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(54) **COLD-WORK TOOL STEEL EXHIBITING SUPERIOR MACHINABILITY**
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Description

TECHNICAL FIELD

[0001] The present invention relates to a cold-work tool steel suitable for a tool material, in particular, a cold-work die material for forming parts of home electric appliances, mobile phones or automobiles.

BACKGROUND ART

[0002] In a field of cold-work tools for use in press forming such as bending, squeezing or punching of a plate material at a room temperature, a steel material has been proposed that can obtain a hardness of not lower than 60 HRC by quenching and tempering (hereinafter, quenching and tempering are referred to as "hardening process") in order to improve wear resistance (see Patent Literatures 1 to 3). Since it is difficult to machine the steel material having such a high hardness into a tool shape after the hardening process, the steel material is usually roughly worked in an annealed state where the hardness is low, and then is subjected to the hardening process to a hardness of not lower than 60 HRC for use. In this case, since the tool is deformed due to the heat treatment of the hardening process, the tool is again subjected to finish machining to correct the deformed portion after the hardening process, and finished in a final tool shape. The main reason for the heat treatment deformation of the tool due to the hardening process is because the steel material transforms from a ferritic structure in the annealed state to a martensitic structure and thus volume expansion generates.

[0003] Besides the above steel material, many pre-hardened steels have been proposed, which are subjected to the hardening process to a used hardness in advance. No hardening process is necessary after the pre-hardened steels are machined to a final tool shape. Thus, it is free of the heat treatment deformation of the tool due to the hardening process and thus the finishing machining is not necessary. Thus, it is effective techniques. With respect to the pre-hardened steels, a cold-work tool steel has been proposed which has good machinability and a hardness of more than 55 HRC through the hardening process, by optimizing an amount of insoluble carbides in a quenched steel material since the insoluble carbides deteriorate machinability (see Patent Literature 4). Also, a cold-work tool steel has been proposed for suppressing tool wear caused by a friction between a cutting tool and a steel material at a time of machining. The steel has self-lubricating properties by adding an element forming an oxide having a melting point of 1200°C or lower ($(FeO)_2 \cdot SiO_2$, Fe_2SiO_4 or $(FeSi)Cr_2O_2$) to form the oxide on a surface of a die by heat generated at the time of machining (Patent Literature 5).

[0004] Patent literature 6 concerns a cold work steel having a wear resistance which is adequate for most applications and at the same time has a very good toughness. This is achieved by a steel composition, containing carbon and vanadium in well-ballanced amounts.

CITATION LIST

PATENT LITERATURES

[0005]

Patent Literature 1: JP-A-2008-189982
Patent Literature 2: JP-A-2009-132990
Patent Literature 3: JP-A-2006-193790
Patent Literature 4: JP-A-2001-316769
Patent Literature 5: JP-A-2005-272899
Patent Literature 6: WO 03/106728 A1

SUMMARY OF THE INVENTION

[0006] The cold-work tool steel disclosed in Patent Literature 4 is a superior pre-hardened steel simultaneously satisfying machinability at the time of machining and wear resistance as a tool. However, with respect to the wear resistance, since an amount of defined insoluble carbides is small and a quenching temperature is restricted, the compositional range is limited for having a hardness of not lower than 60 HRC. Patent Literature 4 discloses that Nb and V are preferably added for suppressing grain growth at a time of heating for quenching. However, the elements are likely to form insoluble MC carbides at the above quenching temperature. Since the MC carbides are hard, there is a problem that machinability after the hardening process is deteriorated in the composition disclosed in Patent Literature 4.

[0007] In addition, the cold-work tool steel disclosed in Patent Literature 5 utilizes a low melting point oxide as a self-lubricating film. However, the lubricating effect is not obtained when the machining temperature is below the melting point of the oxide. On the contrary, when the machining temperature rises too high, there is a problem that a viscosity of the oxide is remarkably reduced and the oxide will not serve as the lubricating film.

[0008] An object of the present invention is to provide a cold-work tool steel having a composition for stably achieving a high hardness of not lower than 60 HRC, and also having remarkably improved machinability after the hardening process without depending on a machining temperature even if an amount of insoluble carbides are further increased.

[0009] The present inventors have studied to improve machinability of a cold-work tool steel. As a result, the inventors have found that Al_2O_3 which is an oxide having a high melting point is positively introduced to form a complex lubricating protective film including Al_2O_3 and MnS, which is a high ductility inclusion, on a surface of a cutting tool by heat generated at a time of machining. The inventors has found a compositional range for the steel material that is capable of forming the complex lubricating protective film as well as having a hardness of not lower than 60 HRC, thereby reaching the present invention.

[0010] The invention is defined in the claims.

[0011] According to the present invention, provided is a cold-work tool steel having improved machinability after the hardening process consisting of, in mass%,

0.6 to 1.2% of C,
0.7 to 2.5% of Si,
0.3 to 2.0% of Mn,
0.02 to 0.1% of S,
3.0 to less than 5.0% of Cr,
one or both of Mo and W being 0.5 to 2.0% in a form of (Mo + 1/2W),
0.04 to less than 0.3% of Al, and
optionally
not greater than 1.0% of Ni in mass%,
not greater than 1.0% of Cu in mass%,
not greater than 1.0% of V in mass%,
not greater than 0.5% of Nb in mass%,
the balance being Fe and inevitable impurities,

wherein a machinability index MP is greater than zero where the machinability index MP is determined by a following expression of the S, Cr and Al contents:

$$MP = 21.9 \times S + 124.2 \times (Al/Cr) - 2.1.$$

Preferably, the hardness after the hardening process is not lower than 60 HRC.

[0012] The cold-work tool steel of the present invention may include not greater than 1.0% of Ni, or may further include not greater than 1.0% of Cu.

[0013] The cold-work tool steel of the present invention may include not greater than 1.0% of V, or may further include not greater than 0.5% of Nb.

[0014] The present invention uses a mechanism for improving machinability, which can be widely applied to a number of steel compositions. Thus, even if an alloy is designed to have a hardness of not lower than 60 HRC and to include a large amount insoluble carbides, the cold-work tool steel can have remarkably improved machinability after the hardening process without depending on a machining temperature. Therefore, the hardness of the cold-work tool steel and the amount of the insoluble carbides can be widely selected depending on various functions, and in particular the invention provides an essential technique for practical use of the pre-hardened cold-work tool steels.

BRIEF DESCRIPTION OF DRAWINGS

[0015]

[Fig. 1A] Fig. 1A is a digital microscope photograph showing a rake face and a flank face of a cutting tool used for machining Sample No. 1 according to the present invention. The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 1B] Fig. 1B is a digital microscope photograph showing a rake face and a flank face of a cutting tool used for machining Sample No. 6 according to the present invention. The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 1C] Fig. 1C is a digital microscope photograph showing a rake face and a flank face of a cutting tool used for machining Sample No. 11 according to the present invention. The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 1D] Fig. 1D is a digital microscope photograph showing a rake face and a flank face of a cutting tool used for machining Sample No. 22 according to comparative example. The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 1E] Fig. 1E is a digital microscope photograph showing a rake face and a flank face of a cutting tool used for machining Sample No. 30 according to comparative example. The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 1F] Fig. IF is a digital microscope photograph showing a rake face and a flank face of a cutting tool used for machining Sample No. 34 according to comparative example. The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 2A] Fig. 2A is a mapping photograph of Al (upper left), O (upper right), Mn (lower left) and S (lower right) in a belag on a surface of the cutting tool in Fig. 1A (for Sample No. 1), analyzed by EPMA (electron probe microanalyzer).

[Fig. 2B] Fig. 2B is a mapping photograph of Al, O, Mn and S in a belag on a surface of the cutting tool in Fig. 1B (for Sample No. 6), analyzed by EPMA.

[Fig. 2C] Fig. 2C is a mapping photograph of Al, O, Mn and S in a belag on a surface of the cutting tool in Fig. 1C (for Sample No. 11), analyzed by EPMA.

[Fig. 2D] Fig. 2D is a mapping photograph of Al, O, Mn and S in a belag on a surface of the cutting tool in Fig. 1D (for Sample No. 22), analyzed by EPMA.

[Fig. 2E] Fig. 2E is a mapping photograph of Al, O, Mn and S in a belag on a surface of the cutting tool in Fig. 1E (for Sample No. 30), analyzed by EPMA.

[Fig. 2F] Fig. 2F is a mapping photograph of Al, O, Mn and S in a belag on a surface of the cutting tool in Fig. IF (for Sample No. 34), analyzed by EPMA.

[Fig. 3A] Fig. 3A is a cross sectional TEM (transmission electron microscope) photograph showing the belag in Fig. 2A (for Sample No. 1) together with a TiN coating.

[Fig. 3B] Fig. 3B is a cross sectional TEM photograph showing the belag in Fig. 2D (for Sample No. 22) together with a TiN coating.

[Fig. 3C] Fig. 3C is a cross sectional TEM photograph showing the belag in Fig. 2E (for Sample No. 30) together with a TiN coating.

[Fig. 4] Fig 4 is a graph showing a relationship between an exposed width of a base material on the flank face of the cutting tool used in machining and a machining length, of the present invention and comparative example.

[Fig. 5A] Fig. 5A is a digital microscope photograph showing the flank face and the rake face of a cutting tool used in machining of Sample No. A according to the present invention (machining length: 25 m). The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 5B] Fig. 5B is a digital microscope photograph showing the flank face and the rake face of a cutting tool used in machining of Sample No. B according to the present invention (machining length: 25 m). The upper side in the figure shows the rake face and the lower sideshows the flank face.

[Fig. 5C] Fig. 5C is a digital microscope photograph showing the flank face and the rake face of a cutting tool used in machining of Sample No. C according to comparative example (machining length: 20 m). The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 5D] Fig. 5D is a digital microscope photograph showing the flank face and the rake face of a cutting tool used in machining of Sample No. D according to comparative example (machining length: 10 m). The upper side in the figure shows the rake face and the lower side shows the flank face.

[Fig. 5E] Fig. 5E is a digital microscope photograph showing the flank face and the rake face of a cutting tool used in machining of Sample No. E according to comparative example (machining length: 15 m). The upper side in the figure shows the rake face and the lower side shows the flank face.

DESCRIPTION OF EMBODIMENTS

[0016] The present invention realizes a cold-work tool steel having not only an improved hardness but also good machinability after the hardening process without depending on a machining temperature even if a large amount of insoluble carbides are formed to, for example, control a grain size. Specifically, a steel material is designed so that a hardness of not lower than 60 HRC is achieved, as well as a complex lubricating protective film of Al_2O_3 as a high melting point oxide and MnS as a high ductility inclusion are formed on a surface of a cutting tool in order to suppress wear of the cutting tool.

[0017] First, the present inventors have studied to improve machinability, which can be widely applied to a composition of a cold-work tool steel. As a result, the inventors have noticed on effectiveness of self-lubricating properties. Then, the inventors have studied the effect of self-lubricating properties of the oxide having a low melting point as Patent Literature 5, and consequently have found a problem that the low melting point oxide depends on a machining temperature. The low melting point oxide having self-lubricating properties is generally a complex oxide including Fe and Cr which are included in a steel material in a large amount. Thus, when the machining temperature changes, a composition and an amount of the complex oxide change and a stable lubricating effect is not obtained.

[0018] Then, intensive studies have been made for improving machinability of a cold-work tool steel without using the low melting point oxide, and it has been found that Al_2O_3 which is an oxide having a high melting point is introduced positively to form a complex lubricating protective film including Al_2O_3 and MnS as a high ductility inclusion on a surface of a cutting tool by heat generated at a time of machining. The complex lubricating protective film can provide stable effects in response to a wide range of the machining temperatures, and also ensure good machinability even in a case where elements for forming hard MC carbides, such as Nb and V, are added. Then, a composition of the steel material has been specified that enables to form the complex lubricating protective film while achieving a hardness of not lower than 60 HRC, thereby reaching the present invention. Hereinafter, the composition of the cold-work tool steel of the present invention will be described.

Carbon: 0.6 to 1.2 mass% (hereinafter, simply expressed as %)

[0019] Carbon is an important element for forming carbides in a steel to make a cold-work tool steel hard. If the carbon content is too small, an amount of the carbides is insufficient, and it is difficult to provide a hardness of not lower than 60 HRC. On the other hand, if an excessive amount of carbon is included, an amount of insoluble carbides increases in quenching, and toughness is likely to be decreased. Therefore, the carbon content is defined as 0.6 to 1.2%. Preferably, the content is not less than 0.7% and/or not greater than 1.0%.

Si: 0.7 to 2.5%

[0020] Si solid-solutes in a steel, and is an important element for making the cold-work tool steel hard. In addition, since Si has a stronger tendency to be oxidized than Fe and Cr and is also likely to form corundum-type oxides with Al_2O_3, Si has an important function to suppress a formation of Fe-based and Cr-based oxides which reduce a melting point of oxides, and to promote formation of an Al_2O_3 protective film. However, if an excessive amount of Si is included, quenching properties and toughness are remarkably deteriorated. Therefore, the Si content is defined as 0.7 to 2.5%. Preferably, the content is not less than 0.8% and/or not greater than 2.0%.

Mn: 0.3 to 2.0%

[0021] Mn is an important element in the present invention. Mn acts as a good lubricating film on the Al_2O_3 protective film formed on a surface of a cutting tool. Mn forms austenitic phase and solid-solutes in the steel to enhance quenching properties. However, if the Mn content is too large, a large amount of retained austenite remains after the hardening process, which causes secular deformation during use of a tool. In addition, since Mn is likely to form low melting point oxides with Fe and Cr, it becomes a factor of inhibiting the function of the Al_2O_3 protective film. Therefore, the Mn content is defined as 0.3 to 2.0% in the present invention. Preferably, the content is not less than 0.4% and/or not greater than 1.5%.

Sulfur: 0.02 to 0.1%

[0022] Sulfur is an important element in the present invention. Sulfur acts as a good lubricating film on the Al_2O_3 protective film formed on a surface of a cutting tool. In order to sufficiently exert such a lubricating action, sulfur is required to be added in an amount of not less than 0.02%. However, sulfur deteriorates toughness of the steel, and therefore an upper limit thereof is defined as 0.1%. Preferably, the sulfur content is not less than 0.03% and/or not greater than 0.08%.

Cr: 3.0 to less than 5.0%

[0023] Cr forms an M_7C_3 carbide in a structure after the hardening process, thereby it makes a cold-work tool steel hard. In addition, Cr has an effect of suppressing grain growth since a part of Cr forms insoluble carbides at a time of quenching heating. However, if Cr is included in an amount of less than 3.0%, an amount of the formed carbides is small, and it is difficult to achieve a hardness of not lower than 60 HRC. On the other hand, if Cr is included in an amount of less than 5.0%, an amount of the insoluble carbides is reduced and toughness is improved. When excessive formation of low melting point oxides including Cr is suppressed, the function of the Al_2O_3 protective film is enhanced and makes it possible to remarkably enhance machinability. In addition, in a case where V and Nb are added for forming hard MC carbides to suppress grain growth and increase hardness, Cr has an effect of suppressing the formation of coarse MC carbides by making M_7C_3 carbides coexist. However, the effect is not sufficient if an amount of Cr is less than 3.0%, and machinability is decreased. Therefore, it is important that the Cr content is 3.0 to less than 5.0%. Preferably, the content is not less than 3.1% and/or not greater than 4.8%.

One or both of Mo and W: 0.5 to 2.0% in a form of (Mo + 1/2W)

[0024] Mo and W increase hardness by precipitation strengthening (secondary hardening) of fine carbides during tempering of the hardening process. However, Mo and W make the decomposition of retained austenite retard during the tempering. Thus, when excessive amount of Mo and W is contained, the retained austenite is likely to remain in the structure after the hardening process. In addition, since Mo and W are expensive, their addition should be reduced as much as possible in terms of practical use. Therefore, the amounts of the elements are defined as 0.5 to 2.0% in a form of relational expression (Mo + 1/2W).

Al: 0.04 to less than 0.3%

[0025] Al is an important element in the present invention. Al forms Al_2O_3, that is a high melting point oxide, on a surface of a cutting tool at the time of machining. Al_2O_3 serves as the protective film. An amount of not less than 0.04% Al forms the protective film having a sufficient thickness, and improves tool lifetime. However, when the Al content is large, Al_2O_3 is formed as a large amount of inclusions in the steel material, and thus machinability of the steel material is deteriorated. Therefore, the upper limit of the Al content is defined as less than 0.3%. Preferably, the Al content is not less than 0.05% and/or not greater than 0.15%.

[0026] Machinability index MP determined by the relational expression of the S, Cr and Al contents: $21.9 \times S + 124.2 \times (Al/Cr) - 2.1$ is greater than 0.

[0027] Adjustment of the machinability index MP is essentially required for sufficiently forming the complex lubricating protective film including Al_2O_3 and MnS, which is a main feature of the present invention, on a surface of a tool at the time of machining. A sufficient amount of Al in the steel material of the present invention forms Al_2O_3 as a high melting point oxide on the surface of the cutting tool by generated heat at the time of machining. Since the melting point of Al_2O_3 is about 2050°C and is much higher than the machining temperature, Al_2O_3 serves as the protective film of the cutting tool. Furthermore, a sufficient amount of S in the steel material of the present invention forms MnS. MnS has good ductility and is compatible with Al_2O_3. Thus, it deposits on the Al_2O_3 protective film to form a good complex lubricating protective film.

[0028] On the other hand, Cr as the main component of the cold-work tool steel is likely to form oxides having a low melting point. Since Cr is contained larger than Al in the steel, Cr becomes a factor of inhibiting the effect of the Al_2O_3 protective film. As a result, Cr inhibits the effect of the complex lubricating protective film including Al_2O_3 and MnS. Accordingly, it is important that the cold-work tool steel of the present invention contain a sufficient amount of not less than 0.04% Al and also to balance (Al/Cr) between the Al content and the Cr content in the steel. By adjusting the amount of S correspondingly, the function of the above complex lubricating protective film is exerted.

[0029] Based on the above functional effects, a relationship between the influence of S, Cr and Al on self-lubricating properties has been researched in detail. As a result, in the cold-work tool steel satisfying the composition of the present invention, it has been found out that the influence of these 3 elements satisfy the relationship "$21.9 \times S + 124.2 \times (Al/Cr) - 2.1$". The value of the relational expression is defined as a machinability index MP. Thus, it is possible to evaluate the machinability in the present invention with high accuracy. If the MP value increases, an effect of enhancing machinability by the complex lubricating protective film using the high melting point oxides of the present invention is exerted. Specifically, if the composition is adjusted so that the index is greater 0, this effect is sufficiently exerted.

Optionally Ni: not greater than 1.0%

[0030] Ni improves toughness and weldability of the steel. In addition, Ni precipitates as Ni_3Al in tempering of the hardening process and effects to increase hardness of the steel. Thus, it is effective to add Ni depending on the Al content in the cold-work tool steel of the present invention. On the other hand, since Ni is an expensive metal, it should be reduced as much as possible in terms of practical use. In the relation, since Cr is also an expensive metal and can be significantly reduced in the cold-work tool steel as compared with JIS-SKD11 as a representative cold-work tool steel, the Ni content can be increased by the reduced amount of Cr. Therefore, in the present invention, Ni may be added up to 1.0%.

Optionally Cu: not greater than 1.0%

[0031] Cu precipitates as ε-Cu in tempering of the hardening process and effects to increase a hardness of the steel. However, Cu causes hot-shortness of the steel material. Therefore, in the present invention, not greater than 1.0% Cu may be added. Ni is preferably added at the same time in order to suppress hot-shortness by Cu. Further preferably, the substantially same amount of Cu and Ni are added.

Optionally vanadium: not greater than 1.0%

[0032] Vanadium forms various carbides and effects to increase hardness of the steel. In addition, the formed insoluble MC carbides effect to suppress grain growth. In particular, vanadium is added in combination with Nb described later to make the insoluble MC carbides fine and uniform at the time of quenching heating, and vanadium acts to effectively suppress grain growth. On the other hand, the MC carbides are hard and deteriorate machinability. The present invention forms the above-described complex lubricating protective film on the surface of the tool at the time of machining to make it possible to ensure good machinability even if a large amount of MC carbides are formed in the steel material. However, if vanadium is excessively added, coarse MC carbides are excessively formed to deteriorate toughness and machinability of the cold-work tool steel. In the present invention, while the Cr content is defined as not greater than 3.0% in order to suppress the formation of coarse MC carbides, the vanadium content is preferably not greater than 1.0% even if it is added. More preferably, the vanadium content is not greater than 0.7%.

Optionally Nb: not greater than 0.5%

[0033] Nb forms MC carbides and effects to prevent coarse grains. However, when excess Nb is added, coarse MC carbides are excessively formed to deteriorate toughness and machinability of the steel. In the present invention, the Cr content is defined as not less than 3.0% in order to suppress the formation of coarse MC carbides. In the case, the Nb content is preferably not greater than 0.5%. More preferably, the Nb content is not greater than 0.3%.

[0034] When the cold-work tool steel of the present invention is used as a pre-hardened steel, it is possible to eliminate heat treatment deformation due to the hardening process and to omit finish machining. However, when the cutting tool is roughly worked in an annealed state and then subjected to the hardening process and finish-machining as conventional, the complex lubricating protective film is formed on the surface of the cutting tool, and thus it is effective for efficient finish machining and improves the tool lifetime. In addition, when a cold-work tool made of the cold-work tool steel of the present invention is subjected to PVD treatment, wear resistance is further improved while maintaining a high dimensional accuracy.

EXAMPLE 1

[0035] Materials were melted with a high frequency induction furnace and ingots having chemical compositions shown in Table 1 were produced. The ingots were hot forged so as to have a forging ratio of about 10, and then cooled and annealed at 860°C. The annealed materials were quenched from 1030°C by air cooling. Then, they were tempered twice at 500 to 540°C so as to have a hardness of 60 ± 2 HRC. Thus, test pieces for evaluating machinability were produced. Sample Nos. 35 and 36 includes small amounts of Cr forming M_7C_3 carbides and Nb and V forming MC carbides, and thus they can not have a hardness of 55 HRC or more in the tempering treatment at 500 to 540°C. They are not suitable for use as a cold-work tool steel.

[Table 1]

Sample No.	Composition (mass%) C	Si	Mn	P	S	Ni	Cr	W	Mo	V	Cu	Al	Nb	Fe	Machinability index MP	Hardness (HRC)	Remarks
1	1.020	1.53	0.85	0.026	0.0620	<0.1	4.06	<0.1	1.01	0.61	<0.1	0.109	<0.1	Bal.	2.592	60.1	Example according to the invention
2	0.701	1.51	1.00	0.029	0.0981	<0.1	4.03	<0.1	0.99	<0.1	<0.1	0.093	<0.1	Bal.	2.915	60.7	
3	0.700	1.50	0.75	0.023	0.0620	<0.1	4.11	<0.1	0.96	<0.1	<0.1	0.112	<0.1	Bal.	2.642	60.6	
4	0.698	2.02	0.98	0.026	0.0571	0.39	4.06	<0.1	0.97	0.30	0.34	0.063	<0.1	Bal.	1.078	61.1	
5	0.640	1.01	0.46	0.026	0.0855	<0.1	3.22	<0.1	1.47	<0.1	<0.1	0.114	<0.1	Bal.	4.170	59.0	
6	0.901	2.04	0.99	0.026	0.0630	0.39	3.19	0.40	0.78	<0.1	<0.1	0.180	<0.1	Bal.	6.288	60.0	
7	0.630	2.29	1.21	0.025	0.0430	<0.1	3.27	<0.1	0.58	<0.1	<0.1	0.052	0.10	Bal.	0.817	59.1	
8	0.610	2.18	0.97	0.024	0.0360	<0.1	4.20	<0.1	1.45	<0.1	<0.1	0.093	<0.1	Bal.	1.439	60.2	
9	0.810	1.52	0.78	0.028	0.0610	0.60	4.48	<0.1	1.18	<0.1	0.39	0.260	<0.1	Bal.	6.444	60.8	
10	0.614	0.90	0.43	0.026	0.0840	<0.1	4.63	0.41	0.69	<0.1	<0.1	0.081	<0.1	Bal.	1.912	59.2	
11	0.622	2.02	0.99	0.026	0.0323	<0.1	4.62	<0.1	0.95	0.30	<0.1	0.070	<0.1	Bal.	0.489	60.2	
12	0.860	0.99	0.42	0.027	0.0620	<0.1	4.72	<0.1	1.31	0.24	<0.1	0.093	<0.1	Bal.	1.705	62.1	
13	1.200	1.54	0.75	0.027	0.0600	0.20	4.64	<0.1	0.98	0.26	<0.1	0.079	<0.1	Bal.	1.329	59.3	
21	0.760	1.97	1.00	0.005	0.0014	<0.1	7.64	<0.1	1.47	0.24	<0.1	0.007	0.13	Bal.	-1.956	60.2	Comparative example
22	0.770	2.00	1.05	0.004	0.0610	<0.1	7.56	<0.1	1.50	0.26	<0.1	0.016	0.12	Bal.	-0.501	60.4	
23	0.819	2.01	1.04	0.005	0.0600	<0.1	7.04	<0.1	1.50	0.25	<0.1	0.010	0.13	Bal.	-0.610	60.4	
24	0.804	1.97	0.96	0.006	0.0580	<0.1	6.95	<0.1	1.48	<0.1	<0.1	0.011	<0.1	Bal.	-0.633	58.1	
25	0.810	1.17	0.57	0.006	0.0600	<0.1	6.96	<0.1	1.45	0.23	<0.1	0.012	0.12	Bal.	-0.572	61.1	
26	1.020	1.53	0.82	0.008	0.0575	<0.1	5.02	<0.1	0.99	0.25	<0.1	0.021	0.12	Bal.	-0.321	59.8	
27	0.997	1.49	0.49	0.008	0.0585	<0.1	5.07	<0.1	0.98	0.25	<0.1	0.012	0.12	Bal.	-0.525	60.0	
28	1.016	1.55	0.86	0.007	0.0550	<0.1	4.14	<0.1	1.02	0.24	<0.1	0.016	0.12	Bal.	-0.416	59.4	
29	1.015	1.54	0.85	0.008	0.0570	<0.1	4.12	<0.1	1.02	0.60	<0.1	0.014	0.12	Bal.	-0.430	59.9	
30	0.580	0.97	0.40	0.027	0.0060	0.40	5.96	<0.1	0.96	0.29	0.34	0.009	<0.1	Bal.	-1.782	60.1	
31	0.765	0.28	0.40	0.028	0.0624	<0.1	7.60	<0.1	1.02	0.26	<0.1	0.027	0.12	Bal.	-0.292	60.2	
32	0.771	2.00	1.01	0.024	0.0025	<0.1	7.65	<0.1	1.49	0.25	<0.1	0.100	0.11	Bal.	-0.205	62.0	
33	0.957	1.51	0.83	0.026	0.0550	<0.1	2.70	<0.1	0.97	0.48	<0.1	0.094	0.15	Bal.	3.429	59.7	
34	1.120	1.01	1.54	0.026	0.0529	<0.1	2.71	<0.1	1.00	0.58	<0.1	0.170	<0.1	Bal.	6.850	60.0	
35	0.808	2.42	1.88	0.026	0.0420	<0.1	2.70	<0.1	<0.1	<0.1	<0.1	0.170	0.1	Bal.	6.640	53.6	
36	0.920	1.01	0.48	0.024	0.0360	<0.1	2.75	<0.1	<0.1	0.29	<0.1	0.131	0.1	Bal.	4.605	54.3	

[0036] A machinability test was conducted by surface-grinding with an insert PICOmini manufactured by Hitachi Tool Engineering Ltd. as a cutting edge replaceable tool that can machine a high hardness material. The insert is made of a cemented carbide alloy as a base material coated with TiN. Machining conditions were as follows:

cutting speed: 70 m/min,
spindle speed: 1857rev/min,
feed speed: 743 mm/min,
feed per tooth: 0.4 mm/ tooth,
axial depth of cut: 0.15 mm,
radial depth of cut: 6 mm, and
number of teeth: 1.

[0037] Machinability was evaluated based on the following two points. First, an amount of the complex lubricating protective film including Al2O3 and MnS on the surface of the cutting tool was evaluated. The amount was determined as follows. When a machining length is 0.8m after the beginning of the machining, the insert was analyzed from a rake face side with EPMA, and the amount was evaluated by average counts of Al and S. Then, the machining length was extended to 8 m and the tool wear at this time was measured using an optical microscope. These evaluation results are shown in Table 2.

[Table 2]

Sample No.	Average count of Al	Average count of S	Tool wear (mm)	Remarks
1	165	66	0.064	Example according to the invention
2	56	191	0.038	
3	79	155	0.032	
4	91	61	0.050	
5	75	159	0.033	
6	136	100	0.040	
7	47	107	0.050	
8	123	109	0.046	
9	125	79	0.046	
10	70	180	0.064	
11	142	82	0.052	
12	76	103	0.048	
13	71	46	0.046	
21	8	3	0.429	Comparative example
22	57	9	0.106	
23	28	8	0.194	
24	19	5	0.071	
25	45	7	0.282	
26	86	24	0.082	
27	37	9	0.106	
28	57	26	0.112	
29	77	10	0.235	
30	7	3	0.100	
31	87	8	0.547	
32	64	3	0.126	
33	110	39	0.091	
34	109	25	0.130	

[0038] In the cold-work tool steels of the present invention, the complex lubricating protective film is formed on the surface of the cutting tool to suppress the tool wear. Even in a case where V and Nb are added for forming insoluble carbides, good machinability is maintained. On the contrary, in the cold-work tool steels that do not satisfy the machinability index MP of the present invention, the tool wear is larger than the steels of the present invention.

[0039] Although Samples Nos. 33 and 34 have a high machinability index MP, they have less machinability. The reason is because large amounts of V and Nb were added in regardless of the small Cr content in order to ensure a hardness of 60 ± 2 HRC, and a large amount of coarse MC carbides are produced.

[0040] Figs. 1A to 1E are digital microscope photographs showing flank faces and rake faces of cutting tools used for, respectively, Samples Nos. 1, 6, 11, 22, 30 and 34. Figs. 2A to 2E are analysis results of belag on the surfaces in, respectively, Figs. 1A to 1E with use of EPMA, in which a high concentration portion of each element is represented in white color. Samples Nos. 1, 6 and 11 exhibit large average counts of Al and S in Table 2, and it has been confirmed that Al and S are attached over a wide region in the EPMA analysis of Figs. 2A to 2C. On the contrary, Sample No. 22 has a minus value of the machinability index MP and has smaller average counts of Al and S and smaller attached Al and S than Samples Nos. 1, 6 and 11. Since Sample No. 30 originally has small Al and S contents in the steel, the average counts of these elements are small and Al and S are hardly detected in the EPMA analysis (detected elements were mostly Fe and Cr which were likely transferred from the test piece). With respect to Sample No. 34, Al and S are attached in EPMA analysis in Fig. 2E. However, S is attached in a narrow region and the average count of S is also small in Table 2. It is because MnS is scraped away by coarse MC carbides although it is once attached on the surface of the tool, and thus the function as the complex lubricating protective film is not sufficiently exerted.

[0041] It is seen from Figs. 1A to 1E showing wear states of the cutting tools that a belag is remarkably attached on the rake face of the tool of each Sample Nos. 1, 6, and 11 corresponding to the above results, and the wear of the tool is suppressed on both of the flank and rake faces. In addition, the wear progresses uniformly and stably. On the contrary, the tool wear of Sample No. 22 is nearly twice that of Sample No. 1, and chipping also occurs on the tool. Surfaces of the tools of Nos. 30 and No. 34 are also severely damaged as Sample No. 22.

[0042] Furthermore, Figs. 3A to 3C are cross sectional TEM (transmission electron microscope) images showing belag confirmed on the surfaces of the tools of respectively Samples No. 1, 22 and 30, together with an underlying TiN coating. In the figures, reference number 1 denotes a protective film for preparing a sample, reference number 2 denotes a belag at the time of machining, reference number 3 denotes a plastically deformed TiN region, and reference number 4 denotes an un-deformed TiN region. According to the above results, Sample No. 1 having large average counts of Al and S has a thick belag, and the belag becomes thinner as the counts decreases as Sample No. 22. Sample No. 30 was hardly observed to have a belag. Although Al2O3 and MnS are also attached on the surface of the tool for Sample No. 22 as Sample No. 1, the thicknesses thereof are thin and chipping occurred as described above. The belag of Sample No. 1 exerts a high lubricating protective function. It can be seen from the fact that the TiN coating on the surface of the tool is prevented from plastic deformation in Sample No. 1 having a thick belag (that is, the narrowest plastically deformed region), while the TiN coating is usually plastically deformed by a frictional stress at the time of machining.

EXAMPLE 2

[0043] The machinability was evaluated using an insert PICOmini manufactured by Hitachi Tool Engineering Ltd., which has a harder TiAlN coating than the TiN coating on a cemented carbide base material. Machining conditions were as follows:

cutting speed; 160 m/min,
spindle speed: 4244rev/min,
feeding speed: 1698 mm/min,
feed per tooth; 0.4 mm/ tooth,
axial depth of cut: 0.15 mm,
radial depth of cut: 6 mm, and
number of teeth: 1.

With use of a tool microscope, an exposed width of the super-hard base material was measured on the flank face of the tool after the TiAlN coating had been peeled off.

[0044] Materials supplied to the machining were prepared from ingots having compositions in Table 3 by using a high frequency induction furnace and an atmosphere arc melting furnace. The ingots were hot forged with a forging ratio of about 5, and then cooled and annealed at 860°C. Then, the annealed materials were quenched from 1030°C by air cooling. Then, they were tempered at 500 to 540°C twice. Thus, they were hardened so as to have a hardness of 60 ± 2 HRC, thereby preparing test pieces.

[Table 3]

Sample No.	Composition (mass%)														Machinability MP	Hardness (HRC)	Remarks
	C	Si	Mn	P	S	Ni	Cr	w	Mo	V	Cu	Al	Nb	Fe			
A	0.70	1.45	0.78	0.027	0.060	<0.1	4.00	<0. 1	0.98	<0.1	<0.1	0.130	<0.1	Bal.	3.251	60.3	Example according to the invention
B	0.91	1.49	0. 77	0.027	0.057	<0.1	4.00	<0. 1	1.01	0.60	<0. 1	0.074	0.11	Bal.	1.446	60.8	
C	0. 76	0.25	0.37	0.026	0.063	<0.1	7.74	<0. 1	1.01	0.25	<0.1	0.015	0.13	Bal.	-0.473	59.8	comparative example
D	0.69	2.03	0.95	0.022	0.067	0.12	6.77	<0. 1	1.50	<0.1	<0.1	0.009	<0.1	Bal.	-0.468	60. 1	
E	0.61	1.02	0.42	0.020	0.017	0.37	6.07	<0.1	0.85	0.26	0.31	0.010	<0.1	Bal.	-1.523	60.4	

[0045] Fig. 4 shows an exposed width of the super-hard base material on the flank face of the cutting tool with respect to a machining length extended to 25 m. Figs. 5A to 5E show digital microscope photographs showing the flank face and the rake face of the cutting tool. In the cold-work tool steel according to the present invention, an exposed width of the base material is 0.02 mm or less even when it is machined at 25 m. Thus, the tool is hardly damaged. On the contrary, in a cold-work tool steel not according to the present invention, 0.05 mm or more of the base material is already exposed at a machining length of 10 m, and chipping occurred in Samples Nos. 3 and 4.

[0046] Thus, the cold-work tool steel of the present invention has been confirmed to exhibit superior machinability even under different machining conditions from those in Example 1.

Claims

1. A cold-work tool steel having improved machinability, consisting of, in mass%:

0.6 to 1.2% of C,
0.7 to 2.5% of Si,
0.3 to 2.0% of Mn,
0.02 to 0.1% of S,
3.0 to less than 5.0% of Cr,
one or both of Mo and W being 0.5 to 2.0% in a form of (Mo + 1/2W),
0.04 to less than 0.3% of Al, and

optionally:

not greater than 1.0% of Ni in mass%,
not greater than 1.0% of Cu in mass%,
not greater than 1.0% of V in mass%,
not greater than 0.5% of Nb in mass%,
the balance being Fe and inevitable impurities,

wherein a machinability index MP is greater than 0 where the machinability index MP is determined by a relational expression of the S, Cr and Al contents:

$$21.9 \times S + 124.2 \times (Al/Cr) - 2.1.$$

2. The cold-work tool steel according to claim 1, having a hardness of not lower than 60 HRC after quenching and tempering.

Patentansprüche

1. Kaltarbeits-Werkzeugstahl, der eine verbesserte Bearbeitbarkeit hat, bestehend aus, in Masse-%:

0,6 bis 1,2 % C,
0,7 bis 2,5 % Si,
0,3 bis 2,0 % Mn,
0,02 bis 0,1 % S,
3,0 bis weniger als 5,0 % Cr,
Mo und/oder W 0,5 bis 2,0 % in einer Form von (Mo + 1/2W),
0,04 bis weniger als 0,3 % Al, und

optional:

nicht mehr als 1,0 % Ni in Masse-%,
nicht mehr als 1,0 % Cu in Masse-%,
nicht mehr als 1,0 % V in Masse-%,

nicht mehr als 0,5 % Nb in Masse-%,
wobei der Rest Fe und unvermeidliche Verunreinigungen sind,
wobei ein Bearbeitbarkeitsindex MP größer als 0 ist, wobei der Bearbeitbarkeitsindex MP durch einen relationalen Ausdruck für den S-, Cr- und Al-Gehalt bestimmt wird:

$$21{,}9 \text{ x } S + 124{,}2 \text{ x } (AlCr) - 2{,}1.$$

2. Kaltarbeits-Werkzeugstahl nach Anspruch 1, der eine Härte von nicht weniger als 60 HRC nach dem Abschrecken und Anlassen hat.

Revendications

1. Acier à outil écroui ayant une usinabilité améliorée, constitué par, en % en masse :

de 0,6 à 1,2 % de C
de 0,7 à 2,5 % de Si,
de 0,3 à 2,0 % de Mn,
de 0,02 à 0,1 % de S,
de 3,0 à moins de 5,0 % de Cr,
un ou les deux de Mo et W représentant de 0,5 à 2,0 % sous une forme de (Mo + 1/2W),
de 0,04 à moins de 0,3 % d'Al, et

éventuellement :

pas plus de 1,0 % de Ni en % en masse,
pas plus de 1,0 % de Cu en % en masse,
pas plus de 1,0 % de V en % en masse,
pas plus de 0,5 % de Nb en % en masse,
le reste étant du Fe et des impuretés inévitables,
dans lequel un indice d'usinabilité MP est supérieur à 0, où l'indice d'usinabilité MP est déterminé par une expression relationnelle des teneurs de S, Cr et Al :

$$21{,}9 \text{ x } S + 124{,}2 \text{ x } (Al/Cr) - 2{,}1.$$

2. Acier à outil écroui selon la revendication 1, ayant une dureté non inférieure à 60 HRC après trempe et trempage.

FIG.1A

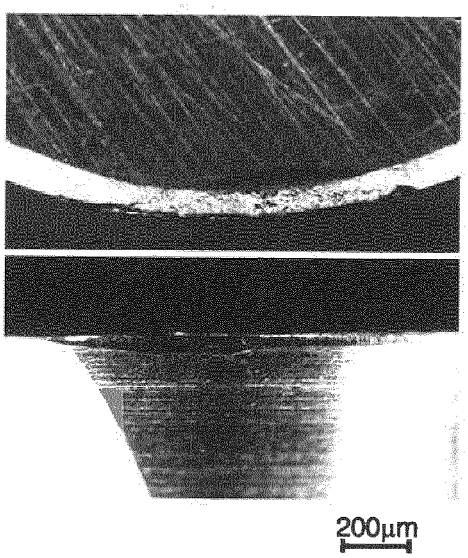


FIG.1B

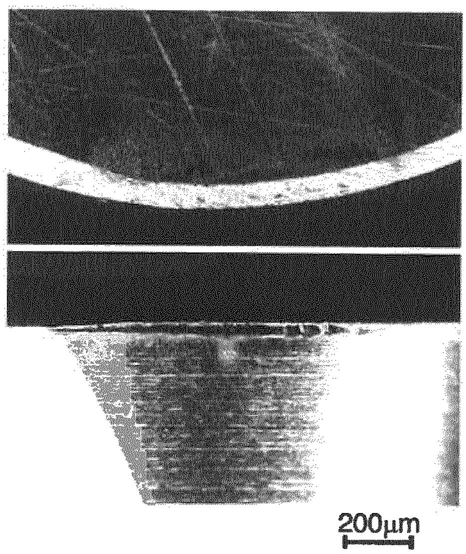


FIG.1C

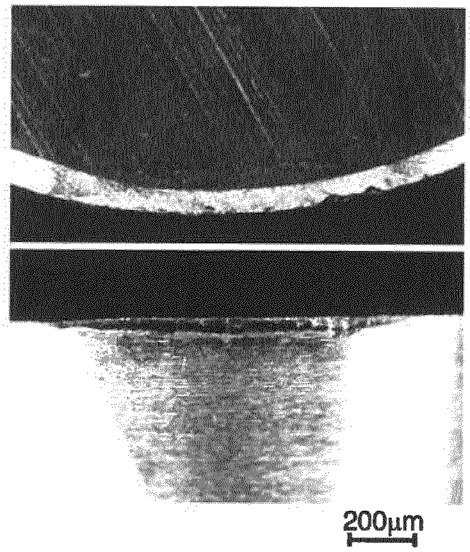


FIG.1D

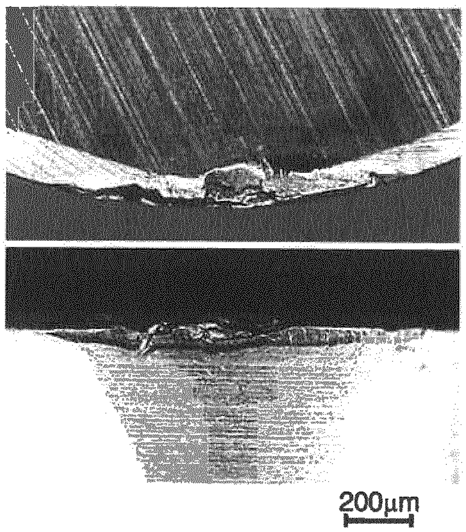


FIG.1E

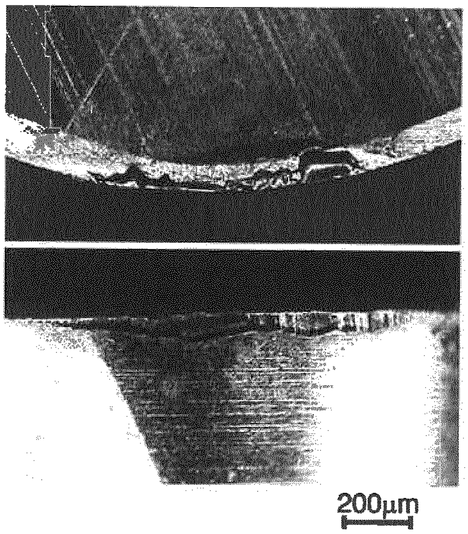


FIG.1F

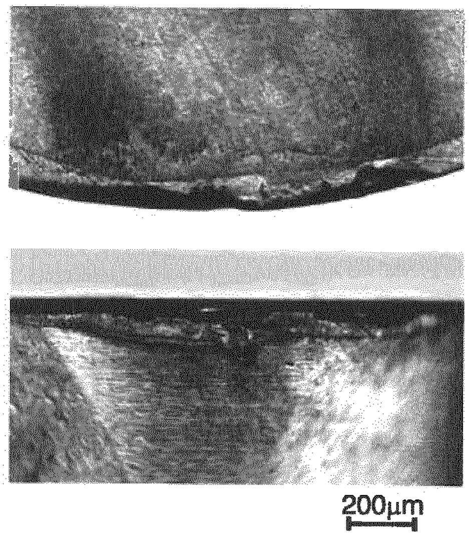


FIG.2A

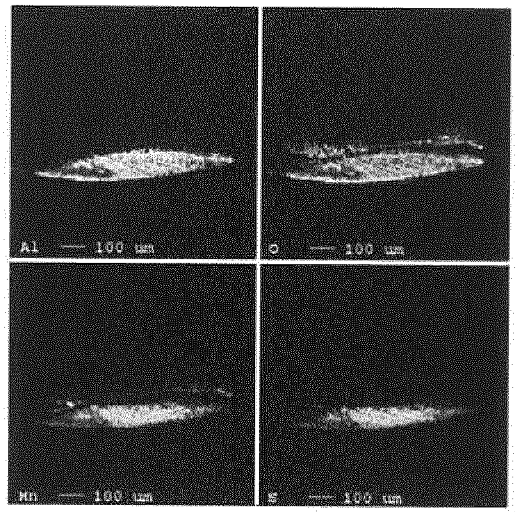

Al — 100 um
O — 100 um
Mn — 100 um
S — 100 um

FIG.2B

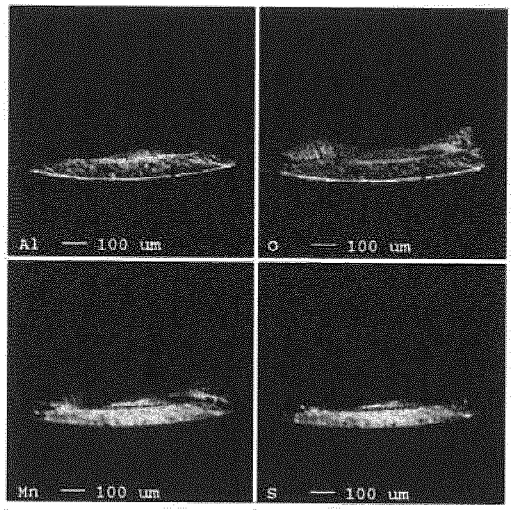

Al — 100 um
O — 100 um
Mn — 100 um
S — 100 um

FIG.2C

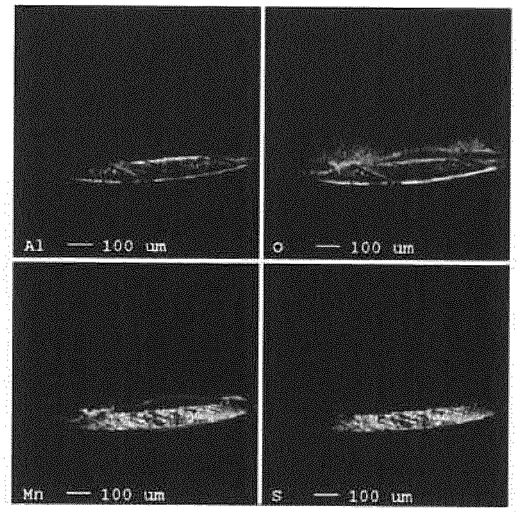

Al 100 um
O 100 um
Mn 100 um
S 100 um

FIG.2D

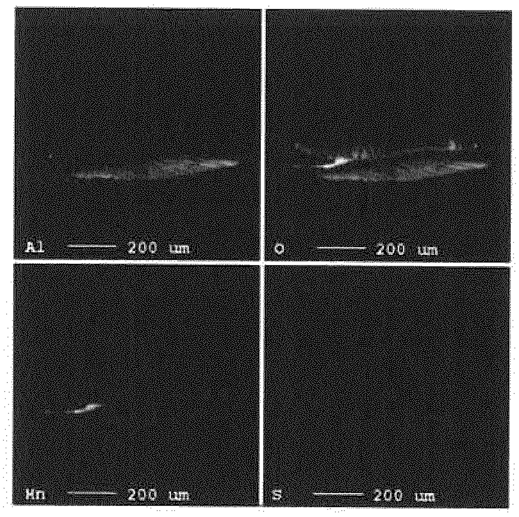

Al 200 um
O 200 um
Mn 200 um
S 200 um

FIG.2E

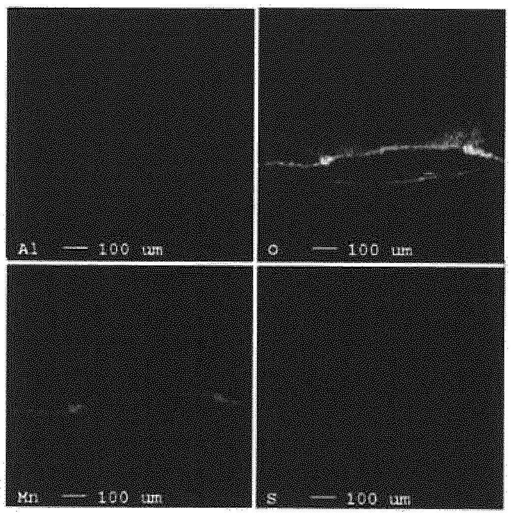

Al — 100 um
O — 100 um
Mn — 100 um
S — 100 um

FIG.2F

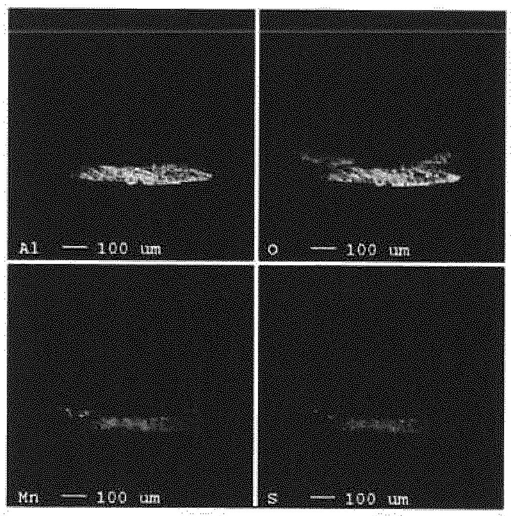

Al — 100 um
O — 100 um
Mn — 100 um
S — 100 um

FIG.3A

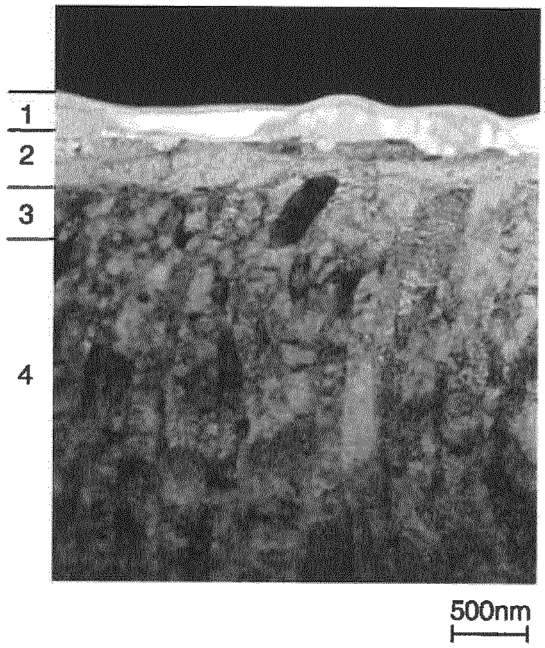


FIG.3B

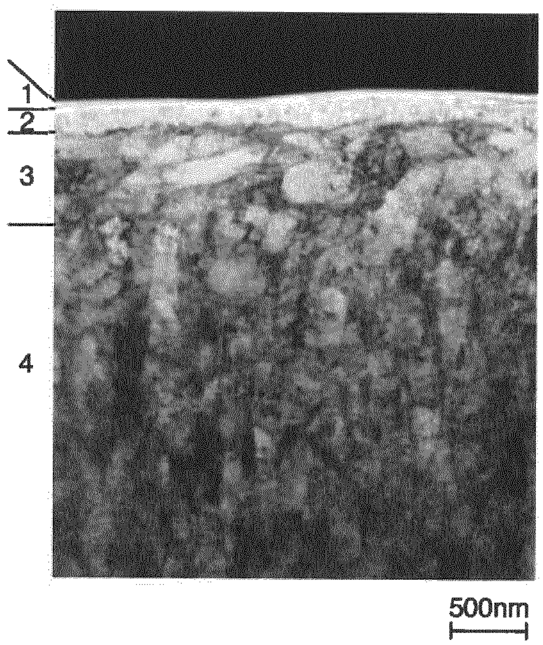


FIG.3C

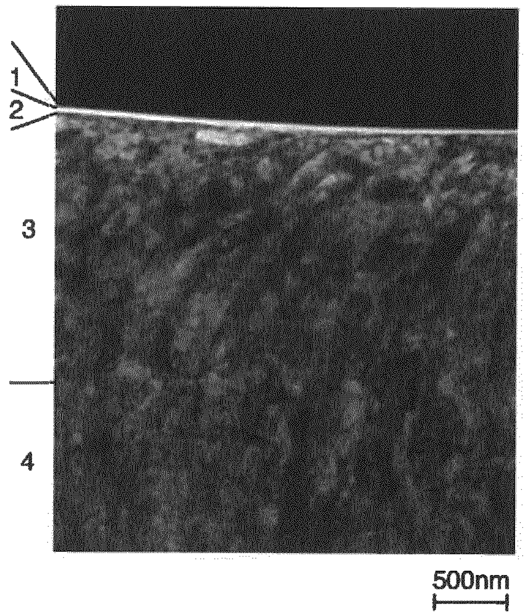

1
2
3
4
500nm

FIG.4

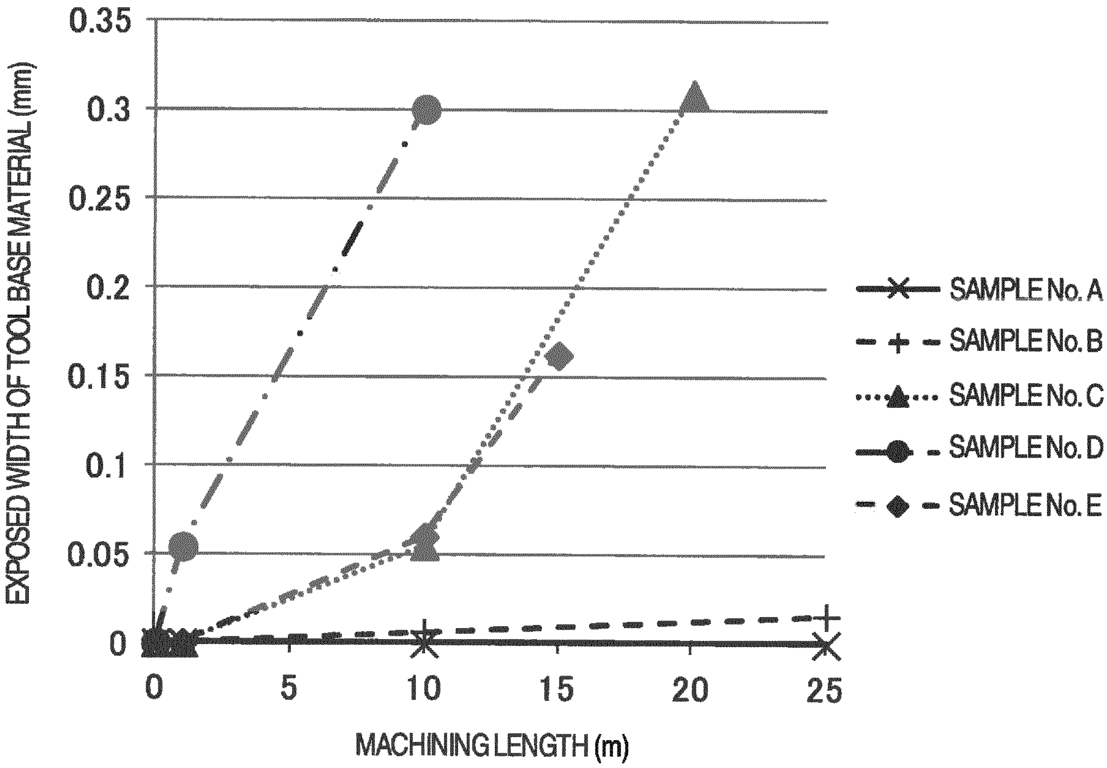

EXPOSED WIDTH OF TOOL BASE MATERIAL (mm)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
MACHINING LENGTH (m)
SAMPLE No. A
SAMPLE No. B
SAMPLE No. C
SAMPLE No. D
SAMPLE No. E

FIG.5A

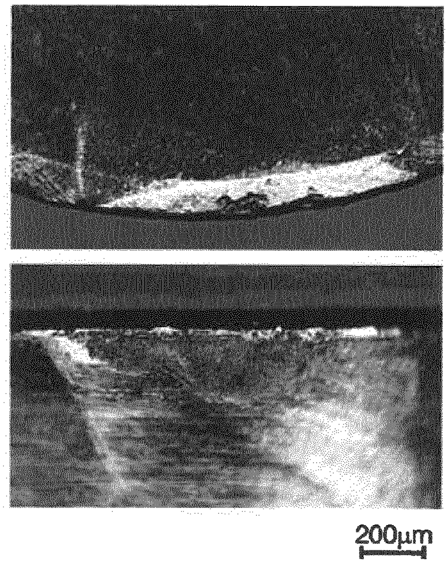


FIG.5B

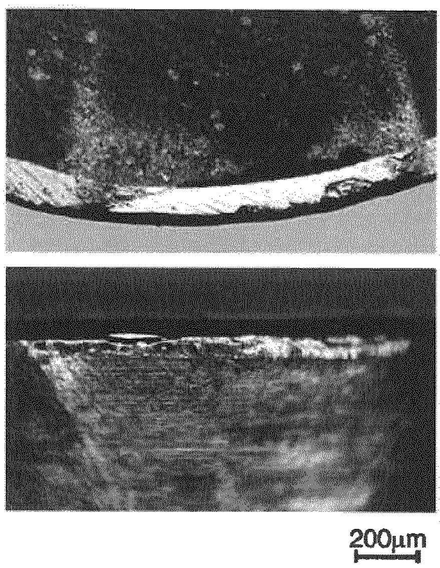


FIG.5C

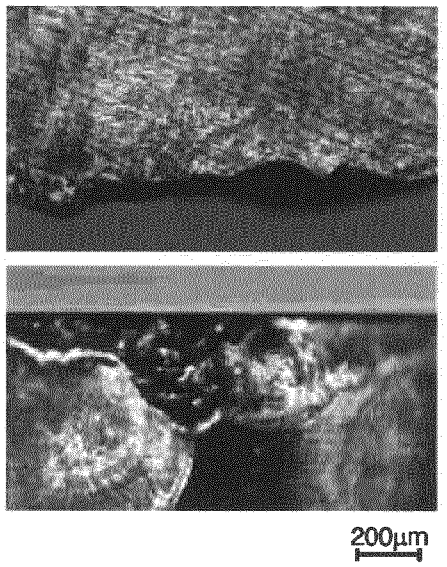


FIG.5D

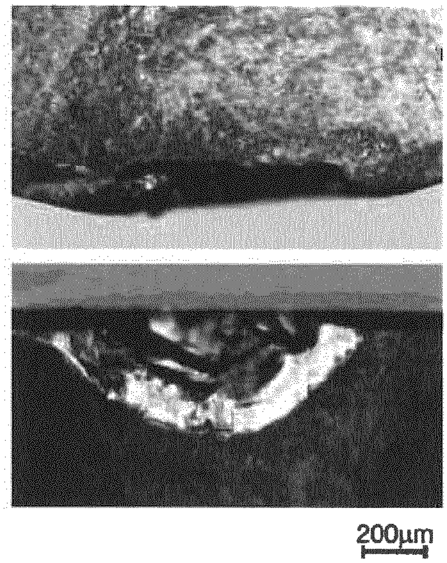
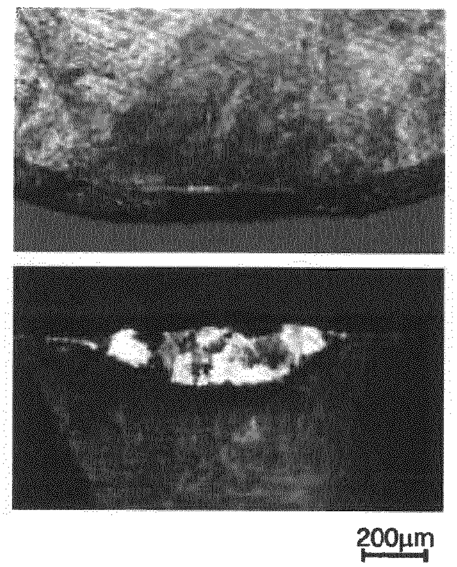


FIG.5E



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- JP 2009132990 A **[0005]**
- JP 2006193790 A **[0005]**
- JP 2001316769 A **[0005]**
- JP 2005272899 A **[0005]**
- WO 03106728 A1 **[0005]**