
| Steel of the invention 3 | 57.2 | 43.3 |
| Steel of the invention 4 | 53.9 | 34.4 |
| Steel of the invention 5 | 53.0 | 40.6 |
| Steel of the invention 6 | 52.5 | 41.1 |
| Steel of the invention 7 | 52.5 | 47.9 |
| Steel of the invention 8 | 54.9 | 41.1 |
| Steel of the invention 9 | 48.4 | 41.5 |
| Steel of the invention 10 | 42.4 | 36.6 |
| Steel of the invention 11 | 47.0 | 34.4 |
| Steel of the invention 12 | 49.3 | 39.7 |
| Steel of the invention 13 | 43.8 | 34.4 |
| Comparative steel 21 | 38.0 | 29.8 |
| Comparative steel 22 | 52.1 | 32.3 |
| Comparative steel 23 | 54.9 | 43.8 |
| Comparative steel 24 | 44.3 | 31.4 |
| Comparative steel 25 | 37.5 | 33.6 |
| Comparative steel 26 | 51.6 | 30.1 |
| Comparative steel 27 | 47.9 | 33.6 |
| Conventional steel 31 | 42.4 | 21.6 |
| Conventional steel 32 | 41.1 | 34.4 |

**[0034]** From the results given in Table 2, it is revealed that if quenching is performed by rapid cooling, even the comparative steels and conventional steels, having a composition out of the composition range of the invention, can provide a relatively high impact value even by using a test piece cut out in the T direction. However, in the case where quenching is performed at a low cooling rate of about half cooling time being 40 minutes, for comparative steel 21 having low Mo content and added with Ni, and comparative steel 22 having low Mo content, the hardenability is poor, and the impact value is low. Also, for comparative steels 24 to 27 having low Si content, the impact value is low.

**[0035]** For conventional steel 31 in which the carbon content is a little low and Ni is not added in addition to the low Mo content, the hardenability is considerably poor, and the impact value is the lowest. For conventional steel 32 in which the Mo content is high and the impact value tends to be low, the machinability is insufficient because of very low Si content.

**[0036]** In contrast, for steels of the invention 1 to 13 in which the chemical composition is controlled optimally, the excellent toughness is maintained even if the steels are quenched at a low cooling rate. For comparative steel 23 having a composition in which only the content of Ni, which is an element for enhancing toughness, deviates greatly from the optimum composition of the invention, the toughness is excellent even if the cooling rate is low.

EXAMPLE 2

**[0037]** Next, high-temperature strengths were compared between the steels of the invention given in Table 1 and comparative steel 23 that provided a high impact value among comparative steels. The test piece was taken so that the longitudinal direction of test piece aligns with the longitudinal direction of forged steel (that is, the piece is cut out in the L direction), and the strength was evaluated by tensile strength obtained through tensile test carried out at a high temperature of 650°C. The tensile test was started after the test piece was heated at 650°C and held for 10 minutes. The test results are given in Table 3.

**[0038]**

[Table 3]

| Sample | Tensile strength at 650°C (MPa) | |
|---|---|---|
| | quenching with half cooling time of 3 min. | quenching with half cooling time of 40 min. |
| Steel of the invention 1 | 645 | 603 |
| Steel of the invention 2 | 656 | 606 |
| Steel of the invention 3 | 675 | 621 |
| Steel of the invention 4 | 638 | 632 |
| Steel of the invention 5 | 650 | 635 |
| Steel of the invention 6 | 678 | 641 |
| Steel of the invention 7 | 664 | 628 |
| Steel of the invention 8 | 657 | 638 |
| Steel of the invention 9 | 661 | 621 |
| Steel of the invention 10 | 648 | 622 |
| Steel of the invention 11 | 667 | 614 |
| Steel of the invention 12 | 638 | 596 |
| Steel of the invention 13 | 675 | 636 |
| Comparative steel 23 | 603 | 589 |

**[0039]** It is found that comparative steel 23 having a composition out of the optimum composition of the invention provides excellent toughness but low high-temperature strength since it contains too high Ni content. On the other hand, it is found that all of steels of the invention have high high-temperature strength.

EXAMPLE 3

**[0040]** For the steels quenched at a low cooling rate of half cooling time of about 40 minutes among the steel of the invention 6, comparative steels 21 to 23 and 26, and conventional steels 31 and 32 manufactured in Example 1, their structures were observed before they were tempered as described below. First, a sample for observing the structure were taken from each of these steels by 10 mm square, and etched through the SPEED method to observe the structure with a scanning electron microscope (x5000). As examples, images obtained from steel of the invention 6 and conventional steel 31 are shown in Figs. 1 and 4, respectively. By using such an image, the area percentages of a granular structure and an acicular structure were measured through image analysis. Similarly, as examples, the measured granular structures of steel of the invention 6 and conventional steel 31 are shown in schematic views of Figs. 2 and 5, respectively, and the measured acicular structures of steel of the invention 6 and conventional steel 31 are shown in schematic views of Figs. 3 (excluding "x" mark) and 6, respectively. Three fields of view were measured on each structure of each sample, and the mean value was made as an area percentage. Also, the above-mentioned sample was polished again, and then finished by electropolishing to measure the quantity of retained austenite through the X-ray diffractometry. The results of the above measurements are collectively given in Table 4.

**[0041]**

[Table 4]

| Sample | Area% of granular structure (A%) | Area% of acicular structure (B%) | Volume% of remaining austenite (C%) |
|---|---|---|---|
| Steel of the invention 6 | 23 | 36 | 12 |
| Comparative steel 21 | 34 | 17 | 8 |
| Comparative steel 22 | 46 | 2 | 8 |
| Comparative steel 23 | 43 | 2 | 9 |
| Comparative steel 26 | 55 | 5 | 9 |
| Conventional steel 31 | 39 | 20 | 9 |
| Conventional steel 32 | 32 | 22 | 9 |

**[0042]** The results of Charpy impact test are given in Table 5 together with the tempered hardnesses of test pieces and the values X derived from the relational expression between the hardness and the percentages of structures of the invention, while the results of Charpy impact test are also given in Example 1.

**[0043]**

[Table 5]

| Sample | 2-mm U-notch Charpy impact value ($J/cm^2$) | Hardness of Charpy impact test piece (HRC) | X |
|---|---|---|---|
| Steel of the invention 6 | 41.1 | 45.2 | 41.3 |
| Comparative steel 21 | 29.8 | 45.1 | 30.7 |
| Comparative steel 22 | 32.3 | 46.0 | 37.8 |
| Comparative steel 23 | 43.8 | 45.3 | 49.0 |
| Comparative steel 26 | 30.1 | 45.6 | 26.2 |
| Conventional steel 31 | 21.6 | 46.2 | 24.5 |
| Conventional steel 32 | 34.4 | 46.5 | 31.3 |
| ※X=[-0.36*(HRC)-1.47*(A%)-1.67*(B%)+6.55*(C%)+72.91] | | | |

**[0044]** From these results, it is revealed that, in the case where the steel is quenched at a cooling rate as low as about half cooling time of 40 minutes, the quenched structures of comparative steel 21 and conventional steel 31 each having a low impact value have much granular structure and less volume of retained austenite, and the acicular structure exerting a great adverse influence on the toughness develops, and moreover the value X is considerably small. For conventional steel 32 having a low impact value as well, the quenched structure thereof is approximate to the those of comparative steel 21 and conventional steel 31, while the toughness tends to be improved by the improved balance of each structure (that is, the increase in value X).

**[0045]** Since comparative steel 22 and comparative steel 26 have low Mo content but too high Ni content, the granular structure develops so that the impact value is low. For these two samples, comparative steel 26 shows a tendency to generate the acicular structure since the Si content thereof is high in addition thereto.

**[0046]** In contrast, the quenched structure of steel of the invention 6 having optimally controlled chemical composition has a developed acicular structure, less granular structure, and much retained austenite effective in improving the toughness. The balance of structures (that is, the value X) is also excellent. The quenched structure of comparative steel 23 which has high toughness due to high Ni content meets a condition that the value X is not less than 40 although it has much granular structure. However, comparative steel 23 has low high-temperature strength as described above.

## INDUSTRIAL APPLICABILITY

**[0047]** A hot-working tool steel having improved toughness and high-temperature strength according to the invention can be applied not only to many kinds of hot-working tools such as press dies, forging dies, die-casting dies, and extruding tools but also to hot-working tool members such as dies to which high load is applied.

BRIEF DESCRIPTION OF THE DRAWINGS

**[0048]**

Fig. 1 is a cross-sectional micrograph showing an example of the quenched structure of a hot-working tool steel according to the invention;
Fig. 2 is schematic view selecting a granular structure from the quenched structure shown in Fig. 1;
Fig. 3 is schematic view selecting an acicular structure from the quenched structure shown in Fig. 1;
Fig. 4 is a cross-sectional micrograph showing an example of the quenched structure of a hot-working tool steel of a comparative example;
Fig. 5 is schematic view selecting a granular structure from the quenched structure shown in Fig. 4; and
Fig. 6 is schematic view selecting an acicular structure from the quenched structure shown in Fig. 4.

## Claims

**1.** A hot-working tool steel having excellent toughness and high-temperature strength, consisting essentially of, by mass percent,
0.34 to 0.40 % of carbon,
0.3 to 0.5 % of Si,
0.45 to 0.75 % of Mn,
0 to less than 0.5 % of Ni,
4.9 to 5.5 % of Cr,
2.5 to 2.9 % of a total amount of Mo and a half of W, Mo and W being contained singly or in combination,
0.5 to 0.7 % of V, and
the balance being Fe and unavoidable impurities.

**2.** The hot-working tool steel according to claim 1, containing 0.35 to 0.39 % of carbon, by mass percent.

**3.** The hot-working tool steel according to claim 1, containing 0.35 to 0.45 % of Si, by mass percent.

**4.** The hot-working tool steel according to claim 1, containing 0.5 to 0.7 % of Mn, by mass percent.

**5.** The hot-working tool steel according to claim 1, containing 0.01 to 0.3 % of Ni, by mass percent.

**6.** The hot-working tool steel according to claim 1, containing 5.0 to 5.4 % of Cr, by mass percent.

**7.** The hot-working tool steel according to claim 1, containing 2.6 to 2.8 % of a total amount of Mo and a half of W, by mass percent, Mo and W being contained singly or in combination.

**8.** The hot-working tool steel according to claim 1, containing 0.55 to 0.65 % of V, by mass percent.

**9.** The hot-working tool steel according to claim 1, having a hardness of not lower than 40HRC.

**10.** The hot-working tool steel according to claim 1, having a hardness of not lower than 43HRC.

**11.** The hot-working tool steel according to claim 1, having a hardness of not lower than 45HRC.

**12.** The hot-working tool steel according to anyone of claims 9 to 11, having a hardness of not higher than 49HRC.

**13.** The hot-working tool steel according to claim 1, wherein the steel has a cross-sectional structure, after quenching, including a granular structure and an acicular structure, an area percentage of the granular structure (A%) being not more than 45%, an area percentage of the acicular structure (B%) being not more than 40%, and a volume percentage of retained austenite (C%) being 5 to 20%.

**14.** A method of producing a hot-working tool steel having excellent toughness and high-temperature strength, wherein the steel according to claim 13 is tempered so that a value X determined by a following relational expression between a tempered hardness (HRC) and percentages of the structures is not smaller than 40:

$$X = [-0.36\times(HRC)-1.47\times(A\%)-1.67\times(B\%)+6.55\times(C\%)+72.91].$$

**15.** The method according to claim 14, wherein the steel is tempered to 40 to 49HRC.

**16.** The method according to claim 14, wherein the steel is tempered to 43 to 49HRC.

**17.** The method according to claim 14, wherein the steel is tempered to 45 to 49HRC.

FIG.1


FIG.2

FIG.3

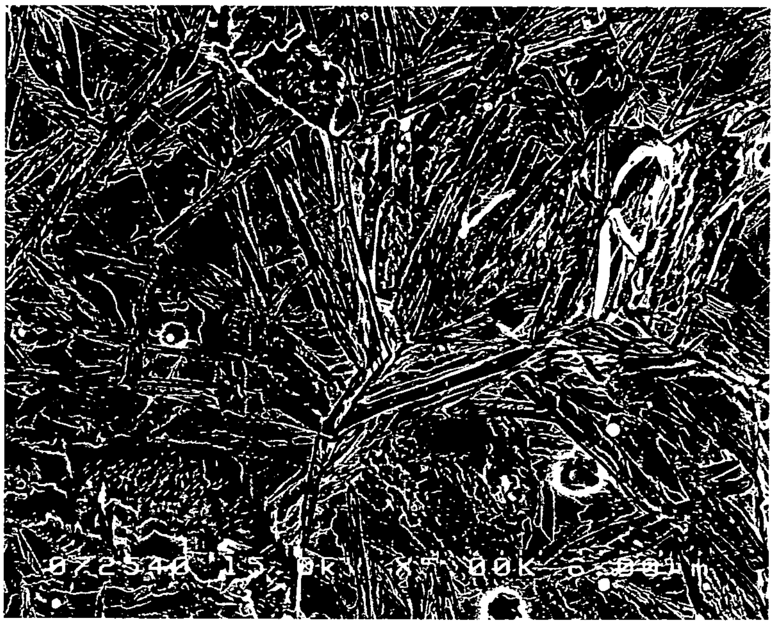

FIG.4

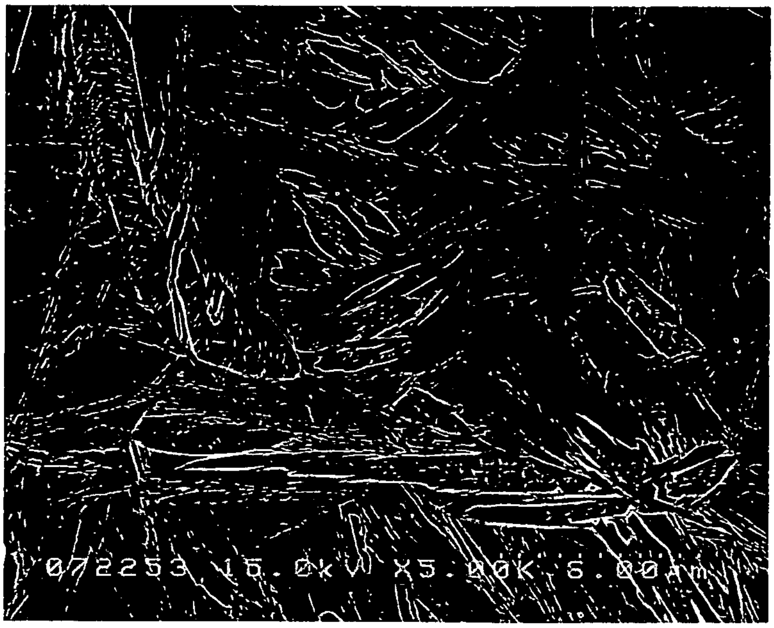

FIG.5

FIG.6

**INTERNATIONAL SEARCH REPORT**

International application No.
PCT/JP2007/067915

A. CLASSIFICATION OF SUBJECT MATTER
*C22C38/00*(2006.01)i, *C22C38/46*(2006.01)i, *C21D6/00*(2006.01)n

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)
C22C38/00-38/60, C21D6/00

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 | 1996-2007 |
| Kokai Jitsuyo Shinan Koho | 1971-2007 | Toroku Jitsuyo Shinan Koho | 1994-2007 |

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
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| X | JP 2-179848 A (Aichi Steel Works Ltd.), 12 July, 1990 (12.07.90), Claims; table 2 (Family: none) | 1-17 |
| X | JP 8-188852 A (Kobe Steel, Ltd., Nippon Koshuha Kogyo Kabushiki Kaisha), 23 July, 1996 (23.07.96), Claims (Family: none) | 1-4,6-17 |

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

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 11 December, 2007 (11.12.07) | 25 December, 2007 (25.12.07) |

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**INTERNATIONAL SEARCH REPORT**

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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## REFERENCES CITED IN THE DESCRIPTION

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