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(71) Applicant: **Hitachi Metals, Ltd.**
Tokyo 105-8614 (JP)

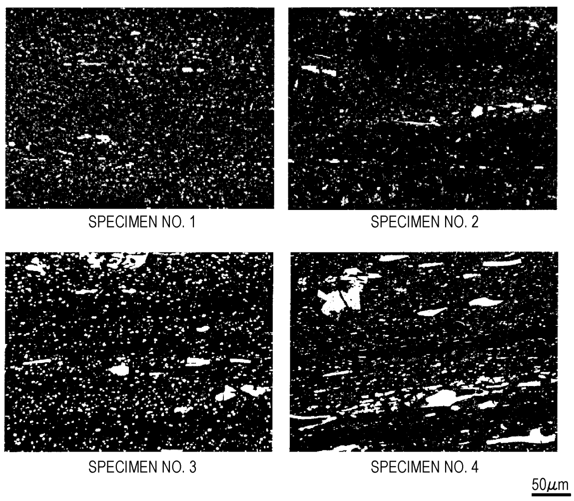
(72) Inventors:
- **SHOUJI Tatsuya**
Yasugi-shi
Shimane 692-8601 (JP)
- **DATE Masayoshi**
Yasugi-shi
Shimane 692-8601 (JP)

(74) Representative: **Herzog, Fiesser & Partner Patentanwälte PartG mbB**
Isartorplatz 1
80331 München (DE)

(54) STEEL MATERIAL FOR DIE AND PROCESS FOR PRODUCING SAME, PROCESS FOR PRODUCING PREHARDENED STEEL PRODUCT FOR DIE, AND PROCESS FOR PRODUCING COLD WORKING DIE

(57) A steel raw material applied to manufacture of a cold working die with a hardness of 58HRC or more, is cut for use as a prehardened steel material having a size corresponding to a dimension of the cold working die. The steel raw material is a steel raw material for a die having a quenched and tempered structure and hardness of 58 HRC or more. The steel raw material for a die contains 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material. Furthermore, manufacturing method of a steel raw material for a die that is preferable to obtain the steel raw material for a die, a subsequent manufacturing method of a prehardened steel material, and a manufacturing method of a cold working die are provided.

FIG. 1



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Description

TECHNICAL FIELD

[0001] The present invention relates to a steel raw material for a cold working die used for molding associated parts of household appliances, cellular phones, automobiles, and the like, and a manufacturing method of the steel raw material. The present invention also relates to a manufacturing method of a prehardened steel material for the die. The present invention further relates to a manufacturing method of the cold working die.

BACKGROUND ART

[0002] For shaping a cold working die used in, for example, press molding such as bending, drawing, and punching of plate materials, a steel material having a dimension corresponding to the entire die is previously prepared in the first place. Then, the prepared steel material is subjected to machining such as drilling and cutting. The steel material is further subjected to quenching and tempering treatments during manufacture of the die to be adjusted to have desired hardness, in order to provide abrasion resistance during use of the manufactured cold working die. Since molding compounds recently have increased strength, the above-described die is required to have high quenching and tempering hardness of preferably 58 HRC or more, and further preferably 60 HRC or more.

[0003] When manufacturing such a die having hardness of as high as 58 HRC or more, a steel material that has been adjusted to have the above-described high hardness cannot be easily machined into a die shape. Therefore, in the manufacturing process of a cold working die having high hardness, an annealed steel material having low hardness is subjected to rough machining to have a shape closer to a final shape of the die in the first place. Thereafter, quenching and tempering treatments are performed. After the quenching and tempering treatments, the steel material is subjected to finish machining for, for example, correcting deformation that has occurred during the quenching and tempering treatments. In this manner, the steel material is shaped into a final die (Patent Literatures 1 to 3).

[0004] As the above-described steel material used in the manufacture of a die, there is provided a steel raw material that has been adjusted into a suitable size corresponding to a dimension of the die in order to facilitate handling and reduce cutting cost in the subsequent cutting. Such adjustment into a suitable size is exclusively performed by cutting. In brief, this adjustment uses, as a steel raw material, a large-sized steel piece, such as a slab, bloom and billet, which is obtained by hot-processing a steel ingot by blooming, forging or the like. Then, the adjustment is performed by a process of cutting this steel raw material into individual steel materials with a blade of a saw such as a band saw and a circular saw. Since the hot-processed steel raw material (that is, a steel piece) is usually in a low-hardness annealed condition before quenching and tempering, the above-described cutting is easily performed.

[0005] It is noted that a prehardened steel material is increasingly used in the above-described manufacturing process of a cold working die in order to reduce man-hours (Patent Literatures 4 to 10). The prehardened steel material is a steel material that has been previously quenched and tempered into desired hardness. In the desired hardness, machining properties such as drilling and cutting of the steel material improves. When the prehardened steel material is used, quenching and tempering are not necessary after this prehardened steel material has been collectively machined into a final die shape. This allows for omission of finish machining.

[0006] The prehardened steel material is also obtained by cutting a steel raw material similarly to the above-described steel material supplied in an annealed condition. It is proposed that, instead of performing quenching and tempering after cutting the annealed steel raw material (a steel piece) into individual steel materials, quenching and tempering for prehardening are performed to the whole steel raw material before cutting (Patent Literatures 11 and 12). In this case, the whole prehardened steel raw material is cut into individual steel materials. This previously prehardened steel raw material is collectively quenched and tempered. For this reason, cutting this steel raw material into individual steel materials enables, for example, a plurality of steel materials having less varied mechanical properties to be obtained at once. Furthermore, a die manufacturer, where a steel raw material supplied from a steel raw material manufacturer is cut into steel materials which are machined to manufacture dies, does not need to perform quenching and tempering. This allows for omission of facilities and labor for heat treatment.

CITATION LIST

PATENT LITERATURE

[0007]

Patent Literature 1: JP-A-2009-132990
Patent Literature 2: JP-A-2006-193790

Patent Literature 3: JP-A-2002-012952
Patent Literature 4: WO 2012/043228 A
Patent Literature 5: WO 2012/115024 A
Patent Literature 6: WO 2012/115025 A
Patent Literature 7: JP-A-2008-189982
Patent Literature 8: JP-A-2001-316769
Patent Literature 9: JP-A-2005-272899
Patent Literature 10: JP-A-2001-107181
Patent Literature 11: JP-A-2006-150487
Patent Literature 12: JP-A-2001-129722

SUMMARY OF INVENTION

PROBLEMS TO BE SOLVED BY THE INVENTION

[0008] When cutting the previously prehardened steel raw material, it is not easy to cut a steel raw material having high hardness. Regarding this cutting, there is proposed a method of easily cutting the prehardened steel raw material for a die by improving a saw blade of a cutting tool to provide durability (Patent Literatures 11 and 12). However, even with this method, the hardness of the prehardened steel material that can be cut is about 35 HRC at best.

[0009] On the other hand, in applications of cold working dies, there are proposed various prehardened steel materials that can achieve high hardness of preferably 58 HRC or more, and further preferably 60 HRC or more, by quenching and tempering. However, when using these high hardness prehardened steel materials, there has not been used the manufacturing method of a cold working die, including: adjusting a steel raw material to have high hardness (58 HRC or more); cutting the adjusted steel raw material; and thereafter performing machining the cut material to obtain a die.

[0010] An object of the present invention is to provide: a steel raw material having excellent cutting properties in high hardness of 58 HRC or more and a manufacturing method of the steel raw material; a method of establishing the steel raw material thereby to manufacture a prehardened steel material directly from this steel raw material previously prehardened; and a manufacturing method of a cold working die including machining the obtained prehardened steel material.

SOLUTIONS TO THE PROBLEMS

[0011] The present inventors have conducted research on factors influencing cutting properties of various steel raw materials that can achieve high hardness of 58 HRC or more by quenching and tempering. As a result, the present inventors understood that a technique of providing carbides to a structure, among various alloy design techniques that have been utilized for providing high hardness of 58 HRC or more, particularly deteriorates cutting properties. The present invention has been achieved by finding that a steel raw material having high hardness of 58 HRC or more and containing a specific regulated amount of carbides can be cut without particularly improving known cutting conditions such as various saw blades.

[0012] Thus, the present invention is a steel raw material for a die to be applied to manufacture of a cold working die having hardness of 58 HRC or more, and to be cut for use as a prehardened steel material having a size corresponding to a dimension of the cold working die. The steel raw material has a quenched and tempered structure and hardness of 58 HRC or more, and contains 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material. The steel raw material preferably has hardness of 60 HRC or more.

[0013] Moreover, the present invention is a manufacturing method of a steel raw material for a die to be applied to manufacture of a cold working die having hardness of 58 HRC or more, and to be cut for use as a prehardened steel material having a size corresponding to a dimension of the cold working die, the method including: a first step of hot-processing a steel ingot to obtain a steel piece; and a second step of quenching and tempering the steel piece obtained in the first step to obtain the steel raw material having hardness of 58 HRC or more and containing 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material.

[0014] Moreover, the present invention is a manufacturing method of a prehardened steel material for a die to be applied to manufacture of a cold working die having hardness of 58 HRC or more, the method including: a first step of hot-processing a steel ingot to obtain a steel piece; a second step of quenching and tempering the steel piece obtained in the first step to obtain a steel raw material having hardness of 58 HRC or more and containing 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material; and a third step of cutting the steel raw material obtained in the second step to obtain a prehardened steel material having a size corresponding to a dimension of the cold working die.

[0015] Furthermore, the present invention is a manufacturing method of a cold working die having hardness of 58 HRC or more, the method including: a first step of hot-processing a steel ingot to obtain a steel piece; a second step of quenching and tempering the steel piece obtained in the first step to obtain a steel raw material having hardness of 58 HRC or more and containing 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material; a third step of cutting the steel raw material obtained in the second step to obtain a prehardened steel material having a size corresponding to a dimension of a cold working die; and a fourth step of machining the prehardened steel material obtained in the third step into a die shape to obtain the cold working die.

[0016] In the above described present invention, the steel raw material in the second step preferably has hardness of 60 HRC or more. The quenching the steel piece in the second step is allowed to be performed after the steel piece obtained by hot-processing a steel ingot in the first step has been annealed. Alternatively, the quenching the steel piece in the second step is also allowed to be direct quenching subsequently performed to the steel piece obtained by hot-processing a steel ingot in the first step.

[0017] The above-described present invention may further include, in addition to the first to fourth steps described above, a fifth step of performing surface treatment to a surface of the cold working die obtained in the fourth step.

EFFECTS OF THE INVENTION

[0018] According to the present invention, the steel material can be cut from the steel raw material which has been previously prehardened to have high hardness of 58 HRC or more. This enables, for example, a plurality of prehardened steel materials having less varied mechanical properties to be obtained at once. Furthermore, the use of these prehardened steel materials allows for omission of quenching and tempering of the die obtained by machining the prehardened steel materials. Therefore, mechanical properties of the cold working die having high hardness of 58 HRC or more can be stabilized, and overall manufacturing efficiency can be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

FIG. 1 is microstructure photographs illustrating examples of primary carbides distributed in cross-sectional structures of specimens Nos. 1 to 4, which are steel raw materials before cutting, according to examples of the present invention and comparative examples in Example 1.
FIG. 2 is drawing-substitute photographs illustrating examples of flanks of saw blades after having cut the specimens Nos. 1 to 4 in Example 1.
FIG. 3 is microstructure photographs illustrating examples of primary carbides distributed in cross-sectional structures of specimens Nos. 5-A and 5-B, which are steel raw materials before cutting, according to examples of the present invention in Example 2.
FIG. 4 is drawing-substitute photographs illustrating examples of flanks of saw blades after having cut the specimens Nos. 5-A and 5-B in Example 2.
FIG. 5 is a graph illustrating areas of abrasion formed on the flanks of the saw blades after having cut the specimens Nos. 1 to 5 (A and B) in Examples 1 and 2.

DESCRIPTION OF EMBODIMENTS

[0020] A feature of the present invention is that the present inventors have found that specific carbide in a structure is a factor directly causing deterioration of cutting properties of a steel raw material. Furthermore, optimal adjustment of a distribution state of the specific carbide enables even a steel raw material having high hardness of 58 HRC or more to be easily cut, and also improves overall efficiency in manufacturing a cold working die with a prehardened steel material. Hereinafter, there will be described a method of manufacturing a cold working die from the steel raw material according to the present invention via the prehardened steel material for a die.

(1) First step: Hot-processing a steel ingot to obtain a steel piece.

[0021] The first step is a step of hot-processing a steel ingot in order, for example, to improve a cast structure of the steel ingot. Known processes or the like may apply to the first step. For example, a method of obtaining a steel ingot is any method including continuous casting, and vacuum arc remelting and electroslag remelting which are performed to a steel ingot temporarily obtained by casting, as well as a standard ingot casting which uses an ingot case. Then, the obtained steel ingot is hot-processed by blooming, forging or the like so as to be shaped into a steel piece such as a slab, bloom and billet. It is noted that the steel ingot and the steel piece may be subjected as necessary to, for example, soaking to be retained at a certain temperature for a certain time as described later.

[0022] (2) Second step: Quenching and tempering the steel piece obtained in the first step to obtain a steel raw material having hardness of 58 HRC or more and containing 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material.

[0023] The second step is a step of obtaining a steel raw material that is previously adjusted into desired hardness of a die by previously prehardening the steel piece obtained in the first step prior to cutting the steel piece in the third step described later. The second step is also a step that is important to the present invention for providing excellent cutting properties to this steel raw material.

[0024] As described above, in applications of cold working dies, there is desired a prehardened steel material that can achieve high hardness of preferably 58 HRC or more, and further preferably 60 HRC or more, by quenching and tempering. When a known steel raw material adjusted to have hardness of 58 HRC or more was cut for obtaining this prehardened steel material, wear such as abrasion and chipping proceeded in a blade of a cutting tool, and cutting resistance was large. When the wear proceeds in the blade of the cutting tool, original cutting ability of the cutting tool is lost, causing occurrence of "blade deviation" in which a cutting line after cutting bends. When this blade deviation becomes excessively large (in general, more than 1 mm above a desired cutting line), the cutting surface loses flatness, possibly causing necessity of extra and drastic correction in shape in a downstream step. Accordingly, productivity of dies decreases. Furthermore, when cutting resistance becomes extremely large, a motor of a cutting machine has excessive load. As a result, when cutting is eventually interrupted, the cutting machine comes to require extra man-hours for maintenance of the cutting machine, thereby significantly reducing productivity of dies too.

[0025] To address this concern, the present inventors investigated the steel raw material adjusted into hardness of 58 HRC or more for factors deteriorating cutting properties. As a result, the present inventors found that a direct factor deteriorating cutting properties is not the value itself of hardness of 58 HRC or more, but is coarse primary carbides richly distributed in the quenched and tempered structure. In brief, the primary carbides in the steel raw material have hardness comparable to that of a sintered hard alloy or hard coat constituting a blade of a cutting tool used for cutting the steel raw material. For this reason, the primary carbides directly influence wear of a blade during cutting. Furthermore, the degree of wear in a blade attributable to, among other primary carbides, the coarse primary carbides having a size of as large as tens microns which can be observed through an optical microscope, is particularly large. Therefore, when a steel raw material according to the present invention contains a reduced area ratio of coarse primary carbides in the above-described structure, even the steel raw material having hardness of 58 HRC or more can have improved cutting properties. Specifically, when primary carbides having a circle-equivalent diameter of 5 μm or more are contained by 2% by area or less in a cross-sectional structure of a steel raw material having hardness of 58 HRC or more, the blade deviation and the cutting resistance can be inhibited from increasing, and the cutting properties can be improved. Such primary carbides are contained by preferably 1.5% by area or less, more preferably 1% by area or less. The degree of wear in a blade attributable to the primary carbides having a circle-equivalent diameter of 5 μm or more is particularly large. When the primary carbides having such a circle-equivalent diameter are contained by more than 2% by area in terms of area ratio, the wear that proceeds in a blade of a cutting tool becomes significant.

[0026] Since the steel raw material according to the present invention has excellent cutting properties, the steel raw material before cutting may have an unlimited size. Thus, the steel raw material according to the present invention can have a large size, such that a steel material having a dimension of as large as 300 mm in thickness and 700 mm in width, which can be used as, for example, a steel material for a large-sized press die for forming an automobile related component, can be cut from the steel raw material.

[0027] The area ratio of the above-described primary carbides in the steel raw material according to the present invention can be obtained by quenching the steel piece obtained in the first step, performing solution treatment on the steel piece as necessary, or the like. The solution treatment allows the coarse primary carbides to be solid-dissolved in a matrix. The steel raw material can also be obtained by performing the soaking or the like on a steel ingot before or during hot-processing in the first step. As a component composition of the steel raw material containing the reduced coarse primary carbides (that is, a prehardened steel material obtained by cutting the steel raw material) according to the present invention, a conventionally proposed composition for cold die steel may be applied such that, for example, hardness of 58 HRC or more is maintained after the quenching and tempering. In the present invention, the component composition is preferably adjusted as below.

[0028] C is an important element which is solid-dissolved in steel and forms carbide together with a carbide-forming element in steel to provide hardness of 58 HRC or more for a cold working die. However, an excessive content of C increases a content of coarse primary carbides in the structure, causing a decrease in cutting properties of the steel raw material. Furthermore, when surface coating treatment by PVD (physical vapor deposition) is performed to a surface of a cold working die, the surface coating treatment properties decrease. Therefore, C is preferably contained by 0.6% by mass or more and 1.2% by mass or less.

[0029] Cr and C described above form M_7C_3 carbide which is primary carbide. This allows Cr to provide hardness to the cold working die. For achieving high hardness of 58 HRC or more, Cr is preferably added by 3.0% by mass or more. However, excessive addition of Cr increases a content of the coarse primary carbide, thereby reducing cutting properties of the steel raw material. Therefore, Cr is preferably added by 9.0% by mass or less. Cr is more preferably added by 7.0% by mass or less, and further preferably added by 5.0% by mass or less.

[0030] V and Nb are elements which are effective in forming MC carbide that is primary carbide in the quenched and tempered structure to achieve the cold working die having hardness of 58 HRC or more. However, the MC carbide is very hard among other primary carbides. Therefore, an excessive content of V or Nb causes formation of the MC carbide in a large amount, thereby significantly reducing cutting properties of the steel raw material. Also, V and Nb each have an effect similar to the above point. Here, the degree of the effect by V is about half of that by Nb when the contents are identical. Therefore, these contents can be comprehensively dealt with based on the relationship of (Nb + 1/2V). One or two of V and Nb according to the relational formula (Nb + 1/2V) are preferably contained by 1.0% by mass or less, and more preferably 0.8% by mass or less.

[0031] As described above, the component composition of the steel raw material (prehardened steel material) according to the present invention is preferably the component composition of cold die steel. That is, C: 0.6 to 1.2% and Cr: 3.0 to 9.0% are contained in terms of % by mass, and selectively, one or two of V and Nb according to the relational formula (Nb+1/2V) are contained by 1.0% by mass or less.

[0032] In addition, the steel raw material (prehardened steel material) according to the present invention may contain Si, Mn, Mo, W, or the like. Mn is an element which is solid-dissolved in steel and effective for providing quenching properties. Si is an element which is solid-dissolved in steel and effective for providing hardness. Mo and W are elements which form fine carbide and are effective for providing temper hardness. The steel raw material (prehardened steel material) according to the present invention may further contain Al, S, Ni, Cu, or the like. Al and S contribute to improvement in machining properties when machining the prehardened steel material adjusted into hardness of 58 HRC or more in the fourth step described later. Al, Ni, and Cu contribute to improvement in hardness and toughness of the cold working die. Furthermore, an appropriate amount of Ca, Ti, Zr, rare earth metal, or the like may be added for finely dispersing primary carbides. The component composition of cold tool steel disclosed in Patent Literatures 5 and 6, for example, may be applied to the component composition of the steel raw material (prehardened steel material) according to the present invention.

[0033] Also, the steel raw material according to the present invention does not need to undergo an annealed condition where cutting is easily performed with low hardness. Therefore, other than performing quenching after annealing the steel piece obtained by hot-processing a steel ingot in the first step, "direct quenching" subsequently performed to the steel piece obtained by hot-processing a steel ingot in the first step can be applied as the quenching to the steel piece to be performed in the second step. The quenching is followed by tempering, thereby enabling manufacture of the steel raw material having high hardness of 58 HRC or more. Thus, an annealing step, which is usually performed after hot-processing, can be omitted.

[0034] (3) Third step: Cutting the steel raw material obtained in the second step to obtain a prehardened steel material having a size corresponding to a dimension of a cold working die.

[0035] A particular design is not necessary for cutting the steel raw material in the third step. The steel raw material can be cut into a prehardened steel material having an individually desired dimension using, for example, a blade of a saw such as a band saw and circular saw, in accordance with a known cutting method or the like. Usually, a hard oxide coat is formed on a surface of the hot-processed steel piece. However, this oxide coat has minor influence on cutting properties of the steel raw material. Therefore, in the present invention, the whole oxide coat does not need to be removed when cutting the steel raw material, except when, for example, accurate positioning of the steel raw material with respect to a cutting machine is intended. This oxide coat also does not need to be removed before the quenching in the second step. Thus, the above-described direct quenching can be applied as the quenching.

[0036] (4) Fourth step: Machining the prehardened steel material obtained in the third step into a die shape to obtain a cold working die.

[0037] The prehardened steel material according to the present invention does not need to be distinguished from a known prehardened steel material, at the time of the "prehardened steel material" which has been already cut into a dimension of an individual cold working die. Therefore, in the fourth step and thereafter, the prehardened steel material can be finished into the shape of a cold working die by a known machining or the like. The use of the prehardened steel material as a steel material for a die eliminates concern with heat treatment deformation caused by quenching and tempering after the prehardened steel material has been collectively machined into a final shape of a die. This allows for omission of finish machining.

[0038] (5) Fifth step: If necessary, performing surface treatment to a surface of the cold working die obtained in the fourth step.

[0039] The cold working die according to the present invention also does not need to be distinguished from a known cold working die at the time of the "cold working die" which has been finished into a desired shape. Therefore, if necessary, a surface of the cold working die may be subjected to, for example, surface hardening treatment for forming a nitride layer, oxide layer or the like, surface coating treatment for forming various hard coats, lubricating coats and the like by a PVD, CVD (chemical vapor deposition), or the like, in accordance with a known surface treatment method or the like.

Example 1

[0040] Steel ingots Nos. 1 to 4 having component compositions illustrated in Table 1 were prepared.

[Table 1]

Steel ingot No.	Component composition (mass%)													
	C	Si	Mn	P	S	Ni	Cr	W	Mo	V	Cu	Al	Nb	Fe
1	0.70	1.97	1.00	0.016	0.0550	0.02	7.23	<0.01	1.51	0.01	0.01	0.018	<0.01	Bal.
2	0.81	1.44	0.80	0.027	0.0540	0.06	4.93	0.01	1.03	0.27	0.03	0.069	<0.01	Bal.
3	1.01	1.01	0.44	0.015	0.0700	0.43	8.49	0.30	0.81	0.02	0.31	0.330	0.08	Bal.
4	1.35	0.29	0.39	0.025	0.005	0.11	11.96	0.04	0.84	0.25	0.03	0.018	<0.01	Bal.

* "<" indicates additive free.

[0041] Next, these steel ingots were hot forged at a forging ratio of about 10 to obtain steel pieces. Then, the steel pieces were cooled, and thereafter annealed at 860°C. Then, specimens to be evaluated for cutting properties (that is, steel raw materials before cutting) Nos. 1 to 4 were prepared from the annealed steel pieces. The specimens each had a dimension of 500 mm in length (an expanding direction by the above-described forging), 300 mm in width, and 75 to 150 mm in thickness. Four surfaces, other than two surfaces each having a dimension of 500 mm × 300 mm, of the surfaces of each specimen, were ground to remove oxide films on the four surfaces. Then, the grinding was followed by quenching treatment with air cooling down from 1030°C, and tempering treatment at 500 to 540°C twice, thereby adjusting each specimen into target hardness of 60 HRC.

[0042] Then, specimens Nos. 1 to 4 were each evaluated for primary carbides distributed in the structure. First, a cross section of 15 mm × 15 mm, which is parallel to the length direction (expanding direction) of the specimen, was designated. This cross section was polished with a diamond slurry into a mirror surface. Next, the cross section was corroded with 10% nital so that boundaries between primary carbides and a matrix become apparent when observing the cross-sectional structure. The corroded cross section was observed using a 200 times optical microscope, and 20 visual fields each being consisted of a region of 877 μm × 661 μm were photographed. FIG. 1 is examples of structure photographs of cross sections for specimens Nos. 1 to 4 (primary carbides are indicated as a distribution in white). These structure photographs were each image-processed to extract primary carbides having a circle-equivalent diameter of 5 μm or more which were observed in the cross-sectional structure, and an area ratio of the primary carbides in the cross-sectional structure was calculated as an average value of those for 20 visual fields.

[0043] Then, the specimen which had been measured for the distribution condition of the primary carbides was evaluated for cutting properties by performing a cutting test with a saw blade. As a cutting machine, a saw cutting machine PCSAW530AX manufactured by Amada Co., Ltd. was used. As a saw blade, a coating sintered hard alloy band saw blade AXCELA G-NBN3N manufactured by Amada Co., Ltd. was used. The cutting condition was a cutting rate of 16 cm^2/min, a saw speed of 50 m/min, and a feeding of 5 mm/min.

[0044] Cutting properties were evaluated in the following procedure. First, an unused saw blade is set in a saw cutting machine, and an appearance of the set saw blade was observed through a microscope to check that chipping or the like do not exist in the saw blade. Next, as a break-in, an annealed material (hardness: 20 HRC) of JIS-SKD11-equivalent steel was cut until the cumulative cutting area reached 2000 cm^2. The cutting condition was the same as the above. Then, an appearance of the saw blade after the break-in was observed again to check that abrasion and chipping hardly exist in the saw blade. Thereafter, the above-described specimens were subjected to a cutting test. It is noted that this was performed for each specimen. In the cutting test, each of the specimens was continuously cut, intending that the cumulative cutting area reaches 4500 cm^2. Every time the cumulative cutting area reached 300 cm^2, blade deviation was measured. Here, blade deviation is reflected on a gap volume (flexible volume of a saw blade) between a line linking both ends of an overall saw length (that is, a desired cutting line) and a saw blade during cutting (that is, an actual cutting line). Therefore, in the example, the blade deviation was measured by measuring largest and average gap volumes (blade deviation) as the gap volume during cutting. The largest gap volume refers to a gap volume having the largest value among a plurality of largest gap volumes obtained every time the cumulative cutting area reached 300 cm^2. The average gap volume refers to a gap volume obtained by calculating an average for the plurality of largest gap volumes. The measurement results of the blade deviation, as well as the hardness and the area ratio of primary carbides for the above-described specimens, are illustrated in Table 2.

[Table 2]

Specimen No.	Steel ingot No.	Cumulative cutting area (cm^2)	Blade deviation (mm)		Hardness (HRC)	Primary carbides area ratio (%)	Remarks
			Average	Largest			
1	1	4500	0.37	0.54	60.0	0.16	Example of the invention
2	2	4500	0.16	0.26	59.0	0.91	
3	3	4500	1.09	1.57	60.5	4.32	Comparative example
4	4	480	Impossible to cut		59.0	7.69	

[0045] Specimens Nos. 1 and 2, which are examples of the present invention, each contained 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in the quenched and tempered structure. These specimens exhibited good cutting properties while having high hardness of 58 HRC or more. That is, the largest value of the blade deviation during cutting was suppressed to less than 1 mm, and a cumulative cutting area of 4500 cm^2 was achieved. On the contrary, specimen No. 3, which is a comparative example, contained the above-described primary carbides by more than 2% by area in terms of area ratio. The specimen could be continuously cut while having high hardness of 58 HRC or more until the cumulative cutting area reached 4500 cm^2. However, the blade deviation during cutting was 1 mm or more in terms of both the largest and average values. Furthermore, specimen No. 4, which is a comparative example, contained the above-described primary carbides by as much as 7% by area or more in terms of area ratio. When the specimen was cut, the increase in cutting resistance caused excessive load to be applied to a motor of a cutting machine in the early stage. Accordingly, the cutting machine stopped when the cumulative cutting area reached 480 cm^2. Thus, cutting was practically impossible.

[0046] FIG. 2 is photographs each obtained by observing one of the flanks of a saw blade used for cutting each specimen through a digital microscope after a cutting test (for specimen No. 4, a flank of a saw blade when the cutting machine stopped is illustrated). FIG. 2 also illustrates a flank of a saw blade after a break-in. Abrasion was smaller in the flank of the saw blade after cutting for specimens Nos. 1 and 2 than for specimen No. 3. Significant abrasion had already occurred in the flank of the saw blade after cutting for specimen No. 4 when the cutting test was interrupted. Furthermore, the saw blade had been partly chipped and lost.

Example 2

[0047] Steel ingot No. 5 having a component composition illustrated in Table 3 (that is, the component composition of steel ingot No. 3 in Table 1) was prepared

[Table 3]

Steel ingot No.	Component composition (mass%)													
	C	Si	Mn	P	S	Ni	Cr	W	Mo	V	Cu	Al	Nb	Fe
5	1.01	1.01	0.44	0.015	0.0700	0.43	8.49	0.30	0.81	0.02	0.31	0.330	0.08	Bal.

[0048] Next, steel ingot No. 5 was hot forged at a forging ratio of about 10 to obtain a steel piece. Then, the steel piece was cooled, and thereafter annealed at 860°C. Then, specimens Nos. 5-A and 5-B (that is, steel raw materials before cutting) to be evaluated for cutting properties were prepared from the annealed steel piece. The specimens each had a dimension of 250 mm in length (an expanding direction by the above-described forging), 300 mm in width, and 150 mm in thickness. Next, specimen No. 5-A was subjected to solution treatment to be retained at 1170°C for 10 hours, and specimen No. 5-B was subjected to solution treatment to be retained at 1170°C for 5 hours. Then, four surfaces, other than two surfaces each having a dimension of 250 mm $\times$ 300 mm, of the surfaces of each specimen after the solution treatment, were ground to remove oxide films on the four surfaces. Then, the grinding was followed by quenching treatment with air cooling down from 1030°C, and tempering treatment at 500 to 540°C twice, thereby adjusting each specimen into target hardness of 60 HRC.

[0049] Specimens Nos. 5-A and 5-B having been adjusted into the above-described hardness were each evaluated for primary carbides distributed in the structure. A procedure for observing the structure is the same as that of Example 1 described above. FIG. 3 is examples of structure photographs of cross sections for specimens No. 5-A and 5-B (primary carbides are indicated as a distribution in white). These structure photographs were each image-processed to extract primary carbides having a circle-equivalent diameter of 5 μm or more which were observed in the cross-sectional structure, and an area ratio of the primary carbides in the cross-sectional structure was calculated as an average value of those for 20 visual fields.

[0050] Then, the specimens which had been measured for the distribution condition of the primary carbides were evaluated for cutting properties by performing a cutting test with a saw blade. The condition of a cutting test and the evaluation procedure of cutting properties were in accordance with those of Example 1 described above. The measurement results of the blade deviation when a predetermined cumulative cutting area was reached, as well as the hardness and the area ratio of primary carbides for the above-described specimens, are illustrated in Table 4.

[Table 4]

Specimen No.	Steel ingot No.	Cumulative cutting area (cm^2)	Blade deviation (mm)		Hardness (HRC)	Primary carbides area ratio (%)	Remarks
			Average	Largest			
5-A	5	4500	0.58	1.02	59.0	1.84	Example of the invention
5-B		3600	0.19	0.25	59.0	1.96	

[0051] Specimens Nos. 5-A and 5-B, which are examples of the present invention, each contained 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in the quenched and tempered structure. These specimens exhibited good cutting properties while having high hardness of 58 HRC or more. That is, blade deviation during cutting was suppressed to less than 1 mm^2 in terms of the average value, and suppressed to around 1 mm even in terms of the largest value. Furthermore, a cumulative cutting area of 3600 cm^2 or more was achieved. It is noted that the cutting test for specimen No. 5-B in which primary carbides having a circle-equivalent diameter of 5 μm or more had a rather high area ratio was terminated when a cumulative cutting area of 3600 cm^2 was achieved in consideration of an increase in cutting resistance. The largest value of the blade deviation before the termination of cutting had been suppressed to 0.25 mm even in terms of the largest value. Here, the cutting result of specimen No. 3 as a comparative example in Example 1 indicated that the blade deviation when a cumulative cutting area of 3600 cm^2 was achieved was 1.06 mm in terms of the average value and 1.57 mm in terms of the largest value. Comparison to this fact demonstrated that even specimen No. 5-B had good cutting properties.

[0052] FIG. 4 is photographs each obtained by observing, through a digital microscope, one of the flanks for each of the saw blades used in the cutting of specimens Nos. 5-A and 5-B after the termination of the cutting test. FIG. 4 also illustrates the flank of the saw blade after a break-in. Abrasion was small in the flanks of the saw blades after the cutting of specimens Nos. 5-A and 5-B. Comparison between the flanks when cutting was performed until a cumulative cutting area of 4500 cm^2 was equally reached demonstrated that abrasion was rather larger in the flank of the saw blade after the cutting of specimen No. 5-A than in the flanks of specimens Nos. 1 and 2 (examples of the present invention) in Example 1. However, the abrasion was smaller than that in the flank of specimen No. 3 (comparative example).

[0053] FIG. 5 is a graph illustrating an average abrasion area per flank for each of the above-described saw blades after the cutting of specimens in Examples 1 and 2. It is noted that the flanks of the saw blades used to cut specimens Nos. 1, 2, 3, 4, 5-A and 5-B are designated as flanks 1, 2, 3, 4, 5-A and 5-B respectively in FIG. 5. FIG. 5 demonstrates that the abrasion area in the flank of the saw blade tends to decrease as the volume of primary carbides in the structure of the cut specimen decreases. From the above results, it is understood that degrees of the blade deviation occurring in a cut steel raw material and the wear of a saw blade have a correlation with the area ratio of coarse primary carbides in the cut steel raw material.

Claims

1. A steel raw material for a die to be applied to manufacture of a cold working die having hardness of 58 HRC or more, and to be cut for use as a prehardened steel material having a size corresponding to a dimension of the cold working die, wherein
   the steel raw material has a quenched and tempered structure and hardness of 58 HRC or more, and contains 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material.

2. The steel raw material for a die according to claim 1, wherein the steel raw material has hardness of 60 HRC or more.

3. A manufacturing method of a steel raw material for a die to be applied to manufacture of a cold working die having hardness of 58 HRC or more, and to be cut for use as a prehardened steel material having a size corresponding to a dimension of the cold working die, the method comprising:

   a first step of hot-processing a steel ingot to obtain a steel piece; and
   a second step of quenching and tempering the steel piece obtained in the first step to obtain the steel raw material having hardness of 58 HRC or more and containing 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material.

4. The manufacturing method of the steel raw material for a die according to claim 3, wherein the steel raw material in the second step has hardness of 60 HRC or more.

5. The manufacturing method of the steel raw material for a die according to claim 3 or 4, wherein the quenching the steel piece in the second step is performed after the steel piece obtained by hot-processing a steel ingot in the first step has been annealed.

6. The manufacturing method of the steel raw material for a die according to claim 3 or 4, wherein the quenching the steel piece in the second step is direct quenching subsequently performed to the steel piece obtained by hot-processing a steel ingot in the first step.

7. A manufacturing method of a prehardened steel material for a die to be applied to manufacture of a cold working die having hardness of 58 HRC or more, the method comprising:

a first step of hot-processing a steel ingot to obtain a steel piece;
a second step of quenching and tempering the steel piece obtained in the first step to obtain a steel raw material having hardness of 58 HRC or more and containing 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material; and
a third step of cutting the steel raw material obtained in the second step to obtain a prehardened steel material having a size corresponding to a dimension of the cold working die.

8. The manufacturing method of the prehardened steel material for a die according to claim 7, wherein the steel raw material in the second step has hardness of 60 HRC or more.

9. The manufacturing method of the prehardened steel material for a die according to claim 7 or 8, wherein the quenching the steel piece in the second step is performed after the steel piece obtained by hot-processing a steel ingot in the first step has been annealed.

10. The manufacturing method of the prehardened steel material for a die according to claim 7 or 8, wherein the quenching the steel piece in the second step is direct quenching subsequently performed to the steel piece obtained by hot-processing a steel ingot in the first step.

11. A manufacturing method of a cold working die having hardness of 58 HRC or more, the method comprising:

a first step of hot-processing a steel ingot to obtain a steel piece;
a second step of quenching and tempering the steel piece obtained in the first step to obtain a steel raw material having hardness of 58 HRC or more and containing 2% by area or less of primary carbides having a circle-equivalent diameter of 5 μm or more in a cross-sectional structure of the steel raw material;
a third step of cutting the steel raw material obtained in the second step to obtain a prehardened steel material having a size corresponding to a dimension of a cold working die; and
a fourth step of machining the prehardened steel material obtained in the third step into a die shape to obtain the cold working die.

12. The manufacturing method of a cold working die according to claim 11, wherein the steel raw material in the second step has hardness of 60 HRC or more.

13. The manufacturing method of a cold working die according to claim 11 or 12, wherein the quenching the steel piece in the second step is performed after the steel piece obtained by hot-processing a steel ingot in the first step has been annealed.

14. The manufacturing method of a cold working die according to claim 11 or 12, wherein the quenching the steel piece in the second step is direct quenching subsequently performed to the steel piece obtained by hot-processing a steel ingot in the first step.

15. The manufacturing method of a cold working die according to any one of claims 11 to 14, further comprising a fifth step of performing surface treatment to a surface of the cold working die obtained in the fourth step.

FIG. 1

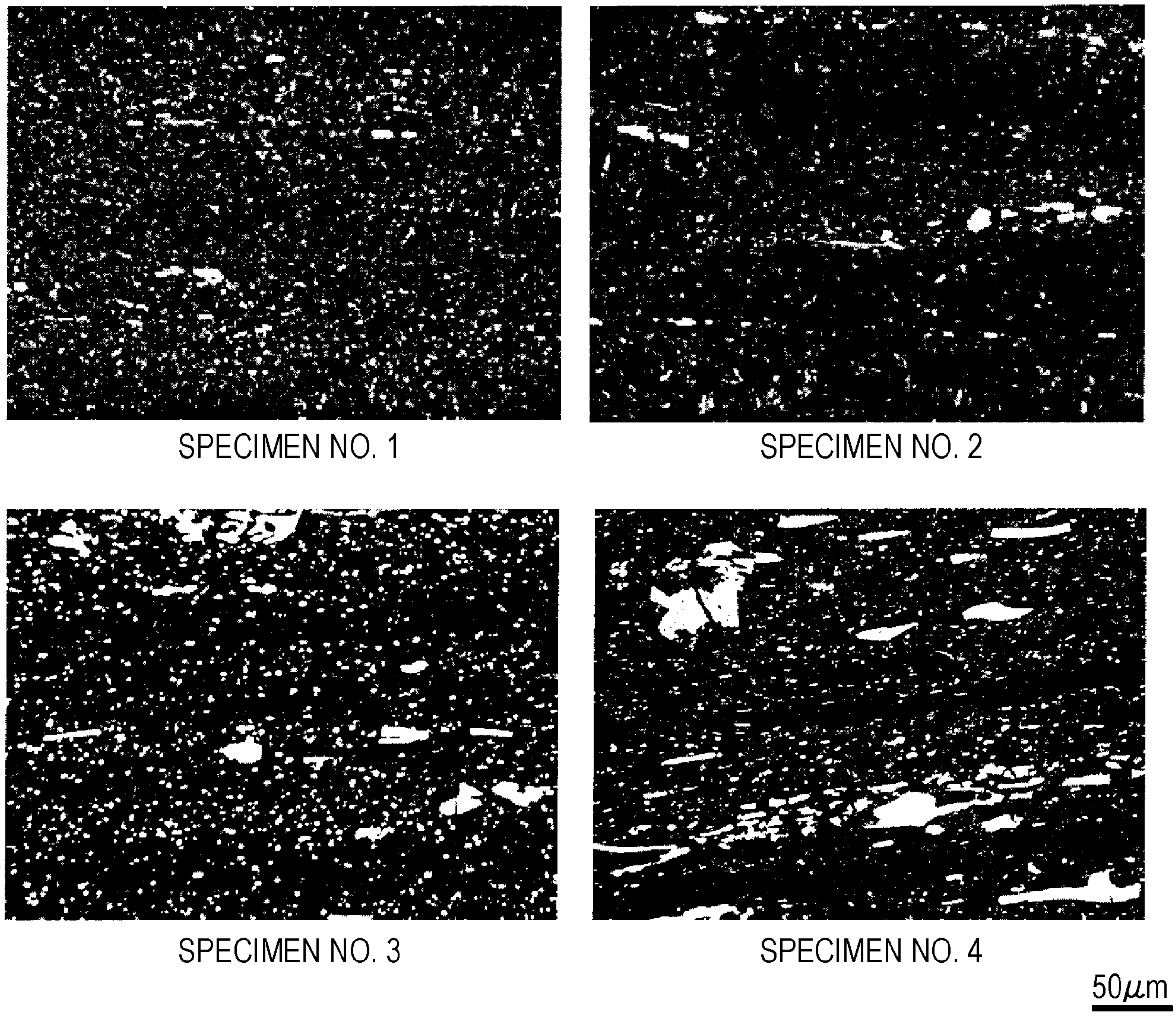
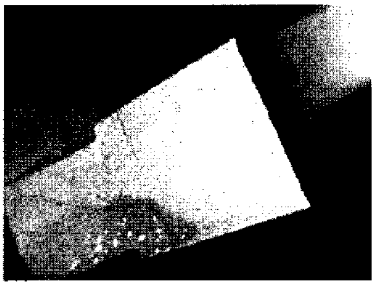
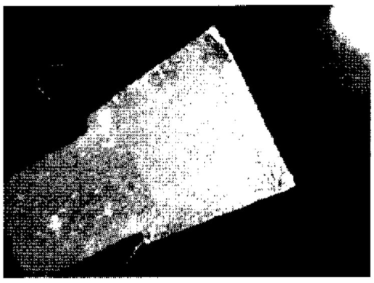


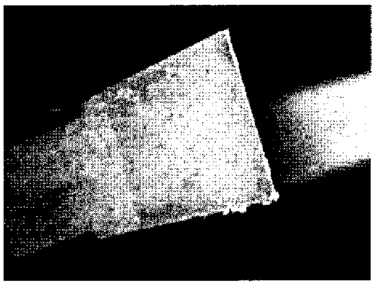
FIG. 2



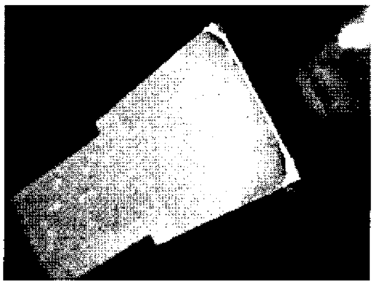
FRANK OF SAW
BLADE AFTER
BREAK-IN



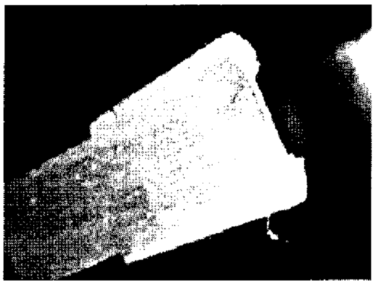
FLANK OF SAW
BLADE AFTER CUTTING
SPECIMEN NO. 1



FLANK OF SAW
BLADE AFTER CUTTING
SPECIMEN NO. 2



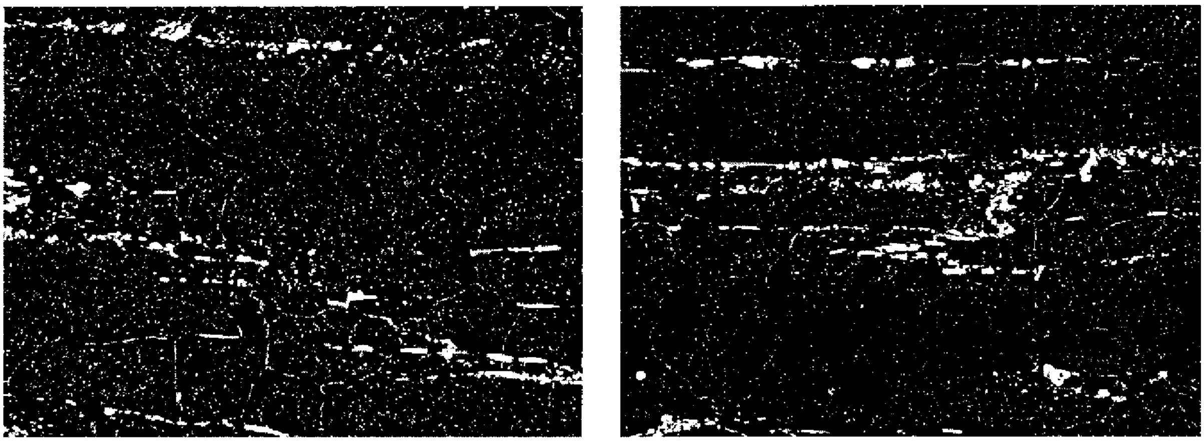
FLANK OF SAW
BLADE AFTER CUTTING
SPECIMEN NO. 3



FLANK OF SAW
BLADE AFTER CUTTING
SPECIMEN NO. 4

1mm

FIG. 3

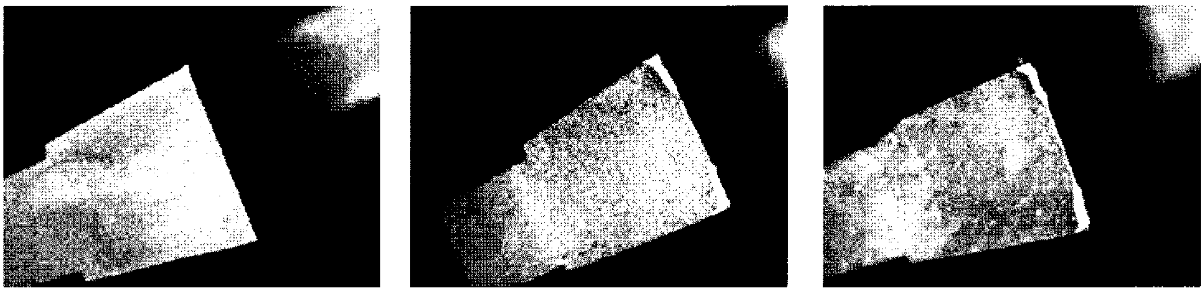


SPECIMEN NO. 5−A

SPECIMEN NO. 5−B

50μm

FIG. 4



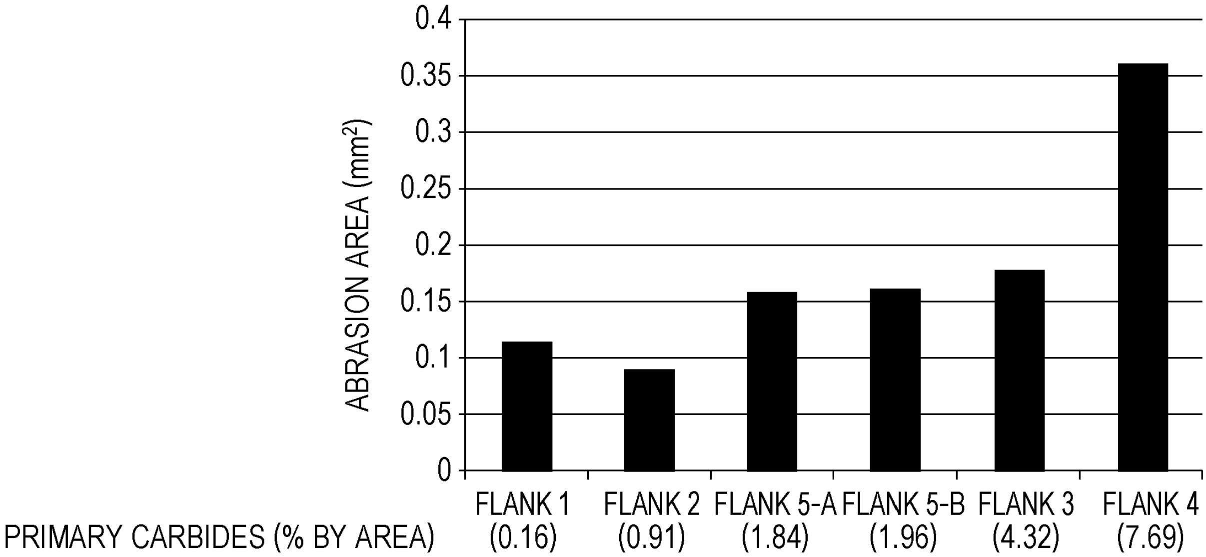
FRANK OF SAW BLADE AFTER BREAK-IN

FLANK OF SAW BLADE AFTER CUTTING SPECIMEN NO. 5−A

FLANK OF SAW BLADE AFTER CUTTING SPECIMEN NO. 5−B

1mm

FIG. 5


0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
ABRASION AREA (mm²)
FLANK 1 (0.16)
FLANK 2 (0.91)
FLANK 5-A (1.84)
FLANK 5-B (1.96)
FLANK 3 (4.32)
FLANK 4 (7.69)
PRIMARY CARBIDES (% BY AREA)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/055274

A. CLASSIFICATION OF SUBJECT MATTER
B21D37/20(2006.01)i, *C21D8/00*(2006.01)i, *C21D9/00*(2006.01)i, *C22C38/00*(2006.01)n, *C22C38/60*(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)
B21D37/20, C21D8/00, C21D9/00, C22C38/00, C22C38/60

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 Y	WO 2012/043228 A1 (Hitachi Metals, Ltd.), 05 April 2012 (05.04.2012), claims; paragraphs [0016] to [0027]; examples & CN 103119187 A	1-5 6-15
X Y	JP 2001-49394 A (Hitachi Metals, Ltd.), 20 February 2001 (20.02.2001), claims; paragraphs [0018], [0023], [0029] to [0040]; examples (Family: none)	1,3,5 6-15
X Y	JP 2001-294974 A (Hitachi Metals, Ltd.), 26 October 2001 (26.10.2001), claims; paragraphs [0019], [0025] to [0039]; examples (Family: none)	1,3,5 6-15

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

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"&" document member of the same patent family

Date of the actual completion of the international search 14 May, 2014 (14.05.14)	Date of mailing of the international search report 27 May, 2014 (27.05.14)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2014/055274

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2012/115025 A1 (Hitachi Metals, Ltd.), 30 August 2012 (30.08.2012), claims; paragraph [0029] & EP 2679697 A1 & CN 103403207 A & TW 201250010 A	6-15
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Y	JP 2006-150487 A (Nachi-Fujikoshi Corp.), 15 June 2006 (15.06.2006), paragraph [0014] (Family: none)	7-15

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REFERENCES CITED IN THE DESCRIPTION

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- JP 2006150487 A **[0007]**
- JP 2001129722 A **[0007]**