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(54) **Low-carbon free cutting steel**

(57) The invention provides a low-carbon resulfurized free cutting steel containing no lead and at least comparable in machinability to the conventional leaded free cutting steels. The steel consists of, by mass percent, C: 0.05 - 0.19 %, Mn: 0.4 - 2.0 %, S: 0.21 - 1.0 %, Ti: 0.03 - 0.30 %, Si: not more than 1.0 %, P: 0.001 - 0.3 %, Al: not more than 0.2 %, O (oxygen): 0.0010 - 0.050 % and N: 0.0001 - 0.0200 %, with the balance being Fe and impurities, the contents of Ti and S satisfying the relation (1) given below and the atomic ratio between Mn and S satisfying the relation (2) given below, and the steel containing MnS with Ti sulfide and/or Ti carbosulfide included therein:

$$\text{Mn/S} \geq 1 \quad (2).$$

The steel may further contain, in addition to the above components, one or more elements selected from the group consisting of Se, Te, Bi, Sn, Zr, Ca, Mg and rare earth elements and/or from the group consisting of Cu, Ni, Cr, Mo, V and Nb.

$$\text{Ti (\% by mass)/S (\% by mass)} < 1 \quad (1)$$

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Description

FIELD OF THE INVENTION

[0001] This invention relates to a low-carbon free cutting steel, which is free of Pb and yet superior in machinability and hot workability to the conventional leaded free cutting steels and composite free cutting steels in which lead and one or more machinability improving elements are used combinedly.

BACKGROUND OF THE INVENTION

[0002] In manufacturing soft small articles not required to have very high strength, steel materials excellent in machinability, namely the so-called free cutting steels, have so far been used for the improvement of productivity. The most known free cutting steels include resulfurized free cutting steels which is improved in machinability by means of MnS resulting from addition of a large amount of S, leaded free cutting steels obtained by addition of Pb, and composite free cutting steels containing both of S and Pb. In particular, leaded free cutting steels are excellent in chip disposability and contribute toward prolonging the tool life. Further, there are free cutting steels containing Te (tellurium) and/or Bi (bismuth) for the purpose of machinability improvement. These are used in large amounts in automotive parts, personal computer and its accompaniment parts, electric machine/appliance parts, molds, and other various machine parts.

[0003] In recent years, the ability of cutting machines has been improved and, as a result, it has become possible to increase the speed of machining. Accordingly, steel materials to be used as raw materials of such parts as mentioned above are also desired to show improved machinability in high-speed machining.

[0004] As for the machinability of steels, they place a special emphasis on not only machinability for prolonging the tool life but also chip separability or, in other words, chip disposability. This is because the chip disposability is indispensable for working line automation and essential for increasing productivity.

[0005] Leaded free cutting steels and composite free cutting steels, in which lead and another machinability improving element are used combinedly, have been regarded as being most outstanding in the above-mentioned machinability. In producing leaded steels, however, it is necessary to install a large-scaled exhauster in the process of production thereof. Further, in view of the recent trend toward suppression of the use of Pb for the preservation of the environment, Pb-free free cutting steel is earnestly desired.

[0006] To meet the above demand, the technology of improving the machinability of low-carbon resulfurized free cutting steels, which are to serve as substitutes for leaded free cutting steels, by increasing the S content and thereby increasing the MnS content in the steels, for instance, has been proposed. However, an increased S content deteriorates the hot workability of steels. Further, in high speed machining at a cutting speed of 150 m/min or higher, even high sulfur free cutting steels are poor in tool life prolonging effect; they are not yet comparable in machinability to leaded free cutting steels.

[0007] In Laid-open Japanese Patent Application (JP Kokai) 2000-319753, there is disclosed a low-carbon resulfurized free cutting steel containing no Pb and having an increased MnS content as a result of addition of S at a level exceeding 0.4 %. With such steel, the tool life is improved to a certain extent but, in high speed machining, that effect is slight. Further, such steel is not improved in chip disposability, which is regarded as important factor of machinability as well as tool life. Thus, that steel cannot be clearly differentiated from the conventional resulfurized free cutting steels in properties.

[0008] In JP Kokai S50-20917, there is disclosed a resulfurized free cutting steel containing not more than 0.5 % of C, 0.3 - 0.75 % of S and 0.1 - 0.5 % of Ti with the proviso that the Ti content does not exceed the S content. This steel is improved in machinability by utilizing iron sulfides in the main and adding Ti thereto to thereby cause iron sulfides to contain Ti and Mn as solid solution. However, as is clear from the description in the example section in the above-cited publication, the C content of this steel is not less than 0.24 %. In that publication, there is no description at all about the fact that marked machinability can be obtained by controlling the constitution and form of sulfides in low carbon steels containing not more than 0.19 % of C. Further, in spite of the attempt to improve machinability based on iron sulfides containing appropriate amounts of Ti and Mn as solid solution, the above steel is not satisfactory in machinability as compared with low carbon free cutting steels and composite free cutting steels, such as the steels of the present invention which are to be mentioned later. Furthermore, the steel disclosed in the above-cited publication is not practicable, since the constituent control of iron sulfides is difficult to control and no satisfactory hot workability can be obtained and it is difficult to produce the steel in such as a continuous casting plant.

[0009] JP Kokai H09-53147 discloses a free cutting steel excellent in carbide tool machinability, which contains C: 0.01 - 0.2 %, Si: 0.10 - 0.60 %, Mn: 0.5 - 1.75 %, P: 0.005 - 0.15 %, S: 0.15 - 0.40 %, O (oxygen): 0.001 - 0.010 %, Ti: 0.0005 - 0.020 % and N: 0.003 - 0.03 %. Within this composition range, it is possible to improve the tool life to some extent. However, because the upper limit to the Ti content is as low as 0.02%, no satisfactory tool life can be obtained, and, at the same time, no good chip disposability, which is important as well as tool life, can be obtained.

[0010] JP Kokai 2001-107182, JP Kokai 2001-152281, JP Kokai 2001-152282 and JP Kokai 2001-152283 disclose a steel containing, as main components, C: less than 0.05 %, Mn: 0.1 - 4.0 %, S: more than 0.15 % and up to 0.5 %, Cr: less than 0.5 %, Ti: 0.003 - 0.3 % and B: 0.0003 - 0.004 %. It is a free cutting steel improved in chip disposability by causing B to segregate around sulfides and at the same time improved in machinability by reducing the C content to a level lower than 0.05 %. However, since the C content is less than 0.05%, plucking of the steel surface may occur during machining, deteriorating the finished surface; thus, no sufficient machinability can be obtained.

[0011] JP Kokai 2001-294976 discloses a free cutting steel containing C: 0.02 - 0.15 %, Mn: 0.3 - 1.8 %, S: 0.2 - 0.5 % and, further, at least one of Ti: 0.1 - 0.6 % and Zr: 0.1 - 0.6 % on condition that "Ti + Zr" amounts to 0.3 - 0.6% and (Ti + Zr)/S is 1.1 - 1.5. This steel is improved in mechanical anisotropy and machinability by employing the above composition to thereby cause the formation of Ti and Zr sulfides, which have high deformation resistance during hot working. However, such sulfides having high deformation resistance make it difficult to obtain a pseudo lubricating effect of sulfides during machining; thus, the cutting force increases and the machinability improving effect is restricted.

SUMMARY OF THE INVENTION

[0012] It is an objective of the present invention to provide a low-carbon resulfurized free cutting steel free of lead (Pb), at least comparable in machinability to the conventional leaded free cutting steels and composite free cutting steels containing lead and another machnability improving element and, further, excellent in hot workability as well.

[0013] In an attempt to improve the machinability of low-carbon resulfurized free cutting steels substantially free of Pb, the present inventors made close investigations concerning the relationship between the form of inclusions resulting from addition of Ti and the machinability. As a result, the following new findings were obtained.

(1) The C content should be 0.05 - 0.19 %.

(2) When the atomic ratio between Mn and S contained in a steel having the above C content satisfies the condition " $Mn/S \geq 1$ " and the steel contains Ti at a level not exceeding the S content (on the % by mass basis), most of sulfides are composed of MnS, not Ti sulfide or iron sulfide.

(3) In the composition restricted in the manner mentioned above under (2), Ti scarcely becomes solid solution in MnS, hence will not form Mn-Ti sulfide, namely (Mn,Ti)S. Ti occurs as Ti sulfide or Ti carbosulfide in a phase separate from MnS. These Ti-based inclusions (sulfide, carbosulfide) occur within MnS, or in a state included in MnS.

(4) Steels in which MnS and the Ti-based inclusions occur in the state mentioned above (3) show good machinability in high speed machining. Thus, when turning is carried out at a high speed of 100 m/min or higher, for instance, MnS adheres to the tool surface and, at the same time, TiN forms a hard lamination thereon. This TiN protects the tool and, as a result, a remarkably longer tool life can be obtained even when compared with the JIS SUM22L-24L composite free cutting steels so far regarded as highest in machinability. Further, when Ti is added under the above restrictions, fine sulfides are formed and the number thereof increases. During machining, these sulfides serve as sources of stress concentration and promote the propagation of crack, so that better chip disposability can be attained simultaneously as compared with the conventional resulfurized free cutting steels and Pb-containing composite free cutting steels. Furthermore, the above-mentioned steels have no hot workability problems, hence can be produced in a continuous casting plant without causing any trouble; they are thus excellent in practicability.

[0014] The present invention has been completed based on the above findings and also on the results of further close investigations concerning the effects of other components than the alloying components mentioned above. The gist of the invention consists in the free cutting steels defined below under (1) to (4).

(1) A low-carbon resulfurized free cutting steel that is characterized by consisting of, by mass percent, C: 0.05 - 0.19 %, Mn: 0.4 - 2.0 %, S: 0.21 - 1.0 %, Ti: 0.03 - 0.30%, Si: not more than 1.0 %, P: 0.001 - 0.3 %, Al: not more than 0.2 %, O (oxygen): 0.0010 - 0.050 % and N: 0.0001 - 0.0200 %, with the balance being Fe and impurities, and that the contents of Ti and S satisfy the relation (1) given below and the atomic ratio between Mn and S satisfies the relation (2) given below, and containing MnS with Ti sulfide and/or Ti carbosulfide included therein.

$$Ti (\% \text{ by mass})/S (\% \text{ by mass}) < 1 \quad (1)$$

$$Mn/S \geq 1 \quad (2).$$

(2) A low-carbon resulfurized free cutting steel that further comprises, in addition to the components specified above (1), one or more elements selected from the group consisting of Se: 0.001 - 0.01 %, Te: 0.001 - 0.01 %, Bi: 0.005 - 0.3 %, Sn: 0.005 - 0.3 %, Ca: 0.0005 - 0.01 %, Mg: 0.0005 - 0.01 % and rare earth elements: 0.0005 - 0.01%, and satisfies the above relations (1) and (2).

(3) A low-carbon resulfurized free cutting steel that further comprises, in addition to the components specified above (1), one or more elements selected from the group consisting of Cu: 0.01 - 1.0 %, Ni: 0.01 - 2.0 %, Cr: 0.01 - 2.5 %, Mo: 0.01 - 1.0 %, V: 0.005 - 0.5 % and Nb: 0.005 - 0.1 %, and satisfies the above relations (1) and (2).

(4) A low-carbon resulfurized free cutting steel that further comprises, in addition to the components specified above (1), one or more elements selected from the group consisting of Se: 0.001 - 0.01%, Te: 0.001 - 0.01 %, Bi: 0.005 - 0.3 %, Sn: 0.005 - 0.3 %, Ca: 0.0005 - 0.01 %, Mg: 0.0005 - 0.01 % and rare earth elements: 0.0005 - 0.01 %, and one or more elements selected from the group consisting of Cu: 0.01 - 1.0 %, Ni: 0.01 - 2.0 %, Cr: 0.01 - 2.5 %, Mo: 0.01 - 1.0 %, V: 0.005 - 0.5 % and Nb: 0.005 - 0.1 %, and satisfies the above relations (1) and (2).

[0015] The free cutting steels defined above (1) to (4) desirably have an Si content of less than 0.1% by mass.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

Fig. 1 is a representation of the results of EPMA (electron probe micro analyzer) analysis of MnS including Ti sulfide and/or Ti carbosulfide observed in a steel according to the invention. Fig. 1(a) shows one inclusion, and Fig. 1(b), Fig. 1(c) and Fig. 1(d) show the occurrence of Ti, Mn and S, respectively, in that inclusion.

Fig. 2 is a graphic representation showing the relationship between chip disposability and tool life for steels of the invention (steels Nos. 1-29) and steels for comparison (steels Nos. 30-47).

Fig. 3 is a graphic representation showing the relationship between reduction of area in hot ductility testing and tool life for steels of the invention (steels Nos. 1-29) and steels for comparison (steels Nos. 30-47).

DETAILED DESCRIPTION OF THE INVENTION

1. MnS with Ti Sulfide and/or Ti Carbosulfide included therein

[0017] One of the important features of the free cutting steel of the invention is that it contains "MnS with Ti sulfide and/or Ti carbosulfide included therein".

[0018] Ti, in trace amounts, can dissolve in MnS and thus may occur as (Mn,Ti)S. However, the amount of Ti dissolving in that MnS is slight and, therefore, this sulfide is substantially composed of MnS. On the other hand, there exists Ti sulfide or Ti carbosulfide representable by the chemical formula TiS or $Ti_4C_2S_2$ and manifestly differing from such MnS. Most of Ti sulfide and Ti carbosulfide in MnS exists as distinctly separated phases from MnS.

[0019] The occurrence of such forms of sulfides as mentioned above can be understood by area analysis and quantitative analysis, using an EPMA (electron probe micro analyzer), an EDX (energy dispersive X-ray microanalyzer) or the like, of a micro test specimen cut out from a steel material.

[0020] Fig. 1 shows the results of area analysis of the steel No. 3 shown in Table 1 given later using the EPMA. One inclusion is shown in (a), and (b) to (d) show the occurrence of Ti, Mn and S respectively in the inclusion.

[0021] As is evident from these figures, the Ti sulfide or Ti carbosulfide occurs in various states, for example in a state of segregation at interface of MnS and matrix, or in a state of being surrounded by MnS. In accordance with the invention, when Ti sulfide and/or Ti carbosulfide occur in that manner together with one MnS particle in separate phases and the percent in area occupied by MnS in one sulfide particle is not less than 50%, such sulfide is defined as "MnS with Ti sulfide and/or Ti carbosulfide included therein".

[0022] The constitution and area percentage of the Ti sulfide and/or Ti carbosulfide included in one MnS particle can be confirmed by using the above-mentioned EPMA or EDX. The "MnS with Ti sulfide and/or Ti carbosulfide included therein" in a steel can also be confirmed by the same method, and the number of particles thereof can also be determined. When the number of particles counted in a plurality of fields of view and expressed in terms of mean number per mm^2 is not less than $10/mm^2$, good machinability can be obtained.

[0023] When a steel containing MnS with Ti sulfide and/or Ti carbosulfide included therein is machined, the soft MnS produces a pseudo lubricating effect on the surface of contact between the work material and the tool, and TiN is formed on the tool surface and the tool is protected thereby. Thus, presumably, Ti sulfide or Ti carbosulfide, together with MnS, adheres to the tool surface in contact with the work material during machining and, further, as the temperature rises due to friction during machining, these Ti-based sulfides react with N (nitrogen) in the atmosphere to form a hard TiN layer having a thickness of several micrometers to scores of micrometers. The occurrence thereof can be confirmed

by area analysis and point quantitative analysis by AES (Auger electron spectroscopy) or using an EPMA, of the tool surface deprived of carbon-based contaminants (oils and fats etc.) by Ar sputtering or the like after completion of machining.

[0024] Upon examination in the above manner, it was found that the area of such laminar TiN film covers about 10 - 80 % of the contact surface between the work material and tool, with the remainder being covered by adhering MnS or Fe or being the tool surface as it is without any adhering matter. The hard TiN film thus formed on the tool surface produces a marked tool-protecting effect and, as a result, the wear resistance of the tool is improved and the life thereof is prolonged. This tool life improving effect is much more marked than that of resulfurized free cutting steels and Pb-containing composite free cutting steels.

[0025] In the steel of the invention, fine inclusions of MnS, Ti sulfide and Ti carbosulfide are contained in addition to the "MnS with Ti sulfide and/or Ti carbosulfide included therein". Thus, the total number of such inclusions is very large, and these inclusions serve as stress concentration points in chips formed during machining and promote crack propagation, whereby the chip disposability is also improved.

[0026] "MnS with Ti sulfide and/or Ti carbosulfide included therein" can be caused to occur in a steel by adjusting the composition of the steel in the manner mentioned hereinabove. For causing this MnS to exist stably, it is desirable to give a thermal hysteresis to the steel, for example, by heating it to a sufficiently high temperature not lower than 1,000°C after casting and maintaining it at that temperature for a sufficiently long time, followed by forging, or by normalizing it at such a high temperature as mentioned above.

2. Grounds for Restriction of the Chemical Composition

[0027] In the following, the grounds for restriction of the chemical composition of the steel of the invention are explained. "%" expressing the contents of respective components means "% by mass".

C: 0.05 - 0.19 %

[0028] C is an important element exerting a great influence on the machinability of the steel. In the case of a steel material for use in a field where importance is attached to machinability, a C content exceeding 0.19 % increases the strength of the steel material, thus deteriorating the machinability. When, however, the C content is less than 0.05 %, the steel material becomes too soft, allowing the occurrence of plucking of the steel surface during machining, and the wear of the tool is rather promoted and the chip disposability is deteriorated. Therefore, the C content is restricted to the range of 0.05 - 0.19 %. A more adequate C content range for obtaining still better machinability is 0.05 - 0.17 %.

Mn: 0.40 - 2.0 %

[0029] Mn is an important element, which forms sulfide inclusions with S and exerts a great influence on the machinability. At levels less than 0.40 %, the absolute quantity of the sulfides is insufficient, hence a satisfactory level of machinability cannot be obtained. At levels exceeding 2.0 %, the strength of the steel material increases and, accordingly, the cutting force increases, so that the tool life is shortened. For reducing the cutting force and improving the tool life, chip disposability and hot workability as well, the relation with the content of S is important. Thus, the amount of S should be such that the atomic ratio relation " $\text{Mn/S} \geq 1$ " should be maintained. For securing those performance characteristics, it is desirable that the Mn content be 0.6 to 1.8 %.

S: 0.21 - 1.0%

[0030] S is an indispensable element that is effective in forming sulfides or carbosulfides with Mn and/or Ti and improves the machinability. The machinability improving effect of MnS, in particular, increases with the increase in the amount thereof. However, at levels below 0.21 %, it is impossible to obtain a sufficient amount of sulfide inclusions; hence, no satisfactory machinability can be expected. Generally, when the S content exceeds 0.35 %, the hot workability of the steel is deteriorated, and segregation of S and cracks occur in the center of the steel ingot in the stage of casting. When the composition specified herein is maintained, however, the upper limit to the S content can be raised to 1.0 %, without such harmful effects. When the yield in the production process is taken into consideration, 0.70 % is a preferred upper limit of the S content.

Ti: 0.03 - 0.30 %

[0031] Ti forms Ti sulfide or Ti carbosulfide with S or S and C, and the occurrence of these in a form included in MnS improves the machinability and hot workability of the steel. Therefore, Ti is an indispensable important element in the

steel of the invention. Even when compared with Mn, Ti is a potent sulfide-forming element and, when its content is not less than 0.03 %, it forms Ti sulfide and/or Ti carbosulfide and these occur in a state included in MnS, so that the machinability improving effect can be obtained to a satisfactory extent. At levels lower than 0.03 %, the effect is insufficient. At levels exceeding 0.30 %, however, the proportion of hard Ti sulfide and/or Ti carbosulfide among the whole sulfide so increases that the cutting force increases and the machinability is deteriorated. A more desirable upper limit to the Ti content is 0.10 %.

Si: not more than 1.0 %

[0032] Si is useful as a deoxidizing element in adjusting the oxygen content in the steel. However, at levels exceeding 1.0 %, it deteriorates the hot workability of the steel and, further, causes solid-solution strengthening of the ferrite phase, so that the cutting force increases and the machinability is impaired. Therefore, the upper limit to the Si content is set at 1.0 %. It is more desirable to reduce the Si content to a level lower than 0.1 %. For the purpose of deoxidation, the Si content is desirably not less than 0.001 %. Even when it is substantially 0 % (zero percent), the machinability will not deteriorate if the oxygen content in the steel can be adjusted to an appropriate level, for example by addition of Al to be mentioned later.

P: 0.001 - 0.3 %

[0033] At levels exceeding 0.3 %, P promotes segregation in the steel ingot and deteriorates the hot workability. Therefore, the upper limit to its content is set at 0.3%. On the other hand, P is an element having a machinability improving effect, so that 0.001 % is selected at the lower limit so as to produce that effect. A more preferred P content is 0.01 - 0.15 %.

Al: not more than 0.2 %

[0034] Al is used as a potent deoxidizing element and may be contained up to a level of 0.2 %. However, the oxide formed by deoxidation is hard. Therefore, when the Al content exceeds 0.2 %, the hard oxide is formed in large amounts, deteriorating the machinability. An Al content of not more than 0.1 % is more preferred. In cases where sufficient deoxidation is possible with the above-mentioned Si, the addition of Al is unnecessary, hence the content thereof may be substantially 0 % (zero percent).

O (oxygen): 0.0010 - 0.05 %

[0035] When an appropriate amount of oxygen is contained in the steel, that oxygen is dissolved in MnS and prevents the elongation of MnS and reduces the anisotropy in mechanical properties. Oxygen further contributes to the improvements in machinability and hot workability and is also effective in preventing the segregation of S. Therefore, it is recommended that oxygen be contained at a level not less than 0.0010 %. At levels exceeding 0.05 %, however, it may produce adverse effects, such as deterioration of and damage to the refractory material in the stage of melting. Therefore, 0.05 % is selected as the upper limit. A more preferred range for properly obtaining the above effects is 0.005 - 0.02 %.

N: 0.0001 - 0.0200 %

[0036] N forms hard nitrides with Al and/or Ti, and these nitrides have an effect making grains finer. This effect is produced at an N content level of not less than 0.0001 %. Generally, these nitrides, when present in large amounts, deteriorate the machinability and increase the wear of the cutting tool. On the contrary, when the steel of the invention is machined, TiN is formed on the tool surface and protects the tool and, therefore, a certain amount of nitrides may be present in the steel without deteriorating the machinability. However, at N contents exceeding 0.0200 %, that effect diminishes. For obtaining a longer tool life, an N content of not more than 0.0150 % is preferred. When a still longer tool life is desired, an N content of not more than 0.0100 % is preferred.

[0037] In accordance with one aspect of the invention, the remainder of the steel other than the components mentioned above comprises Fe and impurities.

[0038] In accordance with another aspect of the invention, the steel of the invention comprises, in addition to the components mentioned above, one or more elements selected from the first group or second group or the first and the second groups of elements mentioned below.

[0039] The first group of elements comprises Se, Te, Bi, Sn, Ca, Mg and rare earth elements. These elements further improve the machinability of the steel. The second group of elements comprises Cu, Ni, Cr, Mo, V and Nb, and these

elements improve the mechanical properties of the steel.

Se: 0.001 - 0.01 %, Te: 0.001 - 0.01 %

5 **[0040]** Se and Te form Mn(S,Se) or Mn(S,Te) with Mn, and are elements effective in machinability improvement. At a level below 0.001 %, the effect of each of these is not significant. On the other hand, at levels exceeding 0.01 %, not only the effect of each of Se and Te arrives at a point of saturation but also the addition thereof becomes uneconomical; in addition, the hot workability deteriorates.

10 Bi: 0.005 - 0.3 %, Sn: 0.005 - 0.3 %

[0041] Bi and Sn occur as low-melting metallic inclusions in the steel and produce a lubricating effect in the step of machining, thus improving the machinability. Such effect becomes significant at a level of not lower than 0.005 %. However, when the content of each exceeds 0.3 %, not only the effect arrives at a point of saturation but also the hot workability becomes deteriorated.

Ca: 0.0005 - 0.01 %, Mg: 0.0005 - 0.01 %

20 **[0042]** Ca and Mg each has a high affinity for S and oxygen in the steel, so that they form sulfides or oxides with these; at the same time, they are dissolved in MnS and occur therein as (Mn,Ca)S and (Mn,Mg)S, respectively. Further, MnS crystallizes with those oxides as nuclei for its formation, so that they are effective in preventing the elongation of MnS. In this way, Ca and Mg control the form of sulfides and thus improve the machinability, so that they may be added according to need. For securing this effect, Ca and Mg may be added each to a content level of not less than 0.0005 %.

25 At a level exceeding 0.01 %, however, the effect arrives at a point of saturation. Since the yield of addition of Ca as well as Mg is low, the addition thereof in large amounts is required to increase the contents thereof and this is unfavorable from the production cost viewpoint. Therefore, the upper limit to the content of each of them is set at 0.01 %.

Rare earth elements: 0.0005-0.01%

30 **[0043]** Rare earth elements constitute a group of elements classified as lanthanoids. When they are added, a misch metal or the like containing them as main components is generally used. The content of rare earth elements, so referred to herein, is expressed in terms of the total content of one or more elements among the rare earth elements. The rare earth elements form sulfides or oxides with S and oxygen and, at the same time, control the form of sulfides and thereby improve the machinability. For securing such effect, their content should be not less than 0.0005 %. However, at content

35 levels exceeding 0.01 %, the effect arrives at a point of saturation and, further, the yield of addition thereof is low, like Ca and Mg, and the addition thereof in large amounts is uneconomical.

Cu: 0.01 - 1.0 %

40 **[0044]** Cu improves the hardenability of the steel. When such effect is desired, it may be added to a content of not less than 0.01 %. However, when its content exceeds 1.0 %, the hot workability of the steel deteriorates and, further, a decrease in machinability is caused.

Ni: 0.01 - 2.0 %

45 **[0045]** Ni is effective in improving the strength of the steel through solid-solution strengthening and further is effective in improving the hardenability and toughness. For obtaining such effects, its content is desirably not less than 0.01 %. However, content levels exceeding 2.0 % cause the machinability to deteriorate and, at the same time, cause the hot workability to deteriorate.

50 Cr: 0.01 - 2.5 %

[0046] Cr is effective in improving the hardenability of the steel. For obtaining such effect, a Cr content of not less than 0.01 % is preferred. However, the machinability deteriorates at content levels exceeding 2.5 %.

55 Mo: 0.01 - 1.0 %

[0047] Mo is effective in making the microstructure of the steel fine and thus improving the toughness. For securing

the effects, a Mo content of not less than 0.01 % is desirable. However, at contents exceeding 1.0 %, the effects arrive at a point of saturation and, in addition, the cost of production of the steel increases.

V: 0.005 - 0.5 %, Nb: 0.005 - 0.1 %

[0048] V and Nb precipitate as fine nitrides or carbonitrides and increase the strength of the steel. For securing such effect, the content of each is desirably not less than 0.005 %. However, when the V content exceeds 0.5 % or the Nb content exceeds 0.1 %, the above effect arrives at a point of saturation and, in addition, nitrides and/or carbides are formed in excess, causing the machinability to deteriorate.

3. Relations (1) and (2)

[0049] The reasons why the Ti content and S content should satisfy the relation (1) are as follows.

[0050] As mentioned above, Ti forms Ti sulfide or Ti carbosulfide with S or C and S. The tendency is larger than the tendency of Mn sulfide formation. The effect of Ti is improvement in the tool life because TiN is formed on the tool surface by formation of Ti-basis inclusions during machining as mentioned above. However, Ti sulfide and Ti carbosulfide are hard inclusions showing a higher deformation resistance as compared with MnS. Therefore, in a composition in which the Ti content is higher than the S content, MnS is formed in smaller amounts and Ti sulfide and/or Ti carbosulfide constitute the majority; as a result, the sulfide-due effect of pseudo lubricating between the tool and work material during machining cannot be produced but the cutting force increases abruptly. The increase in cutting force not only shortens the tool life but also causes such troubles as work material vibration during machining of small-diameter materials.

[0051] When adjustments are made so that the relation represented by the formula (1) may be satisfied, namely that the "Ti (% by mass)/S (% by mass)" may be smaller than 1, MnS, not Ti sulfide or Ti carbosulfide, becomes the main sulfide. In this case, such troubles as an increase in cutting force as encountered when Ti sulfide and/or Ti carbosulfide become main sulfides, as mentioned above, will not be encountered but the tool life and chip disposability can be improved.

[0052] The reason why the atomic ratio between Mn and S should satisfy the relation represented by the formula (2) are as follows.

[0053] S is an element inducing cracking during hot forging. However, when a composition satisfies the atomic ratio relation " $Mn/S \geq 1$ ", S crystallizes as Mn sulfide and the hot workability will not be adversely affected.

[0054] Even when the ratio Mn/S is less than 1, Ti-based sulfides are formed and the hot workability can be improved, if the Ti and S contents are adjusted so as not to satisfy the above relation (1). In that case, however, troubles such as an increase in cutting force and a shortened tool life may occur, as mentioned above. Furthermore, when the ratio Mn/S is less than 1 and Ti is contained at a content level not exceeding the S content, namely when the composition does satisfies the relation (1) but does not satisfy the relation (2), sulfides with FeS included as solid solution in MnS and TiS constitute the majority of inclusions. These sulfides, which contain large amounts of FeS as solid solution, deteriorate the hot workability of the steel and making it difficult to control the operation conditions in producing the steel by continuous casting, for instance.

EXAMPLE

[0055] Steels having respective compositions shown in Table 1 and Table 2 were melted using a high frequency induction furnace, and 150-kg steel ingots, 220 mm in diameter, were prepared. For the stable formation of "MnS with Ti sulfide and/or Ti carbosulfide included therein", these steel ingots were heated to a temperature as high as 1,200 °C and, after 2 hours or a longer period of maintenance at that temperature, forging was performed at a finishing temperature of not lower than 1,000°C and, then, the forgings were air-cooled (AC) to give round bars having a diameter of 65 mm. These round bars were normalized by maintaining them at 950°C for 1 hour, followed by air cooling (AC).

Table 1

Steel No.	Chemical Composition (mass%)										bal.: Fe and Impurities		Mn/S (atomic ratio)	Ti/S (mass% ratio)
	C	Si	Mn	P	S	Al	Ti	N	O	others				
1	0.08	—	0.96	0.017	0.33	—	0.13	0.0035	0.0060	—	—	—	1.70	0.39
2	0.06	0.01	0.92	0.017	0.49	0.001	0.07	0.0050	0.0210	—	—	—	1.10	0.15
3	0.07	—	0.91	0.017	0.47	—	0.12	0.0065	0.0100	—	—	—	1.13	0.26
4	0.06	0.06	0.86	0.020	0.49	0.001	0.25	0.0066	0.0170	—	—	—	1.02	0.51
5	0.07	0.02	0.86	0.075	0.46	0.001	0.26	0.0054	0.0110	—	—	—	1.09	0.57
6	0.06	0.02	0.87	0.018	0.50	0.001	0.13	0.0064	0.0190	—	—	—	1.02	0.26
7	0.07	0.17	0.98	0.018	0.50	0.001	0.14	0.0104	0.0150	—	—	—	1.14	0.28
8	0.06	0.05	0.92	0.019	0.50	0.014	0.14	0.0097	0.0160	—	—	—	1.07	0.28
9	0.19	0.29	0.40	0.016	0.22	0.003	0.10	0.0024	0.0020	—	—	—	1.06	0.45
10	0.10	0.01	1.02	0.022	0.34	0.003	0.05	0.0043	0.0110	—	—	—	1.75	0.15
11	0.09	0.02	1.17	0.023	0.49	0.005	0.05	0.0054	0.0180	—	—	—	1.39	0.11
12	0.05	—	0.93	0.018	0.33	—	0.08	0.0087	0.0091	—	—	—	1.62	0.25
13	0.15	0.01	1.00	0.024	0.39	0.001	0.13	0.0063	0.0158	—	—	—	1.49	0.34
14	0.10	—	0.58	0.017	0.25	—	0.06	0.0088	0.0179	—	—	—	1.35	0.24
15	0.07	—	1.55	0.018	0.69	—	0.25	0.0074	0.0166	—	—	—	1.31	0.51
16	0.08	—	0.95	0.020	0.35	—	0.10	0.0048	0.0135	Te:0.0038	—	—	1.58	0.29
17	0.08	—	0.98	0.018	0.45	—	0.09	0.0055	0.0140	Se:0.0020	—	—	1.27	0.20
18	0.06	0.01	0.88	0.017	0.49	0.001	0.11	0.0062	0.0210	Ca:0.0031	—	—	1.05	0.22
19	0.07	—	0.91	0.015	0.48	—	0.15	0.0111	0.0148	Ca:0.0025, Mg:0.0021	—	—	1.11	0.31
20	0.07	—	0.91	0.016	0.46	0.001	0.13	0.0042	0.0145	REM:0.0035	—	—	1.16	0.27
21	0.06	—	0.95	0.018	0.50	0.001	0.13	0.0078	0.0190	Bi:0.07	—	—	1.11	0.26
22	0.07	0.17	0.89	0.018	0.47	0.001	0.11	0.0056	0.0158	Sn:0.18	—	—	1.10	0.24
23	0.08	—	0.86	0.016	0.36	—	0.08	0.0063	0.0139	Cu:0.38	—	—	1.41	0.24
24	0.09	0.01	0.90	0.017	0.38	0.002	0.13	0.0087	0.0188	Ni:0.15	—	—	1.40	0.34
25	0.05	—	0.89	0.015	0.46	—	0.09	0.0054	0.0096	Cr:0.55	—	—	1.11	0.20
26	0.09	0.15	0.94	0.019	0.50	0.001	0.10	0.0047	0.0075	Mo:0.20	—	—	1.10	0.20
27	0.05	—	0.83	0.018	0.47	—	0.06	0.0085	0.0112	V:0.10	—	—	1.03	0.13
28	0.08	—	0.94	0.015	0.45	0.001	0.20	0.0075	0.0143	Nb:0.03	—	—	1.22	0.44
29	0.07	—	0.89	0.019	0.49	0.003	0.19	0.0026	0.0088	Cr:0.50, Mo:0.18	—	—	1.05	0.39

Table 2

Steel No.	Chemical Composition (mass%)										bal:Fe and Impurities		Mn/S (atomic ratio)	Ti/S (mass% ratio)
	C	Si	Mn	P	S	Al	Ti	N	O	others				
30	0.08	—	0.95	0.055	0.33	0.002	—**	0.0048	0.0185	Pb:0.31**			1.68	—
31	0.07	0.01	1.10	0.060	0.32	0.002	—**	0.0090	0.0150	Pb:0.27**			2.01	—
32	0.08	—	1.02	0.067	0.33	0.002	—**	0.0066	0.0150	—			1.80	—
33	0.06	0.01	0.84	0.018	0.47	0.001	—**	0.0083	0.0210	—			1.04	—
34	0.07	0.01	1.26	0.018	0.62	0.001	—**	0.0059	0.0140	—			1.19	—
35	0.08	—	1.00	0.020	0.35	—	0.01**	0.0076	0.0175	—			1.67	0.03
36	0.19	0.29	0.49	0.016	0.25	0.003	0.35**	0.0061	0.0020	—			1.14	1.40**
37	0.52**	0.17	0.54	0.016	0.21	—	0.05	0.0079	0.0180	—			1.50	0.24
38	0.35**	—	0.50	0.019	0.23	0.002	0.08	0.0046	0.0058	—			1.27	0.35
39	0.01**	—	0.89	0.013	0.33	0.002	0.06	0.0047	0.0148	—			1.57	0.18
40	0.06	—	0.49	0.014	0.15**	—	0.05	0.0095	0.0193	—			1.91	0.33
41	0.07	0.01	1.53	0.018	1.05**	0.001	0.10	0.0072	0.0210	—			0.85**	0.09
42	0.06	—	0.18	0.018	0.34	0.001	0.14	0.0074	0.0090	—			0.31**	0.41
43	0.08	0.01	2.53**	0.018	0.65	0.001	0.15	0.0066	0.0210	—			2.27	0.23
44	0.07	—	0.88	0.4**	0.20	—	0.09	0.0079	0.0176	—			2.57	0.44
45	0.09	0.19	0.82	0.015	0.47	—	0.12	0.0098	0.0064	Cr:4.0**			1.01	0.24
46	0.06	—	0.93	0.019	0.45	0.004	0.14	0.0085	0.0116	V:2.5**			1.19	0.31
47	0.08	—	0.91	0.013	0.46	0.002	0.08	0.0076	0.0063	Cr:2.8**, Mo:1.5**			1.14	0.18

Mark "**" indicates values outside the range specified by the present invention.

(1) Investigation regarding the Constitution and Form of Inclusions

[0056] Test specimens for microscopic observation were taken from the above forgings at a site corresponding to $D_f/4$ (D_f is the diameter of each forging) in the longitudinal sectional direction and, after polishing, subjected to area analysis and quantitative analysis using an EPMA and an EDX. As a result, it was confirmed that, on the average, 10 or more MnS particles with Ti sulfide and/or Ti carbo-sulfide included therein were present in each mm^2 of the steels from No. 1 to No. 29.

(2) Machinability Investigation

[0057] Each round bar obtained by forging was machined into bars of 60 mm diameter and subjected to a cutting test. When a crack was formed during forging due to poor hot workability, the bar was subjected, at the time of crack formation, to normalization by maintaining the bar as it was at 950°C for 1 hour, followed by air cooling (AC) and further followed by machining into 60 mm diameter in order to give a test specimen.

[0058] The machinability test was carried out using a JIS P type carbide tool without TiN coating treatment. The cutting was carried out in the manner of dry turning (without using any lubricating oil) under the following conditions.

Cutting speed: 150 m/min, Feed: 0.10 mm/rev, and

Depth of cut: 2.0 mm.

[0059] After 30 minutes of turning under the above conditions, the mean flank wear (VB) of the cutting tool was measured. For those test specimens showing a mean flank wear of not less than $200\mu\text{m}$ within 30 minutes, the time required for arriving at such wear and the mean flank wear (VB) at that time were measured for each of the specimens. Further, tool life evaluation was carried out using, as a measure, the time required for the mean flank wear (VB) to arrive at $100\mu\text{m}$. When the test specimen became short during testing due to its superiority in suppressing the tool wear and slow wear rate of the tool, the time required for the mean flank wear (VB) to arrive at $100\mu\text{m}$ was calculated from the turning time-tool wear curve by the regression method. The chip disposability was evaluated by collecting at least 200 chips representative of the chips discharged, weighing them, and calculating the number of chips per unit weight.

(3) Hot Workability Evaluation

[0060] The hot workability was evaluated in the following manner. For simulating the production conditions in a continuous casting plant, a test specimen, 10 mm in diameter and 130 mm in height for elevated temperature tensile test was taken from each 150-kg steel ingot. The ingot was produced in the same manner as mentioned above. The test specimen was taken in the direction of the steel ingot height so that the specimen center might be close to the surface of the ingot, namely at a site of $D_i/8$ (D_i is the diameter of the steel ingot). The specimen was heated to $1,250^\circ\text{C}$ for 5 minutes by direct charge of an electric current at a fixation distance of 110 mm, and cooled to $1,100^\circ\text{C}$ at a cooling rate of $10^\circ\text{C}/\text{sec}$. After 10 seconds of keeping at $1,100^\circ\text{C}$, tensile test was carried out at a strain rate of $10^{-3}/\text{sec}$. In the tensile test, the area reduction at the site of breakage was determined and the hot workability was evaluated based thereon.

[0061] The results of the above tests are shown in Table 3 and Table 4. The relationship between chip disposability and tool life is shown in Fig. 2, and the relationship between the area reduction in hot tensile testing and the tool life in Fig. 3.

Table 3

Steel No.	Area Reduction (%)	Tool Wear after 30 minutes (μm)	Time for arriving VB of $100\mu\text{m}$ (minutes)	Chip Disposability (number/g)	Remarks
1	65.8	21	179*	15	
2	55.2	35	110	12	
3	54.8	32	181*	16	
4	56.9	35	117	17	
5	58.8	29	119	21	
6	52.7	38	109	15	
7	56.7	35	116	14	

Mark "*" indicates values calculated by regression from the tool wear curve because of shortage of the specimen.

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Table 3 (continued)

Steel No.	Area Reduction (%)	Tool Wear after 30 minutes (μm)	Time for arriving VB of 100 μm (minutes)	Chip Disposability (number/g)	Remarks
8	55.8	41	101	18	
9	57.7	44	94	13	
10	61.0	42	108	12	
11	57.8	38	111	11	
12	63.2	34	121	15	
13	61.5	39	96	14	
14	60.6	39	94	13	
15	52.1	27	128	23	
16	56.9	25	156	11	
17	52.0	26	135	13	
18	59.7	29	139	19	
19	53.4	24	155	16	
20	55.9	28	130	17	
21	52.1	42	102	15	
22	50.4	35	113	15	
23	63.6	44	91	14	
24	65.8	38	97	13	
25	54.9	45	90	18	
26	58.8	40	93	17	
27	53.8	39	95	14	
28	57.6	36	102	14	
29	54.3	39	90	18	

Table 4

Steel No.	Area Reduction (%)	Tool Wear after 30 minutes (μm)	Time for arriving VB of 100 μm (minutes)	Chip Disposability (number/g)	Remarks
30	47.8	97	36	9	
31	49.6	99	30	8	
32	55.4	165	17	1	
33	51.8	210(20min)	9	6	
34	45.4	68	72	10	
35	54.4	90	39	2	
36	64.2	72	69	15	
37	52.8	93	36	12	
38	67.9	89	38	14	
39	57.5	104	29	7	
40	65.3	138	20	5	
41	5.1	39	102	5	Cracking during forging
42	4.3	48	61	9	Cracking during forging
43	65.7	205(20min)	8	10	
44	13.6	103	28	18	Cracking during forging
45	52.0	245(15min)	7	13	
46	55.3	205(20min)	9	17	

Table 4 (continued)

Steel No.	Area Reduction (%)	Tool Wear after 30 minutes (μm)	Time for arriving VB of 100 μm (minutes)	Chip Disposability (number/g)	Remarks
47	54.7	275(15min)	6	10	

[0062] In Table 2, the steels Nos. 30 and 31 are composite free cutting steels, and the steel No. 32 is a resulfurized free cutting steel. These are steels (materials corresponding to JIS SUM23L or SUM23) are so far regarded as highest in machinability. As is evident from Table 3 and Table 4 as well as Fig. 2, the steels of the invention are definitely superior in suppressing the tool wear even when compared with the steels Nos. 30 and 31. Furthermore, no crack were observed at all in the steels Nos. 1 - 29 according to the invention, and, as regards the area reduction in elevated temperature tensile test simulating the practical production in a continuous casting plant, for instance, those steels are at least comparable to the composite free cutting steels and resulfurized free cutting steel, as shown in Table 3, and thus are free of problems from the practical viewpoint.

[0063] On the other hand, the steels failing to meet at least one requirement prescribed herein, such as the steels Nos. 30 - 47, are inferior in at least one of hot ductility, tool life and chip disposability to the steels of the present invention. The steels Nos. 41 and 42 failing to satisfy the relation (2) with respect to Mn and S are very poor in hot workability.

EFFECTS OF THE INVENTION

[0064] In spite of its Pb-free composition, the free cutting steel of the invention is superior in machinability to the conventional leaded free cutting steels and composite free cutting steels. This steel is excellent in hot workability as well and can be produced at low cost by continuous casting. Therefore, it is suited for use as a raw material of various machine parts.

Claims

1. A low-carbon resulfurized free cutting steel **characterized by** consisting of, by mass percent, C : 0.05 to 0.19%, Mn : 0.4 to 2.0%, S : 0.21 to 1.0%, Ti : 0.03 to 0.30%, Si : not more than 1.0%, P : 0.001 to 0.3%, Al : not more than 0.2%, O (oxygen) : 0.0010 to 0.050% and N : 0.0001 to 0.0200%, and optionally one or more elements selected from Se : 0.001 to 0.01%, Te : 0.001 to 0.01%, Bi : 0.005 to 0.3%, Sn : 0.0050 to 0.3%, Ca : 0.0005 to 0.01%, Mg : 0.0005 to 0.01%, rare earth elements : 0.0005 to 0.01%, Cu : 0.01 to 1.0%, Ni : 0.01 to 2.0%, Cr : 0.01 to 2.5%, Mo : 0.01 to 1.0%, V : 0.005 to 0.5% and Nb : 0.005 to 0.1%, with the balance being Fe and impurities, and in which the contents of Ti and S satisfy the relation (1) given below and the atomic ratio between Mn and S satisfies the relation (2) given below and, further, which contains MnS with Ti sulfide and/or Ti carbosulfide included therein:

$$\text{Ti (\% by mass)/S (\% by mass)} < 1 \quad (1)$$

$$\text{Mn/S} \geq 1 \quad (2).$$

2. A steel according to claim 1 **characterized by** consisting of, by mass percent, C : 0.05 to 0.19%, Mn : 0.4 to 2.0%, S : 0.21 to 1.0%, Ti : 0.03 to 0.30%, Si : not more than 1.0%, P : 0.001 to 0.3%, Al : not more than 0.2%, O (oxygen) : 0.0010 to 0.050% and N : 0.0001 to 0.0200%, with the balance being Fe and impurities.

3. A steel according to claim 1 **characterized by** consisting of, by mass percent, C : 0.05 to 0.19%, Mn : 0.4 to 2.0%, S : 0.21 to 1.0%, Ti : 0.03 to 0.30%, Si : not more than 1.0%, P : 0.001 to 0.3%, Al : not more than 0.2%, O (oxygen) : 0.0010 to 0.050% and N : 0.0001 to 0.0200%, and one or more elements selected from Se : 0.001 to 0.01%, Te : 0.001 to 0.01%, Bi : 0.005 to 0.3%, Sn : 0.005 to 0.3%, Ca : 0.0005 to 0.01%, Mg : 0.0005 to 0.01% and rare earth elements : 0.0005 to 0.01%, with the balance being Fe and impurities.

4. A steel according to claim 1 **characterized by** consisting of, by mass percent, C : 0.05 to 0.19%, Mn : 0.4 to 2.0%, S : 0.21 to 1.0%, Ti : 0.03 to 0.30%, Si : not more than 1.0%, P : 0.001 to 0.3%, Al : not more than 0.2%, O (oxygen) :

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0.0010 to 0.050% and N : 0.0001 to 0.0200%, and one or more elements selected from Cu : 0.01 to 1.0%, Ni : 0.01 to 2.0%, Cr : 0.01 to 2.5%, Mo : 0.01 to 1.0%, V : 0.005 to 0.5% and Nb : 0.005 to 0.1%, with the balance being Fe and impurities.

- 5 **5.** A steel according to claim 1 **characterized by** consisting of, by mass percent, C : 0.05 to 0.19%, Mn : 0.4 to 2.0%, S : 0.21 to 1.0%, Ti : 0.03 to 0.30%, Si: not more than 1.0%, P : 0.001 to 0.3%, Al : not more than 0.2%, O (oxygen): 0.0010 to 0.050% and N : 0.0001 to 0.0200%, one or more elements selected from Se : 0.001 to 0.01%, Te : 0.001 to 0.01%, Bi : 0.005 to 0.3%, Sn : 0.005 to 0.3%, Ca : 0.0005 to 0.01%, Mg : 0.0005 to 0.01% and rare earth elements : 0.0005 to 0.01%, and one or more elements selected from Cu : 0.01 to 1.0%, Ni : 0.01 to 2.0%, Cr : 0.01 to 2.5%, Mo : 0.01 to 1.0%, V : 0.005 to 0.5% and Nb : 0.005 to 0.1%, with the balance being Fe and impurities.
- 10
- 6.** A steel according to any of Claims 1 to 5, wherein the Si content is less than 0.1% by mass.
- 7.** A machine part comprising a steel as claimed in any one of claims 1 to 6.

Fig.1

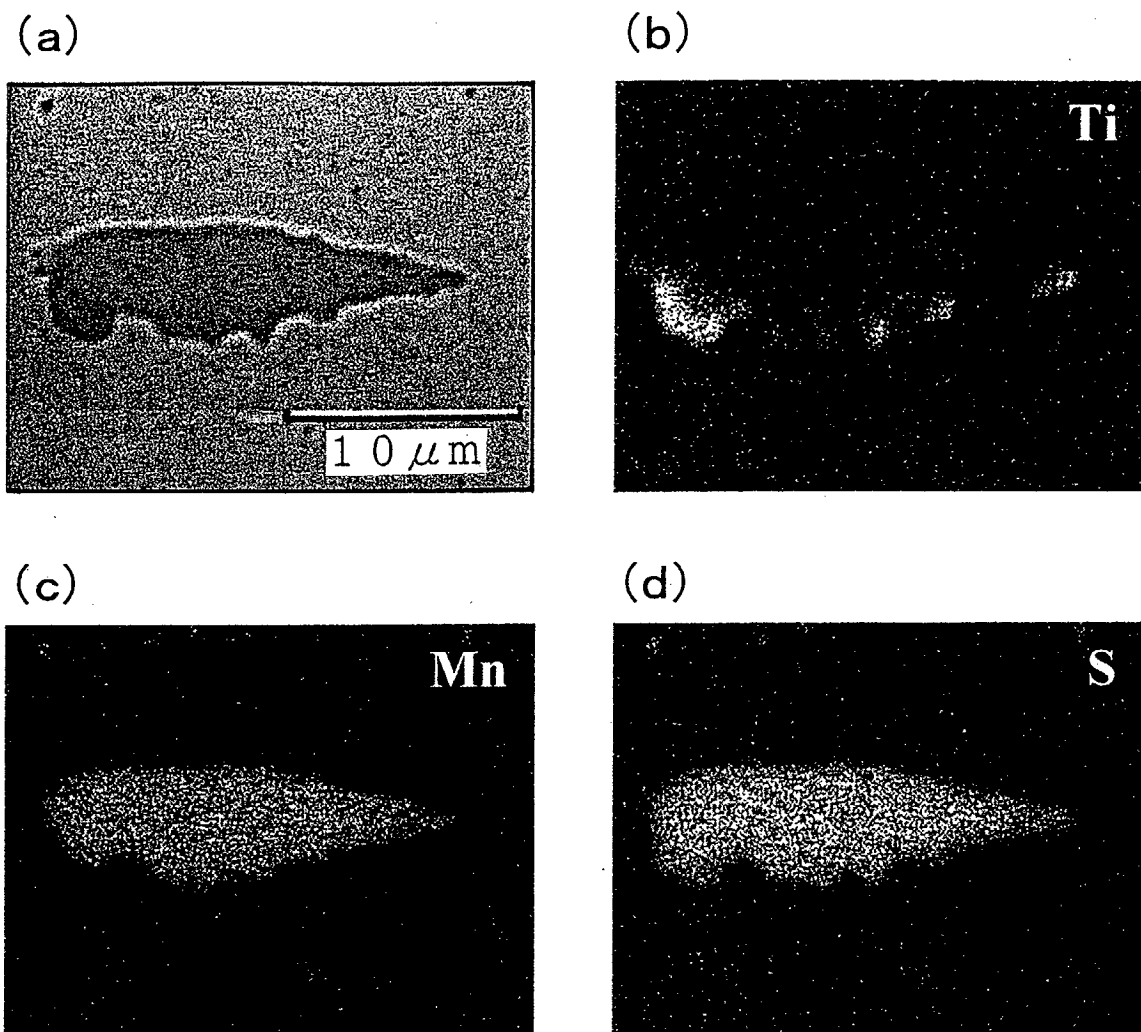


Fig. 2

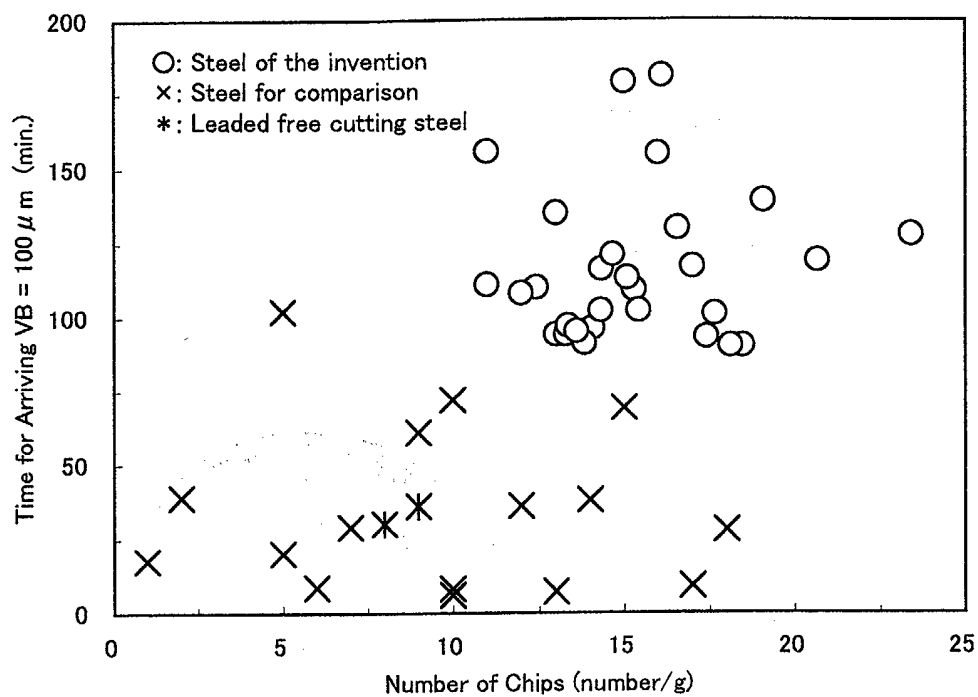
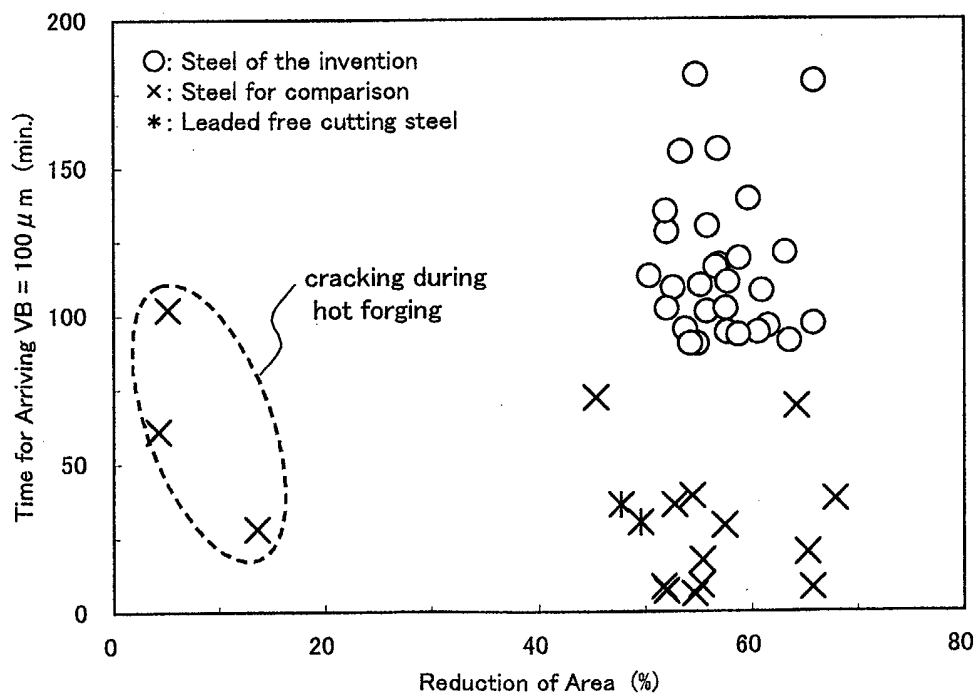


Fig. 3





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EUROPEAN SEARCH REPORT

Application Number
EP 03 25 0686

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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A	PATENT ABSTRACTS OF JAPAN vol. 2000, no. 02, 29 February 2000 (2000-02-29) -& JP 11 310848 A (SUMITOMO METAL IND LTD), 9 November 1999 (1999-11-09) * abstract * --- -/--	1	TECHNICAL FIELDS SEARCHED (Int.Cl.7) C22C
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 21 May 2003	Examiner Lilimpakis, E
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EUROPEAN SEARCH REPORT

Application Number
EP 03 25 0686

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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P,A	EP 1 262 572 A (DAIDO STEEL COMPANY LTD) 4 December 2002 (2002-12-04) * paragraph [0015]; claim 1 *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 21 May 2003	Examiner Lilimpakis, E
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 03 25 0686

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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