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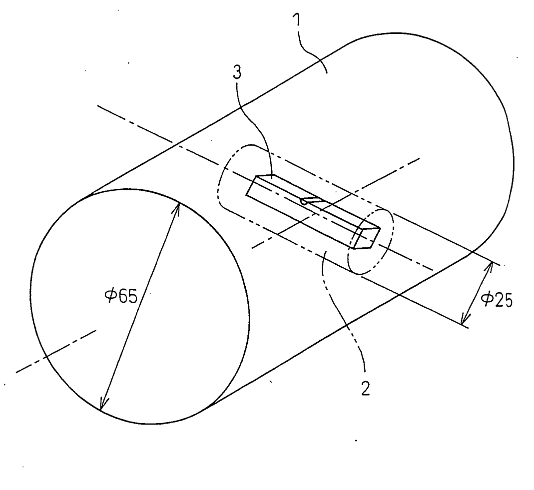
(54) STEEL FOR MACHINE STRUCTURE EXCELLING IN MACHINABILITY AND STRENGTH PROPERTY

(57) The invention provides a machine structural steel excellent in machinability and strength properties that has good machinability over a broad range of machining speeds and also has high impact properties and high yield ratio, which machine structural steel comprises, in mass%, C: 0.1 to 0.85%, Si: 0.01 to 1.5%, Mn: 0.05 to 2.0%, P: 0.005 to 0.2%, S: 0.001 to 0.15%, total Al: greater than 0.05% and not greater than 0.3%, Sb: less than 0.0150% (including 0%), and total N: 0.0035 to 0.020%, solute N being limited to 0.0020% or less, and a balance of Fe and unavoidable impurities.

Fig.1



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Description

FIELD OF THE INVENTION

[0001] This invention relates to a machine structural steel that is to be machined and particularly to a machine structural steel excellent in machinability and strength properties that is amenable to machining over a broad spectrum of machining speeds ranging from relatively low-speed machining with a high-speed steel drill to relatively high speed machining such as longitudinal turning with a super-steel coated tool.

DESCRIPTION OF THE RELATED ART

[0002] Although recent years have seen the development of steels of higher strength, there has concurrently emerged a problem of declining machinability. An increasing need is therefore felt for the development of steels that maintain excellent strength without experiencing a decline in machining performance. Addition of machinability-enhancing elements such as S, Pb and Bi is known to be effective for improving steel machinability. However, while Pb and Bi are known to improve machinability and to have relatively little effect on forgeability, they are also known to degrade strength properties.

[0003] Moreover, Pb is being used in smaller quantities these days owing to the tendency to avoid use because of concern about the load Pb puts on the natural environment. S improves machinability by forming inclusions, such as MnS, that soften in a machining environment, but MnS grains are larger than the those of Pb and the like, so that it readily becomes a stress concentration raiser. Of particular note is that at the time of elongation by forging or rolling, MnS produces anisotropy, which makes the steel extremely weak in a particular direction. It also becomes necessary to take such anisotropy into account during steel design. When S is added, therefore, it becomes necessary to utilize a technique for reducing the anisotropy.

[0004] As pointed out in the foregoing, it has been difficult to achieve good strength properties and good machinability simultaneously because addition of machinability-enhancing elements degrades the strength properties. Further technological innovation is therefore needed to enable simultaneous realization of satisfactory steel machinability and strength properties.

[0005] This situation has led to efforts to provide a machine structural steel enabling prolongation of machine tool life by, for example, incorporating a total of 0.005 mass% or greater of at least one member selected from among solute V, solute Nb and solute Al, and further incorporating 0.001% or greater of solute N, thereby enabling nitrides formed by machining heat during machining to adhere to the tool to function as a tool protective coating (see Japanese Patent Publication (A) No. 2004-107787). In addition, there has been proposed a machine structural steel that achieve improved shavings disposal and mechanical properties by defining C, Si, Mn, S and Mg contents, defining the ratio of Mg content to S content, and optimizing the aspect ratio and number of sulfide inclusions in the steel (see Japanese Patent No. 3706560). The machine structural steel taught by Patent No. 3706560 defines the content of Mg as 0.02% or less (not including 0%) and the content of Al, when included, as 0.1% or less.

SUMMARY OF THE INVENTION

[0006] However, the foregoing existing technologies have the following drawbacks. The steel taught by Japanese Patent Publication (A) No. 2004-107787 is liable not to give rise to the aforesaid phenomenon unless the amount of heat produced by the machining exceeds a certain level. The machining speed must therefore be somewhat high to realize the desired effect, so the invention has a problem in the point that the effect cannot be anticipated in the low speed range. Japanese Patent No. 3706560 is totally silent regarding the strength properties of the steel it teaches. Moreover, the steel of this patent is incapable of achieving adequate strength properties because it gives no consideration to machine tool life or yield ratio.

[0007] The present invention was achieved in light of the foregoing problems and has as its object to provide a machine structural steel that has good machinability over a broad range of machining speeds and also has high impact properties and high yield ratio.

[0008] The machine structural steel excellent in machinability and strength properties according to the present invention comprises, in mass%, C: 0.1 to 0.85%, Si: 0.01 to 1.5%, Mn: 0.05 to 2.0%, P: 0.005 to 0.2%, S: 0.001 to 0.15%, total Al: greater than 0.05% and not greater than 0.3%, Sb: less than 0.0150% (including 0%), and total N: 0.0035 to 0.020%, solute N being limited to 0.0020% or less, and a balance of Fe and unavoidable impurities.

[0009] The machine structural steel can further comprise, in mass%, Ca: 0.0003 to 0.0015%.

[0010] The machine structural steel can further comprise, in mass%, one or more elements selected from the group consisting of Ti: 0.001 to 0.1%, Nb: 0.005 to 0.2%, W: 0.01 to 1.0%, and V: 0.01 to 1.0%.

[0011] The machine structural steel can further comprise, in mass%, one or more elements selected from the group consisting of Mg: 0.0001 to 0.0040%, Zr: 0.0003 to 0.01%, and REMs: 0.0001 to 0.015%.

[0012] The machine structural steel can further comprise, in mass%, one or more elements selected from the group consisting of Sn: 0.005 to 2.0%, Zn: 0.0005 to 0.5%, B: 0.0005 to 0.015%, Te: 0.0003 to 0.2%, Bi: 0.005 to 0.5%, and Pb: 0.005 to 0.5%.

[0013] The machine structural steel can further comprise, in mass%, one or two elements selected from the group consisting of Cr: 0.01 to 2.0% and Mo: 0.01 to 1.0%.

[0014] The machine structural steel can further comprise, in mass%, one or two elements selected from the group consisting of Ni: 0.05 to 2.0% and Cu: 0.01 to 2.0%.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015]

FIG. 1 is a diagram showing a region from which a Charpy impact test piece was cut.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Preferred embodiments of the present invention are explained in detail in the following. The machine structural steel excellent in machinability and strength properties according to the present invention achieves the foregoing object by providing a machine structural steel wherein solute N acting to degrade machinability and impact properties is minimized by adjusting the amounts of added N and nitride-forming elements such as Al, wherein effective cutting performance is established with respect to a broad cutting speed range extending from low to high speed by ensuring presence of suitable amounts of solute Al serving to improve high-temperature embrittlement property and machinability, and Sb serving to produce a matrix embrittlement effect, and forming a crystal structure exhibiting high-temperature embrittlement effect and cleavage, thereby ensuring an appropriate amount of AlN serving to improve machinability, and wherein high impact properties are also realized by increasing Al addition so that at the slab stage segregation is made smaller and MnS of highly uniform dispersibility (type III MnS by SIMS analysis) is made more abundant than in conventional Al-killed steel. Moreover, the steel further achieves a high yield ratio owing to fine precipitation of AlN and presence of solute Al.

[0017] Specifically, the machine structural steel according to the present invention comprises, in mass%, C: 0.1 to 0.85%, Si: 0.01 to 1.5%, Mn: 0.05 to 2.0%, P: 0.005 to 0.2%, S: 0.001 to 0.15%, total Al: greater than 0.05% and not greater than 0.3%, Sb: less than 0.0150% (including 0%), and total N: 0.0035 to 0.020%, solute N being limited to 0.0020% or less, and a balance of Fe and unavoidable impurities.

[0018] The individual elements constituting the machine structural steel of the present invention and the contents thereof of will first be explained. In the ensuing explanation, percentage composition by mass of the steel components is denoted simply by the symbol %. C: 0.1 to 0.85%

[0019] C has a major effect on the fundamental strength of the steel. When the C content is less than 0.1%, adequate strength cannot be achieved, so that large amounts of other alloying elements must be incorporated. When C content exceeds 0.85%, machinability declines markedly because carbon concentration becomes nearly hypereutectoid to produce heavy precipitation of hard carbides. In order to achieve sufficient strength, the present invention therefore defines C content as 0.1 to 0.85%. The preferred lower limit of C content is 0.2%. Si: 0.01 to 1.5%

[0020] Si is generally added as a deoxidizing element but also contributes to ferrite strengthening and temper-softening resistance. When Si content is less than 0.01%, the deoxidizing effect is insufficient. On the other hand, an Si content in excess of 1.5% degrades the steel's embrittlement and other properties and also impairs machinability. Si content is therefore defined as 0.01 to 1.5%. The preferred upper limit of Si content is 1.0%.

Mn: 0.05 to 2.0%

[0021] Mn is required for its ability to fix and disperse sulfur (S) in the steel in the form of MnS and also, by dissolving into the matrix, to improve hardenability and ensure good strength after quenching. When Mn content is less than 0.05%, the steel is embrittled because S therein combines with Fe to form FeS. When Mn content is high, specifically when it exceeds 2.0%, base metal hardness increases to degrade cold workability, while its strength and hardenability improving effects saturates.

Mn content is therefore defined as 0.05 to 2.0%.

P: 0.005 to 0.2%

[0022] P has a favorable effect on machinability but the effect is not obtained at a P content of less than 0.005%. When P content is high, specifically when it exceeds 0.2%, base metal hardness increases to degrade not only cold workability but also hot workability and casting properties. P content is therefore defined as 0.005 to 0.2%,

S: 0.001 to 0.15%

[0023] S combines with Mn to produce MnS that is present in the steel in the form of inclusions. MnS improves machinability but S must be added to a content of 0.001% or greater for achieving this effect to a substantial degree. When S content exceeds 0.15%, the impact value of the steel declines markedly. In the case of adding S to improve machinability, therefore, the S content is made 0.001 to 0.15%.

Total Al: greater than 0.05% and not greater than 0.3%

[0024] Al not only forms oxides but also promotes precipitation of AlN, which contributes to grain size control and machinability, and further improves machinability by passing into solid solution. Al must be added to a content of greater than 0.05% in order to form solute Al in an amount sufficient to enhance machinability. Al also affects the form of MnS grains/precipitation. Moreover, when Al is added in an amount exceeding 0.05%, segregation at the slab stage can be made smaller and MnS of highly uniform dispersibility (type III MnS by SIMS analysis) be made more abundant than in a conventional Al-killed steel. This makes it possible to obtain a machine structural steel also having high impact properties and further to achieve a high yield ratio owing to fine precipitation of AlN and the presence of solute Al. However, machinability starts to decline when total Al content exceeds 0.3%. Total Al content is therefore defined as greater than 0.05% and not greater than 0.3%. The lower limit of total Al content is preferably 0.08% and more preferably 0.1%.

Sb: less than 0.0150% (including 0%)

[0025] Sb improves machinability by suitably embrittling ferrite. This effect of Sb is pronounced particularly when solute Al content is high but is not observed when Sb content is less than 0.0005%. When Sb content is high, specifically when it reaches 0.0150% or greater, Sb macro-segregation becomes excessive, so that the impact value of the steel declines markedly. Sb content is therefore defined as 0.0005% or greater and less than 0.0150%. When high machinability is not required or total Al is greater than 0.1%, addition of Sb can be omitted (Sb content of 0%).

Total N: 0.0035 to 0.020%

[0026] N, which is present not only as solute N but also in nitrides of Ti, Al V and the like, suppresses austenite grain growth. However, no substantial effect is obtained at a total N content of less than 0.0035%. When total N content exceeds 0.020%, it leads to the occurrence of roll marks during rolling. Total N content is therefore defined as 0.0035 to 0.020%.

Solute N: 0.0020% or less

[0027] Solute N hardens the steel. Of particular concern is that it shortens cutting tool life by causing steel near the cutting edge to harden under dynamic strain aging. It also causes occurrence of roll marks during rolling. High solute N content, specifically a content in excess of 0.0020%, aggravates tool wear during cutting because cutting resistance rises due to increased local hardness. Solute N content is therefore held to 0.0020% or less. This helps to reduce tool wear. Moreover, high solute N content also degrades impact properties by causing matrix embrittlement, but such matrix embrittlement can also be mitigated by holding solute N content to 0.0020% or less. Solute N content as termed here means the value obtained by subtracting the N content of AlN, NbN, TiN, VN and other such nitrides from total N content. It can be calculated, for example, in accordance with Equation (1) shown below, using the total N content determined by the inert gas fusion thermal conductivity method and the N content of nitrides determined by SPEED (Selective Potentiostatic Etching by Electrolytic Dissolution) analysis and indophenol absorbency analysis of residue electrolytically extracted using a 0.1 μm filter.

$$(\text{Solute N content}) = (\text{Total N content}) - (\text{Nitride N content}) \ldots (1)$$

[0028] Solute N content can be lowered by the methods explained below:

1) Hold total N content to a low level within the range defined by the present invention. Although total N is defined as 0.020% or less, it is preferably held to 0.01% or less and more preferably to 0.006% or less.
2) When total N content is high, it is helpful to increase the amount of N compounds by adding suitable amounts of Al, a nitride-forming element, as well as other nitride-forming elements.
3) Solute N reduction by fine precipitation of nitrides is preferable in a machine structural steel from the viewpoint of inhibiting grain coarsening. Taking into account that reduction of solute N content by fine precipitation of nitrides requires holding at a high temperature enabling more complete solution treatment into N and nitride-forming element content, solution heat treatment is conducted at a temperature of 1100 °C or greater, preferably 1200 °C or greater, and more preferably 1250 °C or greater, whereafter precipitation is performed by conducting a heat treatment such as normalizing or carburization. Of particular note is that in the case of AlN, solute N can be reduced by utilizing prolonged retention near 850 °C to increase precipitation. By "prolonged" here is meant 0.8 hr or greater, preferably 1 hr or greater and more preferably 1.2 hr or greater.

[0029] The machine structural steel of the present invention can contain Ca in addition to the foregoing components.

Ca: 0.0003 to 0.0015%

[0030] Ca is a deoxidizing element that forms oxides in the steel. In the machine structural steel of the present invention, which has a total Al content of greater than 0.05% and not greater than 0.3%, Ca forms calcium aluminate ($CaOAl_2O_3$). As $CaOAl_2O_3$ is an oxide having a lower melting point than Al_2O_3, it improves machinability by constituting a tool protective film during high-speed cutting However, this machinability-improving effect is not observed when the Ca content is less than 0.0003%. When Ca content exceeds 0.0015%, CaS forms in the steel, so that machinability is instead degraded. Therefore, when Ca is added, its content is defined as 0.0003 to 0.0015%.

[0031] When the machine structural steel of the present invention needs to be given high strength by forming carbides, it can include in addition to the foregoing components one or more elements selected from the group consisting of Ti: 0.001 to 0.1%, Nb: 0.005 to 0.2%, W: 0.01 to 1.0%, and V: 0.01 to 1.0%.

Ti: 0.001 to 0.1%

[0032] Ti forms carbonitrides that inhibit austenite grain growth and contribute to strengthening. It is used as a grain size control element for preventing grain coarsening in steels requiring high strength and steels requiring low distortion. Ti is also a deoxidizing element that improves machinability by forming soft oxides. However, these effects of Ti are not observed at a content of less than 0.001%, and when the content exceeds 0.1%, Ti has the contrary effect of degrading mechanical properties by causing precipitation of insoluble coarse carbonitrides that cause hot cracking. Therefore, when Ti is added, its content is defined as 0.001 to 0.1%.

Nb: 0.005 to 0.2%

[0033] Nb also forms carbonitrides. As such, it is an element that contributes to steel strength through secondary precipitation hardening and to austenite grain growth inhibition and strengthening. Ti is therefore used as a grain size control element for preventing grain coarsening in steels requiring high strength and steels requiring low distortion. However, no high strength imparting effect is observed at an Nb content of less than 0.005%, and when Nb is added to a content exceeding 0.2%, it has the contrary effect of degrading mechanical properties by causing precipitation of insoluble coarse carbonitrides that cause hot cracking. Therefore, when Nb is added, its content is defined as 0.005 to 0.2%.

W: 0.01 to 1.0%

[0034] W is also an element that forms carbonitrides and can strengthen the steel through secondary precipitation hardening. However, no high strength imparting effect is observed when W content is less than 0.01%, Addition of W in excess of 1.0% has the contrary effect of degrading mechanical properties by causing precipitation of insoluble coarse carbonitrides that cause hot cracking. Therefore, when W is added, its content is defined as 0.01 to 1.0%.

V: 0.01 to 1.0%.

[0035] V is also an element that forms carbonitrides and can strengthen the steel through secondary precipitation hardening. It is suitably added to steels requiring high strength. However, no high strength imparting effect is observed when V content is less than 0.01%, Addition of V in excess of 1.0% has the contrary effect of degrading mechanical properties by causing precipitation of insoluble coarse carbonitrides that cause hot cracking. Therefore, when V is added, its content is defined as 0.01 to 1.0%.

[0036] When the machine structural steel of the present invention is subjected to deoxidization control for controlling sulfide morphology, it can comprise in addition to the foregoing components one or more elements selected from the group consisting of Mg: 0.0001 to 0.0040%, Zr: 0.0003 to 0.01%, and REMs: 0.0001 to 0.015%. Mg: 0.0001 to 0.0040%

[0037] Mg is a deoxidizing element that forms oxides in the steel. When Al deoxidization is adopted, Mg reforms Al_2O_3, which impairs machinability, into relatively soft and finely dispersed MgO and Al_2O_3-Mg. Moreover, its oxide readily acts as a precipitation nucleus of MnS and thus works to finely disperse MnS. However, these effects are not observed at an Mg content of less than 0.0001%. Moreover, while Mg acts to make MnS spherical by forming a metal-sulfide complex therewith, excessive Mg addition, specifically addition to a content of greater than 0.0040%, degrades machinability by promoting simple MgS formation. Therefore, when Mg is added, its content is defined as to 0.0001 to 0.0040%.

Zr: 0.0003 to 0.01%.

[0038] Zr is a deoxidizing element that forms an oxide in the steel. The oxide is thought to be ZrO_2, which acts as a precipitation nucleus for MnS. Since addition of Zr therefore increases the number of MnS precipitation sites, it has the effect of uniformly dispersing MnS. Moreover, Zr dissolves into MnS to form a metal-sulfide complex therewith, thus decreasing MnS deformation, and therefore also works to inhibit MnS grain elongation during rolling and hot forging. In this manner, Zr effectively reduces anisotropy. But no substantial effect in these respects is observed at a Zr content of less than 0.0003%. On the other hand, addition of Zr in excess of 0.01% radically degrades yield. Moreover, by causing formation of large quantities of ZrO_2, ZrS and other hard compounds, it has the contrary effect of degrading mechanical properties such as machinability, impact value, fatigue properties and the like. Therefore, when Zr is added, its content is defined as to 0.0003 to 0.01%..

REMs: 0.0001 to 0.015%

[0039] REMs (rare earth metals) are deoxidizing elements that form low-melting-point oxides that help to prevent nozzle clogging during casting and also dissolve into or combine with MnS to decrease MnS deformation, thereby acting to inhibit MnS shape elongation during rolling and hot forging. REMs thus serve to reduce anisotropy. However, this effect does not appear at an REM content of less than 0.0001%. When the content exceeds 0.015%, machinability is degraded owing to the formation of large amounts of REM sulfides. Therefore, when REMs are added, their content is defined as 0.0001 to 0.015%.

[0040] When the machine structural steel of the present invention is to be improved in machinability, it can include in addition to the foregoing components one or more elements selected from the group consisting of Sn: 0.005 to 2.0%, Zn: 0.0005 to 0.5%, B: 0.0005 to 0.015%, Te: 0.0003 to 0.2%, Bi: 0.005 to 0.5%, and Pb: 0.005 to 0.5%.

Sn: 0.005 to 2.0%

[0041] Sn extends tool life by embrittling ferrite and also improves surface roughness. These effects are not observed when the Sn content is less than 0.005%, and the effects saturate when Sn is added in excess of 2.0%. Therefore, when Sn is added, its content is defined as 0.005 to 2.0%.

Zn: 0.0005 to 0.5%

[0042] Zn extends tool life by embrittling ferrite and also improves surface roughness. These effects are not observed when the Zn content is less than 0.0005%, and the effects saturate when Zn is added in excess of 0.5%. Therefore, when Zn is added, its content is defined as 0.0005 to 0.5%.

B: 0.0005 to 0.015%

[0043] B, when in solid solution, has a favorable effect on grain boundary strength and hardenability. When it precipitates, it precipitates as BN and therefore helps to improve machinability. These effects are not notable at a B content of less than 0.0005%. When B is added to a content of greater than 0.015%, the effects saturate and mechanical properties are to the contrary degraded owing to excessive precipitation of BN. Therefore, when B is added, its content is defined as 0.0005 to 0.015%. Te: 0.0003 to 0.2%

[0044] Te improves machinability. It also forms MnTe and, when co-present with MnS, decreases MnS deformation, thereby acting to inhibit MnS shape elongation. Te is thus an element effective for reducing anisotropy. These effects are not observed when Te content is less than 0.0003%, and when the content thereof exceeds 0.2%, the effects saturate and hot rolling ductility declines, increasing the likelihood of flaws. Therefore, when Te is added, its content is defined as: 0.0003 to 0.2%.

Bi: 0.005 to 0.5%

[0045] Bi improves machinability. This effect is not observed when Bi content is less than 0.005%. When it exceeds 0.5%, machinability improvement saturates and hot rolling ductility declines, increasing the likelihood of flaws. Therefore, when Bi is added, its content is defined as 0.005 to 0.5%.

Pb: 0.005 to 0.5%

[0046] Pb improves machinability. This effect is not observed when Pb content is less than 0.005%. When it exceeds 0.5%, machinability improvement saturates and hot rolling ductility declines, increasing the likelihood of flaws. Therefore, when Pb is added, its content is defined as 0.005 to 0.5%.

[0047] When the machine structural steel of the present invention is to be imparted with strength by improving its hardenability and/or temper-softening resistance, it can include in addition to the foregoing components one or two elements selected from the group consisting of Cr: 0.01 to 2.0% and Mo: 0.01 to 1.0%.

Cr: 0.01 to 2.0%

[0048] Cr improves hardenability and also imparts temper-softening resistance. It is therefore added to a steel requiring high strength. These effects are not obtained at a Cr content of less than 0.01%. When Cr content is high, specifically when it exceeds 2.0%, the steel is embrittled owing to formation of Cr carbides. Therefore, when Cr is added, its content is defined as 0.01 to 2.0%. Mo: 0.01 to 1.0%

[0049] Mo imparts temper-softening resistance and also improves hardenability. It is therefore added to a steel requiring high strength. These effects are not obtained at an Mo content of less than 0.01%. When Mo is added in excess of 1.0%, its effects saturate. Therefore, when Mo is added, its content is defined as 0.01 to 1.0%.

[0050] When the machine structural steel of the present invention is to be subjected to ferrite strengthening, it can include in addition to the foregoing components one or two elements selected from the group consisting of Ni: 0.05 to 2.0% and Cu: 0.01 to 2.0%.

Ni: 0.05 to 2.0%

[0051] Ni strengthens ferrite, thereby improving ductility, and is also effective for hardenability improvement and anticorrosion improvement. These effects are not observed an Ni content of less than 0.05%. When Ni is added in excess of 2.0%, mechanical property improving effect saturates and machinability is degraded. Therefore, when Ni is added, its content is defined as 0.05 to 2.0%.

Cu: 0.01 to 2.0%

[0052] Cu strengthens ferrite and is also effective for hardenability improvement and anticorrosion improvement. These effects are not observed a Cui content of less than 0.01%. When Cu is added in excess of 2.0%, mechanical property improving effect saturates. Therefore, when Cu is added, its content is defined as 0.01 to 2.0%. A particular concern regarding Cu is that its effect of lowering hot rollability may lead to occurrence of flaws during rolling. Cu is therefore preferably added simultaneously with Ni.

[0053] As explained in the foregoing, the machine structural steel of the present invention is minimized in solute N content and therefore achieves better machinability and impact properties than conventional machine structural steels. Moreover, total Al content and Sb content are controlled to suitable levels to ensure presence of proper amounts of solute Al, Sb and AlN serving to improve machinability, thereby establishing effective cutting performance with respect to a broad cutting speed range extending from low to high speed. The steel also achieves a high yield ratio owing to fine precipitation of the AlN and presence of solute Al. In addition, excellent impact properties are realized by appropriately regulating the contents of elements affecting MnS precipitation so as to obtain an abundance of MnS of highly uniform dispersibility.

[0054] The machine structural steel excellent in machinability and strength properties according to the present invention can be produced by hot-forging a billet having the aforesaid steel composition into a bar at a temperature of 1200 °C or greater, subjecting the bar to solution heat treatment at a temperature of 1100 °C or greater, and then to a heat treatment such as normalizing or carburization. Of particular note is that in the case of a steel containing the carbide AlN, a machine structural steel markedly reduced in solute N can be obtained by prolonged retention following the solution heat treatment at 1100 °C or greater for 0.8 hr or greater, preferably 1 hr or greater, and more preferably 1.2 hr or greater.

EXAMPLES

First Set of Examples

[0055] The effects of the present invention will now be specifically explained giving Examples and Comparative Examples. In this set of Examples, steels of the compositions shown in Table 1 and Table 2, 150 kg each, were produced in a vacuum furnace, hot-forged under a temperature condition of 1250 °C, and elongation-forged into 65-mm diameter bars. The properties of the Example and Comparative Example steels were evaluated by subjecting them to machinability testing, Charpy impact testing and tensile testing by the methods set out below. In Table 2, underlining indicates a value outside the invention range.

Table 1

	No.	Composition (mass%)												
		C	Si	Mn	P	S	Cr	V	Sb	Ca	Ttl Al	Ttl N	Sol N	Other
Invention Examples	1	0.42	0.19	0.80	0.014	0.022	-	-	0.0100	0.0012	0.110	0.0052	0.0012	
	2	0.40	0.25	0.76	0.012	0.034	-	-	0.0089	0.0008	0.051	0.0060	0.0013	
	3	0.41	0.24	0.76	0.013	0.038	-	0.1	0.0086	-	0.051	0.0060	0.0013	
	4	0.40	0.23	0.78	0.015	0.038	-	-	0.0067	-	0.052	0.0045	0.0014	
	5	0.43	0.23	0.75	0.011	0.022	-	-	0.0087	-	0.060	0.0049	0.0012	Mg:0.0020
	6	0.43	0.20	0.77	0.013	0.039	-	-	0.0074	-	0.051	0.0065	0.0013	Ti:0.04
	7	0.44	0.20	0.78	0.012	0.040	-	-	0.0068	-	0.052	0.0075	0.0016	Nb:0.02
	8	0.41	0.21	0.77	0.011	0.047	-	-	0.0083	-	0.090	0.0058	0.0014	W:0.2
	9	0.45	0.22	0.79	0.012	0.045	-	-	0.0058	-	0.080	0.0055	0.0013	Ni:0.2
	10	0.43	0.23	0.71	0.011	0.051	-	-	0.0071	-	0.110	0.0045	0.0017	Cu:0.5
	11	0.44	0.22	0.72	0.014	0.041	-	-	0.0087	-	0.053	0.0052	0.0010	Sn:0.05
	12	0.45	0.20	0.74	0.010	0.033	-	-	0.0069	-	0.070	0.0051	0.0014	Zn:0.007
	13	0.43	0.24	0.76	0.015	0.041	-	-	0.0077	-	0.090	0.0053	0.0019	B:0.002
	14	0.45	0.22	0.71	0.011	0.043	-	-	0.0073	-	0.080	0.0046	0.0015	Te:0.002
	15	0.43	0.19	0.74	0.011	0.051	1.0	-	0.0051	-	0.090	0.0047	0.0016	
	16	0.44	0.21	0.72	0.013	0.023	0.1	-	0.0085	-	0.070	0.0048	0.0013	
	17	0.42	0.21	0.73	0.012	0.048	-	-	0.0088	-	0.110	0.0071	0.0010	Ti:0.03, Mg:0.0025
	18	0.41	0.20	0.72	0.012	0.035	-	-	0.0059	-	0.090	0.0075	0.0011	Ti:0.04, Zn:0.004
	19	0.42	0.24	0.74	0.013	0.040	1.0	-	0.0083	-	0.060	0.0071	0.0012	Ti:0.03
	20	0.44	0.23	0.75	0.010	0.034	-	-	0.0089	-	0.110	0.0077	0.0015	Ti:0.03, Cu:0.3
	21	0.40	0.20	0.71	0.010	0.037	-	-	0.0074	-	0.110	0.0054	0.0010	Ti:0.02, Mg:0.0025, Sn:0.04
	22	0.42	0.21	0.73	0.012	0.053	1.1	-	0.0098	-	0.110	0.0074	0.0019	Ti:0.03, Mg:0.0025
	23	0.43	0.21	0.77	0.014	0.052	-	-	0.0071	-	0.070	0.0062	0.0019	Ti:0.03, Mg:0.0025, Cu:0.4
	24	0.41	0.19	0.74	0.013	0.054	1.0	-	0.0076	-	0.100	0.0061	0.0015	Ti:0.02, Mg:0.0025, Sn:0.04
	25	0.43	0.23	0.71	0.014	0.021	-	-	0.0058	-	0.060	0.0060	0.0012	Ti:0.03, Mg:0.0025, Sn:0.04, Cu:0.3
	26	0.43	0.25	0.76	0.013	0.024	1.0	-	0.0085	-	0.070	0.0074	0.0010	Ti:0.03, Mg:0.0025, Cu:0.4
	27	0.45	0.23	0.72	0.015	0.034	1.0	-	0.0086	-	0.100	0.0055	0.0012	Ti:0.03, Sn:0.04
	28	0.41	0.19	0.78	0.011	0.025	-	-	0.0087	-	0.080	0.0061	0.0016	Ti:0.03, Sn:0.04. Cu:0.3
	29	0.41	0.21	0.70	0.015	0.025	0.9	-	0.0057	-	0.051	0.0062	0.0017	Ti:0.04, Sn:0.04. Cu:0.3
	30	0.44	0.23	0.71	0.012	0.036	1.0	-	0.0052	-	0.060	6.0056	0.0012	Ti:0.03, Cu:0.3

Table 2

	No.	Composition (mass%)												
		C	Si	Mn	P	S	Cr	V	Sb	Ca	Ttl Al	Ttl N	Sol N	Other
Examples	31	0.44	0.20	0.77	0.014	0.055	-	-	0.0081	-	0.110	0.0047	0.0010	Mg:0.0025, Zn:0.003
	32	0.45	0.21	0.79	0.011	0.029	1.0	-	0.0099	-	0.060	0.0049	0.0013	Mg:0.0019, Zn:0.003
	33	0.43	0.21	0.74	0.010	0.038	-	-	0.0078	-	0.110	0.0048	0.0014	Mg:0.0022, Ca:0.3
	34	0.42	0.25	0.77	0.011	0.036	1.0	-	0.0087	-	0.090	0.0046	0.0014	Mg:0.0020, Sn:0.04
	35	0.44	0.25	0.78	0.015	0.055	-	-	0.0079	-	0.100	0.0050	0.0018	Mg:0.0025, Sn:0.04, Cu:0.1
	36	0.42	0.19	0.74	0.013	0.022	1.0	-	0.0062	-	0.052	0.0047	0.0019	Mg:0.0021, Sn:0.02, Cu:0.1
	37	0.41	0.19	0.77	0.010	0.025	1.1	-	0.0050	-	0.110	0.0049	0.0019	Mg:0.0029, Cu:0.1
	38	0.43	0.20	0.79	0.011	0.020	1.0	-	0.0060	-	0.060	0.0049	0.0010	Sn:0.04
	39	0.42	0.23	0.80	0.015	0.048	-	-	0.0086	-	0.070	0.0046	0.0016	Sn:0.03, Cu:0.1
	40	0.41	0.19	0.78	0.010	0.042	1.0	-	0.0069	-	0.100	0.0046	0.0009	Sn:0.04, Cu:0.1
	41	0.43	0.21	0.79	0.010	0.035	0.9	-	0.0080	-	0.080	0.0046	0.0014	Cu:0.2
	42	0.44	0.19	0.77	0.013	0.042	-	-	0.0087	-	0.060	0.0055	0.0014	Nb:0.01, Mg:0.0026, Sn:0.04, Ca:0.3
Comparative Examples	43	0.45	0.24	0.78	0.010	0.025	-	-	0.0069	-	0.025	0.0052	0.0018	
	44	0.43	0.25	0.76	0.010	0.041	-	-	0.0092	-	0.035	0.0051	0.0019	
	45	0.41	0.24	0.73	0.011	0.035	-	-	0.0098	-	0.040	0.0053	0.0017	
	46	0.44	0.25	0.78	0.014	0.022	-	-	0.0059	-	0.030	0.0034	0.0019	
	47	0.41	0.24	0.72	0.011	0.051	-	-	0.0087	-	0.003	0.0049	0.0034	
	48	0.44	0.25	0.77	0.015	0.052	-	-	0.0062	-	0.358	0.0062	0.0011	
	49	0.41	0.21	0.72	0.013	0.021	-	-	0.0055	-	0.103	0.0058	0.0025	
	50	0.42	0.20	0.73	0.013	0.037	-	-	0.0077	-	0.153	0.0057	0.0026	
	51	0.44	0.24	0.79	0.013	0.038	-	-	0.0157	-	0.067	0.0054	0.0016	
	52	0.45	0.23	0.76	0.010	0.036	-	-	0.0175	-	0.103	0.0049	0.0010	
	53	0.44	0.19	0.73	0.014	0.044	-	-	0.0211	-	0.243	0.0046	0.0016	
	54	0.45	0.19	0.71	0.010	0.025	-	-	0.0223	-	0.060	0.0046	0.0009	

Machinability test

[0056] Machinability testing was conducted with respect to Example and Comparative Example steels that had been elongation-forged under heating at 1250 °C by first subjecting them to heat treatment consisting of normalization under temperature condition of 850 °C for 1 hr, 0.5 hr in the case of Comparative Examples No. 49 and No. 50, followed by air-cooling. A machinability evaluation test piece was then cut from each heat-treated steel and the machinabilities of the Example and Comparative Example steels were evaluated by conducting drill boring testing under the cutting conditions shown in Table 3 and to longitudinal turning testing under the conditions shown in Table 4. The maximum cutting speed VL1000 enabling cutting up to a cumulative hole depth of 1000 mm was used as the evaluation index in the drill boring test, and the maximum width VB_max of wear of the relief flank after 10 min was used as the evaluation index in the longitudinal turning test.

Table 3

Cutting conditions	Speed: 10 - 120 m/min
	Feed: 0.25 mm/rev
	Cutting fluid: Water-soluble cutting oil
Drill	Drill diameter: 3 mm
	NACHI ordinary drill
	Overhang: 45 mm
Other	Hole depth: 9 mm
	Tool life: Until breakage

Table 4

Cutting conditions	Cutting speed: 250 m/min
	Feed: 0.3 mm/rev
	Depth of cut: 1.5 mm
	Dry cutting
Tool	Holder: PTGNR2525M16
	Tool shape: TNMG160408N-UZ
	Material: AC2000

Charpy impact test

[0057] FIG. 1 is a diagram showing a region from which a Charpy impact test piece was cut. In the Charpy impact test, first, as shown in FIG. 1, a cylinder 2 measuring 25 mm in diameter was cut from a steel 1 heat-treated by the same method and under the same conditions as the aforesaid machinability test piece so that its axis was perpendicular to the elongation-forging direction of the steel 1. Next, the cylinder 2 was held under temperature condition of 850 °C for 1 hr, 0.5 hr in the case of Comparative Examples No. 49 and No. 50, then oil-quenched by cooling to 60 °C, and further subjected to tempering with water cooling in which it was held under temperature condition of 550 °C for 30 min. Next, the cylinder 2 was machined to fabricate a Charpy test piece 3 in conformance with JIS Z 2202, which was subjected to a Charpy impact test at room temperature in accordance with the method prescribed by JIS Z 2242. Absorbed energy per unit area (J/cm^2) was adopted as the evaluation index. Tensile test

[0058] A cylinder 2 sampled parallel to the elongation-forging direction was oil-quenched and tempered by the same methods and under the same conditions as in the aforesaid Charpy impact test, whereafter it was processed into a tensile test piece measuring 8 mm in parallel section diameter and 30 mm in parallel section length, and then tensile tested at room temperature in accordance with the method prescribed by JIS Z 2241. Yield ratio (= (0.2% proof stress YP) / (tensile strength TS) was adopted as the evaluation index.

[0059] The results of the foregoing tests are shown in Tables 5 and 6.

Table 5

	No.	VL1000 (m/min)	VB_max (μm)	Impact value (J/cm^2)	YP / TS
Examples	1	87	118	27	0.85
	2	89	119	22	0.83
	3	85	124	20	0.89
	4	88	126	25	0.82
	5	85	125	20	0.84
	6	89	123	21	0.86
	7	89	128	22	0.83
	8	92	129	22	0.86
	9	89	126	20	0.86
	10	92	122	21	0.82
	11	91	121	21	0.83
	12	87	130	22	0.84
	13	90	127	22	0.82
	14	90	125	21	0.84
	15	90	125	24	0.86
	16	85	121	26	0.87
	17	93	128	24	0.86
	18	86	124	22	0.85
	19	90	128	25	0.86
	20	89	126	20	0.82
	21	89	121	24	0.84
	22	96	125	21	0.82
	23	93	129	22	0.83
	24	94	126	23	0.82
	25	82	126	26	0.82
	26	86	120	25	0.84
	27	89	130	26	0.85
	28	86	127	20	0.86
	29	83	129	20	0.84
	30	86	122	24	0.86
	31	95	129	26	0.86
	32	89	130	22	0.83
	33	89	123	21	0.87
	34	90	126	24	0.85
	35	94	121	22	0.82
	36	83	127	20	0.85
	37	83	121	20	0.85
	38	82	127	30	0.83
	39	93	127	21	0.83
	40	90	124	27	0.86
	41	89	127	23	0.84
	42	91	126	21	0.87

Table 6

	No.	VL1000 (m/min)	VB_max (μm)	Impact value (J/cm^2)	YP / TS
Comparative Examples	43	54	149	21	0.68
	44	62	141	24	0.66
	45	60	142	25	0.67
	46	53	158	22	0.68
	47	64	178	9	0.65
	48	48	178	22	0.82
	49	62	149	16	0.83
	50	69	150	15	0.85
	51	99	122	14	0.85
	52	98	124	11	0.87
	53	104	128	12	0.84
	54	100	128	13	0.85

[0060] The Steels No.1 to No. 42 shown in Tables 1, 2 and 5 are Examples of the present invention, and the steels No. 43 to No. 51 shown in Tables 2 and 6 are Comparative Example steels. As shown in Tables 5 and 6, the steels of Examples No 1 to No. 42 exhibited good values for all of the evaluation indexes, namely VL1000, VB_max, impact value (absorbed energy), and YP / TS (yield ratio), but the steels of the Comparative Examples were each inferior to the Example steels in at least one of the properties. Specifically, the steels of Comparative Examples No. 43 to No. 46 had total Al contents below the range of the present invention and were therefore inferior to the Example steels in machinability evaluation index VL1000 and yield ratio (YP / TS). Moreover, the steel of Comparative Example No.47 had a total Al content far below the range of the present invention, so that its solute N content was above the range of the present invention, and the steel was therefore inferior to the steels of the Examples in machinability (VL1000, VB_max), impact value, and yield ratio (YP / TS).

[0061] The steel of Comparative Example No. 48 had a total Al content above the range of the present invention, so that its hardness increased, and the steel was therefore inferior in machinability (VL1000, VB_max). The steels of Comparative Examples No. 49 and No. 50 were maintained at 850 °C, the temperature at which AlN readily precipitates, for a shorter holding time than the steels of the Examples, so that their solute N contents were above the range of the present invention, and the steels were therefore inferior to the steels of the Examples in machinability (VL1000, VB_max) and impact value. The steels of Comparative Examples No. 51 to No. 54 had Sb contents above the range of the present invention and were therefore inferior to the steels of the Examples in impact value.

Second Set of Examples

[0062] In this set of Examples, steels of the compositions shown in Table 7 and Table 8, 150 kg each, were produced in a vacuum furnace, hot-forged under a temperature condition of 1250 °C, and elongation-forged into 65 mm diameter bars. The properties of the Example and Comparative Example steels were evaluated by subjecting them to machinability testing, Charpy impact testing and tensile testing by the methods set out below. In Tables 7 and 8, underlining indicates a value outside the invention range.

Table 7

	No	Composition (mass%)										
		C	Si	Mn	P	S	Cr	Ca	Ttl Al	Ttl N	Sol N	Other
Examples	1	0.44	0.25	0.76	0.015	0.017	-	0.0000	0.121	0.0052	0.0012	
	2	0.44	0.26	0.76	0.015	0.012	-	0.0006	0.101	0.0052	0.0012	
	3	0.44	0.25	0.75	0.016	0.010	-	0.0008	0.250	0.0060	0.0013	
	4	0.44	0.25	0.76	0.015	0.008	-	0.0010	0.075	0.0045	0.0011	
	5	0.46	0.26	0.76	0.015	0.013	-	0.0006	0.099	0.0049	0.0012	Mg:0.0020
	6	0.44	0.24	0.74	0.015	0.011	-	0.0008	0.193	0.0065	0.0013	Ti:0.04
	7	0.45	0.25	0.74	0.015	0.013	-	0.0008	0.178	0.0075	0.0016	Nb:0.02
	8	0.44	0.24	0.74	0.015	0.011	-	0.0006	0.169	0.0058	0.0014	W:0.2
	9	0.45	0.24	0.74	0.016	0.010	-	0.0012	0.175	0.0055	0.0013	Ni:0.2
	10	0.46	0.26	0.76	0.015	0.014	-	0.0005	0.142	0.0045	0.0017	Cu:0.5
	11	0.44	0.26	0.75	0.015	0.015	-	0.0007	0.127	0.0052	0.0010	Sn:0.05
	12	0.44	0.25	0.76	0.015	0.011	-	0.0004	0.147	0.0051	0.0014	Zn:0.007
	13	0.45	0.24	0.76	0.014	0.011	-	0.0012	0.144	0.0053	0.0019	B:0.002
	14	0.45	0.26	0.75	0.015	0.011	-	0.0012	0.187	0.0046	0.0015	Te:0.002
	15	0.41	0.24	0.78	0.015	0.014	1.0	0.0010	0.108	0.0047	0.0016	
	16	0.44	0.25	0.76	0.015	0.013	0.1	0.0012	0.112	0.0048	0.0013	
	17	0.44	0.24	0.74	0.015	0.010	-	0.0006	0.131	0.0071	0.0010	Ti:0.03, Mg:0.0025
	18	0.45	0.26	0.75	0.016	0.010	-	0.0009	0.109	0.0075	0.0010	Ti:0.04, Zn:0.004
	19	0.41	0.24	0.75	0.016	0.010	1.0	0.0008	0.168	0.0071	0.0012	Ti:0.03
	20	0.44	0.26	0.74	0.016	0.010	-	0.0011	0.113	0.0077	0.0015	Ti:0.03, Cu:0.3
	21	0.44	0.24	0.75	0.016	0.014	-	0.0008	0.104	0.0054	0.0010	Ti:0.02, Mg:0.0025, Sn:0.04
	22	0.41	0.25	0.75	0.015	0.010	1.1	0.0005	0.192	0.0074	0.0019	Ti:0.03, Mg:0.0025
	23	0.45	0.24	0.75	0.015	0.013	-	0.0009	0.119	0.0062	0.0019	Ti:0.03, Mg:0.0025, Cu:0.4
	24	0.40	0..26	0.75	0.015	0.012	1.0	0.0005	0.198	0.0061	0.0015	Ti:0.02, Mg:0.0025, Sn:0.04
	25	0.44	0.26	0.75	0.014	0.015	-	0.0008	0.169	0.0060	0.0012	Ti:0.03, Mg:0.0025, Sn:0.04, Cu:0.3
	26	0.42	0.24	0.75	0.014	0.013	1.0	0.0011	0.116	0.0074	0.0010	Ti:0.03, Mg:0.0025, Cu:0.4
	27	0.41	0.24	0.74	0.015	0.014	1.0	0.0004	0.198	0.0055	0.0012	Ti:0.03, Sn:0.04
	28	0.46	0.25	0.75	0.015	0.010	-	0.0010	0.179	0.0061	0.0016	Ti:0.03, Sn:0.04, Cu:0.3
	29	0.41	0.25	0.75	0.016	0.011	0.9	0.0008	0.156	0.0062	0.0017	Ti:0.04, Sn:0.04, Cu:0.3
	30	0.41	0.26	0.75	0.014	0.012	1.0	0.0009	0.137	0.0056	0.0012	Ti:0.03, Cu:0.3
	31	0.45	0.24	0.75	0.015	0.013	-	0.0013	0.109	0.0047	0.0010	Mg:0.0025, Zn:0.003
	32	0.41	0.25	0.76	0.016	0.015	1.0	0.0011	0.104	0.0049	0.0013	Mg:0.0019, Zn:0.003
	33	0.45	0.24	0.75	0.015	0.011	-	0.0013	0.109	0.0048	0.0014	Mg:0.0022, Cu::0.3
	34	0.40	0.25	0.75	0.016	0.015	1.0	0.0008	0.105	0.0046	0.0014	Mg:0.0020, Sn:0.04
	35	0.45	0.24	0.74	0.015	0.014	-	0.0009	0.110	0.0050	0.0018	Mg:0.0025, Sn:0.04, Cu:0.1
	36	0.42	0.25	0.75	0.014	0.012	1.0	0.0012	0.107	0.0047	0.0019	Mg:0.0021, Sn:0.02, Cu:0.1
	37	0.41	0.24	0.75	0.015	0.014	1.1	0.0005	0.104	0.0049	0.0019	Mg:0.0029, Cu::0.1
	38	0.42	0.25	0.76	0.015	0.011	1.0	0.0009	0.102	0.0049	0.0010	Sn:0.04
	39	0.44	0.24	0.76	0.015	0.012	-	0.0010	0.110	0.0046	0.0016	Sn:0.03, Cu:0.1
	40	0.41	0.25	0.75	0.015	0.011	1.0	0.0009	0.108	0.0046	0.0009	Sn:0.04, Cu:0.1
	41	0.41	0.25	0.75	0.015	0.011	0.9	0.0003	0.102	0.0046	0.0014	Cu:0.2
	42	0.46	0.25	0.76	0.015	0.011	-	0.0003	0.102	0.0055	0.0014	Nb:0.01, Mg:0.0026, Sn:0.04, Cu:0.3
Comparative Examples	43	0.44	0.24	0.76	0.014	0.011	-	0.0006	0.025	0.0052	0.0018	
	44	0.45	0.25	0.76	0.015	0.014	-	0.0006	0.035	0.0051	0.0019	
	45	0.45	0.24	0.75	0.015	0.014	-	0.0008	0.040	0.0053	0.0017	
	46	0.45	0.25	0.76	0.014	0.011	-	0.0010	0.030	0.0034	0.0019	
	47	0.46	0.25	0.74	0.016	0.011	-	0.0008	0.003	0.0043	0.0034	
	48	0.44	0.24	0.75	0.014	0.009	-	0.0007	0.103	0.0058	0.0025	

Table 8

	No	Composition (mass%)										
		C	Si	Mn	P	S	Cr	Ca	Ttl Al	Ttl N	Sol N	Other
Examples	52	0.45	0.26	0.75	0.016	0.025	-	0.0002	0.101	0.0052	0.0012	
	53	0.44	0.25	0.76	0.015	0.030	-	0.0000	0.250	0.0060	0.0013	
	54	0.45	0.25	0.74	0.015	0.042	-	0.0001	0.123	0.0048	0.0012	
	55	0.45	0.24	0.75	0.015	0.090	-	0.0002	0.106	0.0049	0.0013	
	56	0.45	0.24	0.75	0.014	0.042	-	0.0001	0.102	0.0052	0.0011	Mg:0.0020
	57	0.45	0.24	0.74	0.015	0.042	-	0.0001	0.190	0.0065	0.0016	Ti:0.04
	58	0.46	0.25	0.76	0.016	0.047	-	0.0001	0.154	0.0075	0.0012	Nb:0.02
	59	0.45	0.25	0.74	0.015	0.044	-	0.0001	0.129	0.0058	0.0017	W:0.2
	60	0.44	0.25	0.76	0.015	0.044	-	0.0001	0.109	0.0055	0.0015	Ni:0.2
	61	0.45	0.26	0.74	0.016	0.041	-	0.0001	0.148	0.0045	0.0015	Cu:0.5
	62	0.46	0.25	0.75	0.016	0.047	-	0.0000	0.111	0.0052	0.0013	Sn:0.03
	63	0.46	0.25	0.75	0.015	0.051	-	0.0001	0.188	0.0051	0.0012	Zn:0.007
	64	0.45	0.24	0.76	0.015	0.073	-	0.0002	0.197	0.0053	0.0011	B:0.002
	65	0.44	0.25	0.75	0.015	0.092	-	0.0002	0.109	0.0046	0.0010	Te:0.002
	66	0.45	0.25	0.74	0.015	0.062	-	0.0000	0.200	0.0046	0.0011	Cr:0.1
	67	0.45	0.26	0.76	0.014	0.049	-	0.0001	0.109	0.0070	0.0012	
	68	0.45	0.26	0.76	0.016	0.040	-	0.0000	0.172	0.0072	0.0010	Ti:0.03, Mg:0.0025
	69	0.45	0.25	0.75	0.014	0.040	-	0.0001	0.110	0.0068	0.0010	Ti:0.04, Zn:0.004
	70	0.41	0.25	0.75	0.015	0.043	0.9	0.0000	0.125	0.0075	0.0009	Ti:0.03
	71	0.45	0.25	0.76	0.015	0.043	-	0.0002	0.110	0.0069	0.0009	Ti:0.03, Cu:0.3
	72	0.45	0.24	0.76	0.015	0.047	-	0.0000	0.125	0.0062	0.0018	Ti:0.03, Mg:0.0015, Sn:0.04
	73	0.40	0.26	0.75	0.014	0.049	1.0	0.0001	0.142	0.0065	0.0017	Ti:0.03, Mg:0.0025
	74	0.45	0.24	0.75	0.015	0.044	-	0.0001	0.149	0.0062	0.0017	Ti:0.03, Mg:0.0025, Cu:0.4
	75	0.41	0.26	0.76	0.016	0.041	1.0	0.0001	0.129	0.0059	0.0019	Ti:0.05, Mg:0.0025, Sn:0.04
	76	0.44	0.24	0.76	0.015	0.043	-	0.0001	0.188	0.0061	0.0014	Ti:0.03, Mg:0.0025, Sn:0.04, Cu:0.3
	77	0.40	0.26	0.75	0.016	0.046	0.9	0.0001	0.172	0.0064	0.0013	Ti:0.03, Mg:0.0025, Cu:0.4
	78	0.41	0.25	0.75	0.016	0.042	1.0	0.0000	0.111	0.0063	0.0013	Ti:0.03, Sn:0.04
	79	0.46	0.25	0.76	0.015	0.047	-	0.0001	0.151	0.0067	0.0012	Ti:0.03, Sn:0.04, Cu:0.3
	80	0.40	0.26	0.76	0.016	0.043	0.9	0.0001	0.120	0.0072	0.0017	Ti:0.02, Sn:0.04, Cu:0.3
	81	0.41	0.26	0.74	0.015	0.046	1.1	0.0001	0.144	0.0069	0.0010	Ti:0.03, Cu:0.3
	82	0.46	0.24	0.76	0.014	0.040	-	0.0001	0.105	0.0051	0.0010	Mg:0.0028, Zn:0.003
	83	0.41	0.24	0.76	0.014	0.047	0.9	0.0000	0.102	0.0052	0.0013	Mg:0.0019, Zn:0.003
	84	0.45	0.24	0.76	0.015	0.041	-	0.0001	0.102	0.0069	0.0011	Mg:0.0022, Cu::0.3
	85	0.41	0.26	0.75	0.016	0.041	1.0	0.0000	0.109	0.0055	0.0012	Mg:0.0020, Sn:0.04
	86	0.44	0.25	0.76	0.016	0.047	-	0.0001	0.103	0.0062	0.0010	Mg:0.0025, Sn:0.04, Cu:0.1
	87	0.42	0.26	0.75	0.015	0.042	1.0	0.0001	0.101	0.0057	0.0011	Mg:0.0017, Sn:0.04, Cu:0.1
	88	0.41	0.25	0.75	0.015	0.046	1.1	0.0001	0.106	0.0067	0.0013	Mg:0.0025, Cu::0.1
	89	0.41	0.25	0.74	0.014	0.046	1.0	0.0000	0.109	0.0059	0.0016	Sn:0.02
	90	0.45	0.26	0.75	0.015	0.042	-	0.0001	0.100	0.0066	0.0013	Sn:0.04, Cu:0.1
	91	0.41	0.24	0.74	0.015	0.046	1.1	0.0001	0.105	0.0065	0.0012	Sn:0.04, Cu:0.1
	92	0.41	0.26	0.75	0.015	0.040	1.1	0.0000	0.109	0.0058	0.0014	Cu:0.1
	93	0.44	0.24	0.75	0.015	0.057	-	0.0001	0.101	0.0051	0.0017	Nb:0.01, Mg:0.0025, Sn:0.04, Cu:0.3
Comparative Examples	94	0.45	0.25	0.74	0.014	0.026	-	0.0001	0.025	0.0051	0.0017	
	95	0.45	0.24	0.75	0.014	0.043	-	0.0001	0.024	0.0052	0.0018	
	96	0.46	0.24	0.75	0.016	0.046	-	0.0002	0.032	0.0051	0.0019	
	97	0.46	0.24	0.76	0.015	0.046	-	0.0002	0.104	0.0078	0.0034	
	98	0.45	0.25	0.74	0.016	0.043	-	0.0001	0.103	0.0058	0.0025	
	99	0.44	0.26	0.76	0.016	0.051	-	0.0000	0.243	0.0057	0.0026	
	100	0.45	0.24	0.75	0.014	0.073	-	0.0001	0.111	0.0067	0.0031	
	101	0.46	0.25	0.75	0.014	0.099	-	0.0001	0.142	0.0077	0.0035	

Machinability test

[0063] Machinability testing was conducted with respect to Example and Comparative Example steels that had been elongation-forged under heating at 1250 °C by first subjecting them to heat treatment consisting of normalization under temperature condition of 850 °C for 1 hr, 0.5 hr in the case of Comparative Examples No. 48, No. 49 and No. 97 to No. 101, followed by air-cooling. A machinability evaluation test piece was then cut from each heat-treated steel and the machinabilities of the Example and Comparative Example steels were evaluated by conducting drill boring testing under the cutting conditions shown in Table 9 and to longitudinal turning testing under the conditions shown in Table 10. The maximum cutting speed VL1000 enabling cutting up to a cumulative hole depth of 1000 mm was used as the evaluation index in the drill boring test, and the maximum width VB_max of wear of the relief flank after 10 min was used as the evaluation index in the longitudinal turning test.

Table 9

Cutting conditions	Speed	10 - 120 m/min
	Feed	0.25 mm/rev
	Cutting fluid	Water-soluble cutting oil
Drill	Drill diameter (ϕ)	3 mm
	NACHI	Ordinary drill
	Overhang	45 mm
Other	Hole depth	9 mm
	Tool life	Until breakage

Table 10

Cutting conditions	Cutting speed	250 m/min
	Feed	0.3 mm/rev
	Mode	Dry cutting
Tool	Holder	PTGNR2525M16
	Shape	TNMG160408N-UZ
	Material	AC2000

Charpy impact test

[0064] FIG. 1 is a diagram showing a region from which a Charpy impact test piece was cut. In the Charpy impact test, first, as shown in FIG. 1, a cylinder 2 measuring 25 mm in diameter was cut from a steel 1 heat-treated by the same method and under the same conditions as the aforesaid machinability test piece so that its axis was normal to the elongation-forging direction of the steel 1. Next, the cylinder 2 was held under temperature condition of 850 °C for 1 hr, 0.5 hr in the case of Comparative Examples No. 48, No. 49 and No. 97 to No. 101, then oil-quenched by cooling to 60 °C, and further subjected to tempering with water cooling in which it was held under temperature condition of 550 °C for 30 min. Next, the cylinder 2 was machined to fabricate a Charpy test piece 3 in conformance with JIS Z 2202, which was subjected to a Charpy impact test at room temperature in accordance with the method prescribed by JIS Z 2242. Absorbed energy per unit area (J/cm^2) was adopted as the evaluation index.

Tensile test

[0065] A cylinder 2 oil-quenched and tempered by the same methods and under the same conditions as in the aforesaid Charpy impact test was processed into a tensile test piece measuring 8 mm in parallel section diameter and 30 mm in parallel section length, and then tensile tested at room temperature in accordance with the method prescribed by JIS Z 2241. Yield ratio (= (0.2% proof stress YP) / (tensile strength TS) was adopted as the evaluation index.

[0066] The results of the foregoing tests are shown in Tables 11 and 12.

Table 11

	No.	VL1000 (m/min)	VB_max (μm)	Impact value (J/cm$^{2)}$	YP / TS
Examples	1	70	121	39	0.87
	2	65	121	40	0.82
	3	65	123	41	0.84
	4	65	125	42	0.80
	5	70	115	39	0.83
	6	65	121	42	0.83
	7	65	123	41	0.86
	8	65	120	40	0.85
	9	65	116	42	0.85
	10	65	122	43	0.86
	11	70	123	44	0.85
	12	70	120	38	0.83
	13	70	119	39	0.84
	14	70	120	40	0.85
	15	55	132	37	0.89
	16	65	124	40	0.86
	17	65	125	40	0.82
	18	70	124	39	0.85
	19	55	131	39	0.84
	20	65	126	38	0.82
	21	70	118	39	0.83
	22	55	133	39	0.84
	23	70	128	38	0.83
	24	60	130	39	0.85
	25	70	119	39	0.83
	26	55	131	40	0.83
	27	65	132	40	0.83
	28	70	121	40	0.84
	29	60	131	39	0.86
	30	55	131	38	0.85
	31	70	120	41	0.83
	32	55	133	37	0.86
	33	70	125	40	0.87
	34	60	134	39	0.86
	35	70	120	39	0.87
	36	60	133	41	0.87
	37	55	131	41	0.84
	38	60	130	38	0.86
	39	70	119	39	0.86
	40	60	131	38	0.84
	41	55	132	37	0.84
	42	65	124	41	0.83
Comparative Examples	43	45	122	41	0.66
	44	45	116	40	0.67
	45	45	117	41	0.67
	46	50	110	42	0.67
	47	35	156	22	0.68
	48	50	149	30	0.87
	49	50	140	29	0.85

Table 12

	No.	VL1000 (m/min)	VB_max (μm)	Impact value (J/cm^2)	YP / TS
Examples	52	85	121	25	0.85
	53	85	123	24	0.85
	54	95	121	23	0.82
	55	105	112	21	0.85
	56	95	120	22	0.85
	57	95	123	22	0.85
	58	90	123	22	0.85
	59	95	121	22	0.83
	60	90	124	22	0.83
	61	95	120	22	0.87
	62	95	115	22	0.83
	63	95	125	22	0.85
	64	100	117	21	0.84
	65	105	113	21	0.84
	66	95	121	20	0.86
	67	80	131	20	0.83
	68	95	122	25	0.87
	69	100	120	24	0.84
	70	80	131	20	0.84
	71	95	122	23	0.85
	72	100	118	26	0.83
	73	80	130	21	0.84
	74	95	122	25	0.85
	75	85	128	20	0.85
	76	100	119	25	0.86
	77	80	132	22	0.83
	78	85	128	20	0.82
	79	100	120	24	0.82
	80	85	126	21	0.84
	81	80	133	21	0.83
	82	105	120	23	0.84
	83	80	130	21	0.83
	84	95	124	24	0.86
	85	85	129	22	0.87
	86	95	117	23	0.87
	87	85	128	21	0.84
	88	80	129	21	0.86
	89	85	126	20	0.83
	90	95	119	21	0.86
	91	85	125	20	0.87
	92	80	133	20	0.83
	93	100	112	22	0.86
Comparative Examples	94	60	180	22	0.68
	95	65	179	20	0.69
	96	65	174	19	0.68
	97	70	157	18	0.84
	98	75	149	18	0.82
	99	70	143	18	0.86
	100	75	152	15	0.79
	101	75	163	12	0.86

[0067] The steels No.1 in Tables 7 and 11 are embodiments of claim 1 and the steels No.2 to No. 42 in the same tables are embodiments of claim 2. The steels No. 52 to No. 93 in Table 8 and Table 12 are embodiments of claim 1. The comparative steels No. 43 to No. 49 satisfy the S content and Ca content requirements of claim 2, and the comparative steels No. 94 to No. 101 satisfy the S content and Ca content requirements of claim 1.

[0068] As shown in Tables 11 and 12, the steels of Examples No 1 to No. 42 and No. 52 to No. 93 exhibited good values for all of the evaluation indexes, namely VL1000, VB_max, impact value (absorbed energy), and YP / TS (yield ratio), but the steels of the Comparative Examples were each inferior to the Example steels in at least one of the properties. Specifically, the steels of Comparative Examples No. 43 to No. 46 had total Al contents below the range of the present invention and were therefore inferior to the Example steels in machinability (VL1000) and yield ratio (YP / TS). Moreover, the steel of Comparative Example No.47 had a total Al content below the range of the present invention, so that its solute N content was above the range of the present invention, and the steel was therefore inferior to the steels of the Examples in machinability (VL1000, VB_max), impact value, and yield ratio (YP / TS).

[0069] The steels of Comparative Examples No. 48 and No. 49 were maintained at 850 °C, the temperature at which AlN readily precipitates, for a shorter holding time than the steels of the Examples, so that their solute N contents were above the range of the present invention, and the steels were therefore inferior to the steels of the Examples in machinability (VL1000, VB_max) and impact value. Moreover, the steels of Comparative Examples No.94 to No. 96 had a total Al content below the range of the present invention and were therefore inferior to the steels of the Examples in machinability (VL1000, VB_max) and yield ratio (YP / TS). Further, the steels of Comparative Examples No. 97 to No. 101 were maintained at 850 °C, the temperature at which AlN readily precipitates, for a shorter holding time than the steels of the Examples, so that their solute N contents were above the range of the present invention, and the steels were therefore inferior to the steels of the Examples in machinability (VL1000, VB_max) and impact value.

INDUSTRIAL APPLICABILITY

[0070] The present invention provides a machine structural steel that has good machinability over a broad range of machining speeds and also has high impact properties and high yield ratio.

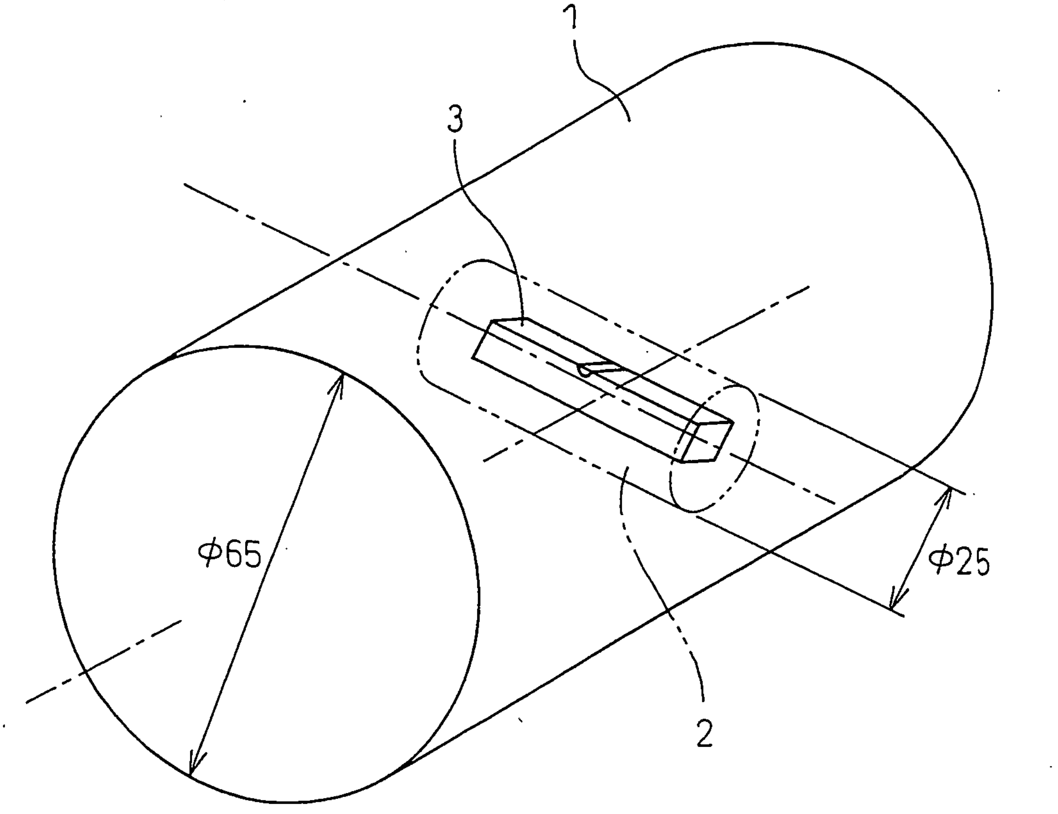
Claims

1. A machine structural steel excellent in machinability and strength properties comprising, in mass%:

    C: 0.1 to 0.85%,
    Si: 0.01 to 1.5%,
    Mn: 0.05 to 2.0%,
    P: 0.005 to 0.2%,
    S: 0.001 to 0.15%,
    total Al: greater than 0.05% and not greater than 0.3%,
    Sb: less than 0.0150% (including 0%), and
    total N: 0.0035 to 0.020%,
    solute N being limited to 0.0020% or less, and a balance of Fe and unavoidable impurities.

2. A machine structural steel excellent in machinability and strength properties according to claim 1, further comprising, in mass%, one or more of Ca: 0.0003 to 0.0015%, Ti: 0.001 to 0.1%, Nb: 0.005 to 0.2%, W: 0.01 to 1.0%, V: 0.01 to 1.0%, Mg: 0.0001 to 0.0040%, Zr: 0.0003 to 0.01%, REMs: 0.0001 to 0.015%, Sn: 0.005 to 2.0%, Zn: 0.0005 to 0.5%, B: 0.0005 to 0.015%, Te: 0.0003 to 0.2%, Bi: 0.005 to 0.5%, Pb: 0.005 to 0.5%, Cr: 0.01 to 2.0%, Mo: 0.01 to 1.0%, Ni: 0.05 to 2.0% and Cu: 0.01 to 2.0%.

Fig.1



INTERNATIONAL SEARCH REPORT	International application No. PCT/JP2007/075350

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

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C38/00-38/60, C21D8/00-8/10

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2008
Kokai Jitsuyo Shinan Koho	1971-2008	Toroku Jitsuyo Shinan Koho	1994-2008

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 7-316718 A (Kawasaki Steel Corp.), 05 December, 1995 (05.12.95), Examples (Family: none)	1,2
X	JP 7-188847 A (Kawasaki Steel Corp.), 25 July, 1995 (25.07.95), Table 5 (Family: none)	2
X	JP 7-150293 A (Kawasaki Steel Corp.), 13 June, 1995 (13.06.95), Table 2 (Family: none)	2

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

* Special categories of cited documents:
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Date of the actual completion of the international search 03 March, 2008 (03.03.08)	Date of mailing of the international search report 11 March, 2008 (11.03.08)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	JP 7-41851 A (Kawasaki Steel Corp.), 10 February, 1995 (10.02.95), Table 1 (Family: none)	2
A	JP 2004-107787 A (Kobe Steel, Ltd.), 08 April, 2004 (08.04.04), Table 1 (Family: none)	1,2

Form PCT/ISA/210 (continuation of second sheet) (April 2007)

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- JP 2004107787 A **[0005] [0006]**
- JP 3706560 B **[0005] [0005] [0006]**