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(54) **ENVIRONMENTALLY-FRIENDLY, PB-FREE FREE-MACHINING STEEL, AND MANUFACTURING METHOD FOR SAME**

(57) A lead-free free-cutting steel includes, by wt%, about 0.03-0.13% of carbon (C), about 0.1% or less of silicon (Si), about 0.7-2.0% of manganese (Mn), about 0.05-0.15% of phosphorous (P), about 0.2-0.5% of sulfur (S) of, about 0.001-0.01% of boron (B), about 0.1-0.5% of chromium (Cr), about 0.003-0.2% of titanium (Ti), about 0.005-0.015% of nitrogen (N), about 0.03% or less of oxygen (O), residual iron (Fe), and other unavoidable impurities. In the lead-free free-cutting steel, the number of manganese sulfide (MnS) inclusions having a particle size of about 5 μm^2 or more may include in the range of about 300-1000 per mm^2 of a material in a section of a wire rod rolling direction. The present invention is also related to a method of manufacturing an eco-friendly lead-free free-cutting steel by properly controlling a total oxygen content by step in steelmaking steps.

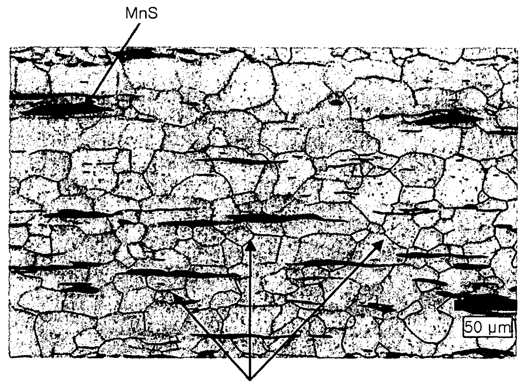

FIG. 2

EP 2 322 680 A2

Description

[Technical Field]

[0001] The present invention relates to an eco-friendly lead-free free-cutting steel having excellent machinability and a manufacturing method thereof, and more particularly, to an eco-friendly lead-free free-cutting steel and a manufacturing method thereof in which machinability and hot-rolling characteristics are improved by: ① forming non-metallic inclusions and precipitates by adding an appropriate amount of titanium (Ti), chromium (Cr) and nitrogen (N), etc.; ② controlling a manganese (Mn)/sulfur (S) ratio among components to about 3.5 or more; ③ limiting a total oxygen (T. [0]) content to about 300 ppm or less and ④ controlling the number of manganese sulfide (MnS) inclusions such that the number of MnS having an area of about 5 μm^2 or more is in the range of about 300-1000 per mm^2 in a section of a rolling direction.

[Background Art]

[0002] A free-cutting steel denotes a steel in which machinability, commonly called as cuttability, is highly improved. The free-cutting steel is widely used as materials for hydraulic parts of an automobile, shafts of office automation equipment enabling to be used in a printer or the like and cutting parts, etc., and applications and demands thereof has been in a gradually increasing trend.

[0003] The free-cutting steel basically has excellent cuttability, particularly mechanical cuttability, and for this purpose, cuttability is typically improved by a method of adding various alloying elements or forming inclusions in the free-cutting steel. Particularly, non-metallic inclusions are used as a mechanism for improving cuttability, and a well-known material among non-metallic inclusions is manganese sulfide (MnS).

[0004] Cuttability of the free-cutting steel can be obtained by controlling a size, a shape, or a distribution of MnS. More particularly, during cutting of steel using a machining apparatus like a lathe, non-metallic inclusions such as MnS or the like act as a stress concentration source in a contact portion between a tool tip and the steel to generate voids at interfaces between the non-metallic inclusions and a matrix, so that crack growth may be promoted at the voids, which is a principle to reduce force required for cutting. Therefore, in order to improve cuttability of the free-cutting steel, basically, ① MnS should exist in a large amount, ② MnS should be distributed randomly, and ③ it is better if a size of MnS is large, and particularly a shape of MnS is close to a spherical shape.

[0005] The shapes of MnS existed in the free-cutting steel may change greatly depending on an oxygen content of a continuous casting tundish, and the shapes are largely classified into three types, i.e., a spherical shape (Type I), a dendritic shape (Type II) and an irregular shape (Type III).

[0006] It is known that cuttability of the free-cutting steel is improved as MnS is close to the spherical type (Type I). In the case where a tundish total oxygen (T.[0]) content is high as much as about a few hundred ppm, MnS will be crystallized into complex sulfides such as Mn(0,S) or the like while solidifying in molten steel at a high temperature together with a deoxidation process. On the other hand, a dendritic (Type II) structure does not crystallize in a molten steel state during solidification when the tundish T.[0] content is relatively low as much as about a few ten ppm, but precipitates along primary grain boundaries. Thereafter, the dendritic (Type II) structure easily elongates along a rolling direction in a hot-rolling process of steels, thus greatly deteriorating anisotropy of a material. The dendritic structure is a shape generated during solidification of ordinary steels except the free-cutting steel, and greatly deteriorates mechanical properties of steels. Therefore, in order to suppress MnS precipitation in a refining process, many efforts have been made such as reducing an S content extremely to about a few ppm or the like.

[0007] Finally, the irregular shape (Type III) MnS has a characteristic of being formed as isolated inclusions of MnS mainly at a high temperature when the tundish T.[0] content is low as much as about a few ppm and a melted aluminum content is high. The irregular shape (Type III) MnS exists in an angular shape in an aluminum deoxidized steel.

[0008] Among related arts for the free-cutting steel, there is a technology that limits elements, such as carbon (C), silicon (Si), manganese (Mn), sulfur (S), phosphorous (P), niobium (Nb) and oxygen (0), etc., in a specific range and simultaneously limits an area ratio of polygonal ferrite as a microstructure to about 5% or more. However, although high-priced alloying elements, such as Nb, molybdenum (Mo), zirconium (Zr) or the like are added in a large amount, the related art is not able to clearly suggest functions of these alloying elements in the free-cutting steel. Also, there exists a limitation that although the area ratio of the polygonal ferrite was limited to a desired range, a measurement method thereof was not suggested specifically.

[0009] Another related art for the free-cutting steel is that alloying elements, such as carbon (C), silicon (Si), manganese (Mn), sulfur (S), oxygen (0), bismuth (Bi) or the like, are added to a constant amount, and the number of Bi inclusions per mm^2 in a section of a rolling direction and a ratio of a Bi content are limited to a constant value or more. However, although the related art limits the number of Bi inclusions and the ratio of the Bi content, it is actually difficult to control the ratio in a manufacturing process of the free-cutting steel. Furthermore, the related art is characterized in that oxygen is added to about 0.003 wt% or less, but it is difficult to provide a high-oxygen free-cutting steel having excellent cuttability, in which a MnS shape is controlled to the Type I, i.e. a spherical shape, by the above oxygen content.

[0010] Another related art for the free-cutting steel is related to a sulfur-based continuous casting free-steel having an equivalent level of cuttability to a free-cutting steel manufactured by a typical ingot making method. It is characterized in that carbon (C), manganese (Mn), phosphorous (P), sulfur (S), nitrogen (N) and oxygen (0) are included in a constant amount, and an average size of MnS inclusions is about 50 μm^2 or less. However, the related art is disclosing contents related to MnS, but it only suggests sizes of particles thereof and does not explain about effects of MnS shapes on cuttability.

[0011] Another related art for the free-cutting steel is characterized in that carbon (C), manganese (Mn), phosphorous (P), sulfur (S), nitrogen (N) and oxygen (0) are used as basic components, silicon (Si) and aluminum (Al) are limited to about 0.1 wt% or less and about 0.009 wt% or less, respectively, and N is in the range of about 20-150 ppm and a total mass of oxide-based inclusions is about 50% or more. However, when considering the fact that it is actually difficult to measure the mass of the oxide-based inclusions in the free-cutting steel, it is considered that the related art, which controls a value difficult to measure within a fixed range, has limitations in effectiveness and reality thereof.

[0012] Another related art for the free-cutting steel is related to a manufacturing method of a Bi-S based free-cutting steel, and is characterized in that high-temperature ductility is increased by controlling grain sizes of a free-cutting steel and austenite having excellent physical properties to a constant size. That is, the Bi-S based free-cutting steel includes: by wt%, carbon; about 0.05-0.15%, Mn; about 0.5-2.0%, S; about 0.15-0.40%, P; about 0.01-0.1%, 0; about 0.003-0.020%, Bi; about 0.03-0.3%, Si; about 0.01% or less and Al; 0.0009% or less, and the rest includes iron and unavoidable impurities. Also, the Bi-S based free-cutting steel was suggested in which a cross-sectional fraction of MnS-based inclusions absorbing MnS and Bi is about 0.5-2.0%, and the cross-sectional fraction of Bi is about 0.030-0.30%. However, it is related to the Bi-S based free-cutting steel, and it does not provide a method related to controlling MnS shapes like the present invention.

[Disclosure]

[Technical Problem]

[0013] An aspect of the present invention provides a free-cutting steel that is appropriate for environmental regulation standards and has excellent characteristics of cuttability, hot-rolling ability and the like.

[Technical Solution]

[0014] According to an aspect of the present invention, there is provided a lead-free free-cutting steel including: about 0.03-0.13 wt% of carbon (C); about 0.1 wt% or less of silicon (Si); about 0.7-2.0 wt% of manganese (Mn); about 0.05-0.15 wt% of phosphorous (P); about 0.2-0.5 wt% of sulfur (S); about 0.001-0.01 wt% of boron (B); about 0.1-0.5 wt% of chromium (Cr); about 0.003-0.2 wt% of titanium (Ti); about 0.005-0.015 wt% of nitrogen (N); about 0.03 wt% or less of oxygen (0); residual iron (Fe); and other unavoidable impurities. The number of manganese sulfide (MnS) inclusions having a particle size of about 5 μm^2 or more may is in the range of about 300-1000 per mm^2 of a material in a section of a wire rod rolling direction. In this case, the weight ratio of Mn to S (Mn/S) may be 3.5 or more.

[0015] According to another aspect of the present invention, there is provided a method of manufacturing a lead-free free-cutting steel including: a converter refining step of ending an oxygen blowing when a free oxygen concentration is in the range of about 400-1000 ppm by blowing oxygen with a supersonic speed in a molten metal; a tapping step of tapping the molten metal after the ending of the oxygen blowing into a teaming ladle in a non-deoxidation state; a molten steel heating step of performing a ladle furnace (LF) refining until a free oxygen concentration is in the range of about 100-200 ppm after transporting the teaming ladle to the LF; a continuous casting step of casting the molten steel into a billet when the free oxygen concentration is in the range of about 50-150 ppm at a point of time of about 10-50% of total casting time; and a wire rod rolling step of rolling the billet into a wire rod while the billet is maintained at a temperature of about 1200-1350°C in a heating furnace for about 2-5 hours. In this case, in the continuous casting step, the molten steel is manufactured into a bloom, and then the bloom may be manufactured into a billet through bloom rolling. At this time, the method may further include a bloom rolling step, of rolling the bloom into the billet while maintaining the bloom at a heating furnace temperature of about 1250°C or more for about 4-10 hours.

[0016] According to another aspect of the present invention, the lead-free free-cutting steel may include about 0.03-0.13 wt% of carbon (C), about 0.1 wt% or less of silicon (Si), about 0.7-2.0 wt% of manganese (Mn), about 0.05-0.15 wt% of phosphorous (P), about 0.2-0.5 wt% of sulfur (S), about 0.001-0.01 wt% of boron (B), about 0.1-0.5 wt% of chromium (Cr), about 0.003-0.2 wt% of titanium (Ti), about 0.005-0.015 wt% of nitrogen (N), about 0.03 wt% or less of oxygen (0), residual iron (Fe), and other unavoidable impurities. The number of manganese sulfide (MnS) inclusions having a particle size of about 5 μm^2 or more may be in the range of about 300-1000 per mm^2 of a material in a section of a wire rod rolling direction. Particularly, the continuous casting operation may use a mold electromagnetic stirrer device, a soft reduction device or the mold electromagnetic stirrer device and the soft reduction device, and the weight ratio of Mn to S (Mn/S) may be 3.5 or more.

[Advantageous Effects]

[0017] As described above, according to the free-cutting steel and the manufacturing method thereof, a S free-cutting steel can be easily manufactured in steelmaking and continuous casting processes. An eco-friendly lead-free free-cutting steel, which has an excellent hot-rolling ability as well as cuttability that is greatly increased by crystallizing a large amount of spherically shaped MnS in a steelmaking step, can be also provided.

[Description of Drawings]

[0018] The above and other aspects, features and other advantages of the present invention will be more clearly understood from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a micrograph showing an image of manganese sulfide (MnS) inclusions;
FIG. 2 is a micrograph showing an image in which chromium (Cr), titanium (Ti), nitrogen (N) and sulfur (S)-based precipitates coexist with MnS inclusions in a high-oxygen free-cutting steel;
FIG. 3 is a diagram schematically illustrating a manufacturing process of an eco-friendly free-cutting steel of the present invention;
FIG. 4 is a graph comparing tool life of a Comparative Example with that of an Experimental Example satisfying conditions of the present invention; and
FIG. 5 is a graph comparing surface roughness of a Comparative Example with that of an Experimental Example satisfying conditions of the present invention.

[Best Mode]

[0019] Exemplary embodiments of the present invention will now be described in detail with reference to the accompanying drawings.

[0020] In order to achieve the above-described objects, the inventors of the present invention manufactured a free-cutting steel by: ① forming non-metallic inclusions and precipitates by adding an appropriate amount of titanium (Ti), chromium (Cr) and nitrogen (N), etc.,; ② controlling a manganese (Mn)/sulfur (S) ratio among components to about 3.5 or more; ③ limiting a total oxygen (T.[0]) content to about 300 ppm or less and ④ controlling the number of manganese sulfide (MnS) inclusions such that the number of MnS having an area of 5 μm^2 or more is in the range of about 300-1000 per mm^2 in a section of a rolling direction.

[0021] The MnS inclusions exist in the free-cutting steel with a shape as shown in FIG. 1. Particularly, when Ti, Cr and N are properly limited by the foregoing technical configuration, a large amount of (Cr, Ti)S-based or (Cr, Ti)N-based fine precipitates having a size ranging about 0.1-5 μm are precipitated at grain boundaries during solidification as shown in FIG. 2, thus enabling to: ① improve cuttability by preventing work hardening from occurring during a machining operation of parts, and in addition, ② suppress a build-up edge (BUE, hereinafter refer to as BUE) formation by improving fracture toughness of steels and improve cuttability of the free-cutting steel by making chip segmentation better. Thus, effects of improving surface roughness of steels as well as extending tool life can also be presented.

[0022] Hereinafter, a component system constituting the foregoing lead-free free-cutting steel will be described in more detail.

Carbon (C): about 0.03-0.13 wt%

[0023] C is an element that increases strength and hardness of a material by forming carbides. C plays a role to suppress a BUE formation in a tool during cutting steels by partially existing as pearlite in the free-cutting steel. When the C content is less than about 0.03 wt%, it is difficult to increase hardness of a material to a desired range, and there is no effect of suppressing a BUE. On the other hand, when the C content is more than about 0.13 wt%, hardness of the material is increased excessively such that tool life is greatly reduced. Therefore, the C content is limited in the range of about 0.03-0.13 wt% in the present invention.

Silicon (Si): about 0.1 wt% or less

[0024] Silicon is an element that remains in a material due to a pig iron or a deoxidizer. Since most of Si is dissolved in ferrite if an oxide, i.e. silicon dioxide (SiO_2) is not formed, it is known that Si does not give great effects on mechanical properties of an ordinary free-cutting steel. However, according to experiments of the inventors of the present invention or the like, when the Si content is more than 0.1 wt% in a high-oxygen free-cutting steel, SiO_2 is formed so that tool life is remarkably reduced during machining of the free-cutting steel. Therefore, in principle, Si is not added in the present invention. However, since Si may be entered unavoidably from alloy irons and refractories or the like in a steelmaking process, the Si content existed in the free-cutting steel of the present invention is limited to about 0.1 wt% or less.

Manganese (Mn): about 0.7-2.0 wt%

[0025] Mn is an important alloying element that forms MnS non-metallic inclusions for providing machinability of steels, and the MnS inclusions can be effectively crystallized when adding about 0.7 wt% or more. Furthermore, Mn can suppress an effect of increasing surface defects of a bloom during hot-rolling. However, if the Mn content is excessively high of more than about 2.0 wt%, hardness of steels increases so that tool life may be rather decreased. Also, when the Mn content is in the range of about 0.7-2.0 wt%, some of Mn is combined with oxygen to form MnO. MnO will play a role to promote a formation of spherical MnS inclusions by acting as a MnS forming nuclei during a solidification process.

Phosphorous (P): about 0.05-0.15 wt%

[0026] P is an element for suppressing a BUE which can be easily formed in a tip of a cutting tool. When the P content is less than about 0.05 wt%, it is difficult to expect suppressing effects of a BUE formation. On the other hand, although the suppressing effects of the BUE formation is excellent when the P content is more than about 0.15 wt%, a reduction of cutting tool life caused by increasing hardness of steels will be concerned. Therefore, the P content is limited in the range of about 0.05-0.15 wt% in the present invention.

Sulfur (S): about 0.2-0.5 wt%

[0027] S is used for forming MnS inclusions during solidification in the free-cutting steel. As described above, since MnS plays a role to reduce wear of cutting tools and improve surface roughness of a workpiece by improving cuttability of steels, S is very important in the present invention. For this purpose, S is added to about 0.2 wt% or more. However, according to experiments of the inventors of the present invention, an addition of S in an excessively large amount may promote precipitation of iron sulfide (FeS) having a reticular shape at grain boundaries. Since FeS is very brittle and has a low melting point, hot-rolling ability may be greatly reduced. Also, if the S content is increased more than necessary, toughness and ductility of steels are remarkably decreased as well as surface defects of the steels are increased. Therefore, the S content should not be more than about 0.5 wt%.

Boron (B): about 0.001-0.01 wt%

[0028] B plays a role to increase hardenability in steels, and for this purpose, is added to about 10-100 ppm in the present invention. When B is added to less than about 10 ppm, it is difficult to obtain an appropriate effect of increasing hardenability. According to experiments of the inventors of the present invention, although sufficient hardenability can be obtained when the B content is more than about 100 ppm, hot-rolling is difficult due to decrease in high-temperature ductility. Therefore, a range thereof is limited.

Chromium (Cr): about 0.1-0.5 wt%

[0029] Cr is an element that acts to enlarge an austenite region in a carbon steel, and Cr is an important and a universal alloying element which is low cost and has characteristics of forming carbides that do not cause an embrittlement even if Cr is added in a large amount. Coarse (Cr, Mn)S-based non-metallic inclusions are formed during an addition of Cr, and deformation of the non-metallic inclusions is suppressed during rolling and it makes the non-metallic inclusions having a uniform distribution in a matrix phase. Cr is added to improve cuttability in the present invention. According to experiments of the inventors of the present invention, an effect of improving machinability is not large when Cr is added to less than about 0.1 wt%. On the other hand, when Cr is added to more than about 0.5 wt%, machinability reaches a limiting value such that no further improvement is achieved. Therefore, an amount of Cr addition is limited to about 0.1-0.5 wt%. Cr may be added to about 0.2-0.4 wt%.

Titanium (Ti): about 0.003-0.2 wt%

[0030] Ti shows strong chemical affinity with any element of oxygen (0), nitrogen (N), carbon (C), sulfur (S) and hydrogen (H), and is also particularly used for a deoxidation, a denitrification and a desulphurization reaction, etc. Also, Ti easily forms carbides and acts to refine grains. Even in experiments related to the present invention, it could be confirmed that cuttability is greatly improved by grain refinement when adding Ti to more than about 0.003 wt%. Also, hardness increase during an addition of Ti suppresses a BUE formation such that cuttability is improved. However, when adding more than about 0.2 wt%, an effect of improving cuttability reaches a limit. Since hardness is rather excessively increased due to a large amount of fine precipitates and titanium dioxide (TiO_2) formed in a material, it shows a limitation that cutting tool life is shortened. Therefore, the Ti content is limited to about 0.003-0.2 wt%, and may be limited to about 0.008-0.15 wt%.

Nitrogen (N): about 0.005-0.015 wt%

[0031] N is an element affecting a BUE formation in cutting tools and surface roughness of cutting parts. When the N content is less than about 0.005 wt%, it is not good because the BUE formation is increased and the surface roughness is deteriorated. Although the BUE formation is decreased as the N content increases, there may be a limitation caused by increasing surface defects of a free-cutting steel bloom after complete casting when the N content is more than about 0.015 wt%. Therefore, the N content is limited to about 0.005-0.015 wt% in the present invention.

Oxygen (O): about 0.03 wt% or less

[0032] Oxygen forms a fine manganese oxide (MnO) at an initial solidification stage of molten steel in a mold during casting the free-cutting steel, and MnO will act as a nucleation site for crystallizing MnS. Herein, the oxygen means a total oxygen (T.[0]) content of a slab (or a bloom) after complete casting. As described above, when oxygen is about a few ten ppm or less, Type II or Type III shape of MnS precipitates during solidification, and it will be a limitation because these shapes of MnS deteriorate cuttability of the free-cutting steel. Crystallization of Type I, i.e. spherically shaped MnS is targeted for maximizing cuttability in the present invention. According to experiments, experimental results show a tendency that the spherically shaped MnS is effectively crystallized as the oxygen content is high. However, when the oxygen content is excessive to be more than about 0.03 wt%, surface defects, such as pin holes and blow holes or the like, may be greatly increased in a slab after complete solidification. Therefore, an upper limit of the oxygen content is set.

A weight ratio of Mn over S: $Mn/S \geq 3.5$

[0033] In addition to the above content regulations, in order to provide a free-cutting steel having excellent ductility at a high temperature according to the present invention, a relation of Mn and S is controlled to satisfy that the Mn/S ratio based on wt% is about 3.5 or more. This is for avoiding hot brittleness due to FeS by combining Mn with S, because securing of the Mn content above a certain amount is important. Particularly, when the Mn/S ratio is less than about 3.5, hot-rolling ability is reduced so that it is difficult to manufacture the free-cutting steel pursued in the present invention.

[0034] The number of MnS: the number of MnS having a size of about 5 μm^2 or more is about 300-1000 per mm^2 in a section of a rolling direction In the foregoing free-cutting steel, cuttability is greatly changed depending on sizes and distribution of MnS non-metallic inclusions remaining in the steel. In general, it has been known that cuttability of steels is better as MnS size is large and the number is high. According to optical microscopic observations and cuttability evaluation results by the inventors of the present invention, cuttability of the steels is the best when the number of MnS having a size of more than about 5 μm^2 is about 300-1000 per mm^2 in a section of a rolling direction, i.e. a L direction. When the number of MnS is less than about 300, tool life is reduced due to a decrease in cuttability, and surface roughness of machined parts is also deteriorated. On the other hand, when the number exceeds more than about 1000, it appears that chip carrying ability is poor although tool life may be increased. Therefore, the number of MnS may be controlled to about 300-1000.

[0035] Hereinafter, a manufacturing method of the free-cutting steel, which includes the foregoing alloying components and may use the alloying components effectively for the present invention, will be described in more detail through FIG. 3.

A converter refining step

[0036] First, impurities, such as C, Si, Mn, P or the like contained in a molten metal, are removed into the atmosphere or slag by blowing oxygen at a supersonic speed in the molten metal in a converter. In the converter refining, oxygen blowing is stopped when free oxygen in the molten metal is in the range of about 400-1000 ppm. This is because that since a carbon content of the molten metal will exceed a compositional range of the present invention when oxygen is less than about 400 ppm, control of the carbon component is difficult. On the other hand, if oxygen is more than about 1000 ppm, it is disadvantageous because it may cause excessive erosion of refractories in the converter, a teaming ladle and the like.

A non-deoxidation tapping step

[0037] Subsequently, a step is undergone in which a molten metal after the complete oxygen blowing is tapping into a teaming ladle in a non-deoxidation state, i.e. a state of not deoxidizing the molten metal. A subsidiary material such as an alloy iron may be added during the tapping step if necessary. Adding the alloy iron or the subsidiary material is for making molten steel and slag in an appropriate range.

A heating step of molten steel (ladle furnace (LF) heating)

[0038] When finishing the tapping step, the teaming ladle is transported to a ladle furnace (LF), and heating of molten steel is performed. The Heating of the molten metal is performed with increasing a temperature of the molten steel by supplying an electric arc to the molten steel through carbon electrodes installed in advance in the LF. An alloy iron or a subsidiary material may be also added during performing the heating if necessary. In some cases, the molten steel sample may be collected and an oxygen concentration of the molten steel may be also measured. Since oxygen compounds in slag or oxygen in the atmosphere are decomposed to flow into a molten metal in a heating process of the molten steel, the oxygen concentration will be increased. LF refining may be ended in a free oxygen concentration of the molten metal ranging about 100-200 ppm in the LF. If the LF refining is ended in the free oxygen concentration of less than about 100 ppm, it is difficult to form a desired MnS. On the other hand, if the LF refining is ended in a condition of more than about 200 ppm, it is difficult to predict a change of molten steel components in a subsequent process such that control of components will not be easy. Therefore, the free oxygen concentration at the end of the LF refining is limited in the range of about 100-200 ppm.

A bloom continuous casting step

[0039] A continuous casting is performed by transporting the molten steel after the complete LF refining by the heating to a continuous casting machine. The free oxygen concentration of the molten steel is measured after starting the continuous casting, and this is for finding out in advance whether cuttability of the free-cutting steel is good or bad. The free oxygen concentration is measured at a point of time of about 10-50% of total casting time, and at this time, the free oxygen concentration is sufficient if it is in the range of about 50-150 ppm. If the free oxygen concentration is measured when a casting time is less than about 10%, it is difficult to obtain an accurate free oxygen concentration due to effects of tundish refractories or tundish insulation materials, etc. If measured when the casting time is more than about 50%, it is disadvantageous because an opportunity enabling to control the oxygen concentration is lost. Also, when the measured free oxygen concentration is less than about 50 ppm, cuttability is relatively poor according to experiments. On the other hand, when the concentration is more than 150 ppm, it is not good because pin holes and blow holes in a slab are somewhat increased. In the continuous casting of the free-cutting steel, a better slab may be obtained if an electronic stirring device of a mold, i.e. a mold electromagnetic stirrer (EMS) and a soft reduction device are operated. It is advantageous to obtain spherically shaped and large-sized MnS inclusions if the mold EMS device is operated. The soft reduction device is very advantageous to reduce center segregation of the slab and surface defects such as pin holes and blow holes or the like at a surface of the slab. In the continuous casting of the free-cutting steel, even if the continuous casting is performed for blooms in the size of about 300 mm X 400 mm and about 400 mm X 500 mm, etc., or for billets in the size of about 120 mm X 120 mm and about 160 mm X 160 mm, etc., all of them are basically possible methods. If the casting is only performed for the blooms, a bloom rolling process, i.e., a process for manufacturing the billets, may be undergone, and if rolling is performed for the billets, it is sufficient if the bloom rolling process is omitted and wire rod rolling is performed.

A bloom rolling step

[0040] When a bloom casting instead of a billet casting is performed in the continuous casting step, a subsequent process of performing rolling the bloom into the billet is additionally included. If the blooms in the size of about 300 mm X 400 mm and about 400 mm X 500 mm are used for rolling into the billets in the size of about 120 mm X 120 mm and about 160 mm X 160 mm, this is generally called as bloom rolling or billetizing. The most important factors in the bloom rolling process are temperature of the bloom and holding time of a heating furnace. Since a surface of a manufactured billet may be badly damaged if the rolling is performed in a low temperature state of the bloom, it is limited in the present invention for maintaining a heating furnace temperature at about 1250 °C or more for about 4-10 hours. If the bloom temperature was less than about 1250 °C, it was experimentally confirmed that surface quality of the manufactured billet was poor no matter how long it was maintained. On the other hand, even if the bloom temperature was maintained at about 1250 °C or more, the surface quality of the billet was also poor if the holding time was less than about 4 hours. Also, in the case of maintaining in the heating furnace for more than about 10 hours while the bloom temperature was maintained at about 1250 °C or more, productivity was greatly reduced and the surface quality of the billet was only the same level with a case of maintaining for about 4-10 hours. Therefore, the holding time of the heating furnace is limited to about 4-10 hours.

A wire rod rolling step

[0041] If the free-cutting steel is casted for the billet or casted for the bloom and then the billet is manufactured by performing the bloom rolling, rolling of the billet into wire rods is performed subsequently. The most important factors for manufacturing the wire rods from a free-cutting steel billet by the present step are temperature of a billet heating furnace and heating time. In order to obtain the free-cutting steel wire rods having excellent surface quality, a billet temperature in the heating furnace may be maintained at a temperature ranging about 1200-1350 °C for about 2-5 hours. When the billet temperature was less than about 1200 °C, it was difficult to obtain the wire rods having good surface quality even if the holding time of the heating furnace was made long. When the temperature was more than about 1350 °C, it was difficult to obtain the wire rods having relatively better surface quality than the temperature of about 1200-1350 °C. Also, it was difficult to obtain the wire rods having good surface quality in the above temperature range when the holding time of the heating furnace is less than 2 hours. It came to the conclusion that even if the holding time is more than about 5 hours, it is difficult to obtain the wire rods having better surface quality when comparing with a case of about 2-5 hours.

[Mode for Invention]

[0042] Hereinafter, the present invention will be described in more detail through exemplary embodiments.

[Exemplary Embodiment 1]

[0043] In the present embodiment, blooms, which have compositions of Experimental Examples and a Comparative Example (SUM24L) in the following Table 1, were manufactured in a high-frequency induction melting furnace in the 200 kg class. Herein, the Comparative Example is a lead (Pb) free-cutting steel which is most widely used at present, i.e., SUM24L. The blooms of the Experimental Examples and the Comparative Example were manufactured through the same experimental facilities and manufacturing processes, and the size of the blooms manufactured at that time was about 230 mm × 230 mm × 350 mm.

[Table 1]

	C	Si	Mn	P	S	N(ppm)	Other Components
Experimental Example 1	0.09	0.01	1.0	0.08	0.25	98	Cr 0.4, Ti 0.2
Experimental Example 2	0.08	0.02	1.1	0.08	0.30	78	Cr 0.1, Ti 0.02
Experimental Example 3	0.08	0.03	1.2	0.08	0.30	83	Cr 0.3, Ti 0.006
Experimental Example 4	0.07	0.02	1.3	0.09	0.32	65	Cr 0.5, Ti 0.06
Experimental Example 5	0.08	0.03	1.2	0.08	0.30	83	Cr 0.2, Ti 0.005
Comparative Example 1	0.08	0.03	1.2	0.08	0.33	85	Pb 0.25

[0044] The above blooms were heated at about 1300 °C in the heating furnace, and rolled into a plate having a thickness of about 30 mm using a pilot rolling mill. Subsequently, the plate was cut into squares having a size of about 30 mm × 30 mm in a rolling direction, and then the squares were machined into round bars with a diameter of about 25 mm in a lathe. Thereafter, tool life and surface roughness of a cut surface were measured by performing cuttability evaluation experiments on the round bars with a diameter of about 25 mm in a computer numerical control (CNC) lathe. The cuttability evaluation experiments were performed by selecting cutting conditions that include a cutting speed of about 100 m/min, a cutting depth of about 1.0 mm and a feed rate of about 0.1 mm/rev., and a dry condition that does not use a cutting oil was maintained.

[0045] In the foregoing experiments, the tool life was measured by Flank wear depending on cutting time which is widely used in general. The surface roughness was derived from the surface roughness depending on the cutting time. Units of the Flank wear and the surface roughness are μm, respectively, and it means that the surface roughness is excellent as this value is small. FIG. 4 is a graph showing tool lives of the Experimental Example and the Comparative Example, and it shows that the Experimental Examples of the present invention present an equivalent level of tool life as compared to comparative steels. Furthermore, it could be confirmed that surface characteristics also show an equivalent level or a better region as compared to the Pb free-cutting steel in FIG. 5.

[0046] The reason that the present invention can show an equivalent or a superior level of surface roughness as well as tool life as compared to the Pb free-cutting steel by adding a prescribed amount of Cr, Ti and N instead of Pb which is harmful to the human body is as follows; In case of adding Cr of about 0.1-0.5%, Ti of about 0.003-0.2% and N of about 0.005-0.015% to a high oxygen free-cutting steel having S ranging about 0.2-0.5%, coarse (Cr,Mn)S-based precipitates, and a large amount of (Cr,Ti)S-based and (Cr,Ti)N-based fine precipitates, which have a size of about 1 μm, are precipitated at grain boundaries during solidification of molten steel. Subsequently, effects, such as prevention of work-hardening of steels during machining of parts, reduction of fracture toughness of steels or the like, are presented by these precipitates. Therefore, the reason is considered due to the fact that suppression of a BUE formation and improvement of chip segmentation are possible by the above effects.

[Exemplary Embodiment 2]

[0047] A free-cutting steel bloom having a size of about 300 mm × 400 mm after complete continuous casting was rolled into a billet having a size of about 160 mm × 160 mm in a bloom rolling process, and subsequently, the billet was rolled into wire rods having a diameter of about 25 mm in a wire rod rolling process. At that time, the bloom and the billet were heated and cooled by typical free-cutting steel rolling conditions. Samples were collected from the wire rods after the complete rolling, and a total oxygen content was measured by an N/0 analyzer, and an area and a shape of MnS were observed by an optical microscope. Meanwhile, cold drawing was performed on the wire rods after the complete wire rod rolling to manufacture cold-drawn (CD) bars having a diameter of about 23 mm, and thereafter, tool life was measured after performing cutting experiments using a CNC lathe in the same conditions. The following Table 2 shows total oxygen contents (ppm) of the wire rods, the number of MnS having an area of 5 μm^2 or more per mm^2 and tool lives which were obtained through the foregoing experiments. In the Table 2, the tool life means the relative number of parts which can be machined by one cutting tool.

[Table 2]

Item	Total oxygen content (T.[0]), ppm	The number of MnS per unit area (an area of about 5 μm^2 or more)	Tool life (times)
Experimental Example 6	133	316	5300
Experimental Example 7	138	627	5500
Experimental Example 8	290	525	6500
Experimental Example 9	235	467	6200
Comparative Example 2	116	288	4400
Comparative Example 3	220	219	3100
Comparative Example 4	315	527	5800
Comparative Example 5	380	427	5700

[0048] When the total oxygen contents of the wire rods are included in the limited range of the present invention of about 300 ppm or less from the above Table 2, if the number of MnS per unit area is in the range of about 300-1000 (the Experimental Examples 6 through 9), the tool life showed about 5000 times or more which is required by a customer company of free-cutting steel parts. On the other hand, although the total oxygen contents were included in the range of the present invention like the Comparative Examples 2 and 3, tool life was under 5000 times when the number of MnS per unit area was less than 300. This is considered as a phenomenon that occurred when generation and propagation of cracks are relatively less progressed during cutting due to the lack of MnS having a relatively large area. Meanwhile, in the case of the Comparative Examples 4 and 5, although the number of MnS per unit area was included in the limited range of the present invention and cutting tool life was also more than a reference value of about 5000 times, a recovery rate of the CD bars from a slab was less than about 80%. The reason is that the total oxygen contents are excessively high of more than about 300 ppm such that pin holes and blow holes or the like were primarily remained at a surface of the slab, and it could be understood that no more improvement was obtained in the subsequent bloom rolling and wire rod rolling. Therefore, when the total oxygen content is excessively high, it is difficult to achieve objects pursued in the present invention due to many surface defects, a low recovery rate and a cost increase.

[0049] As described above, according to the free-cutting steel and the manufacturing method thereof, a S free-cutting steel can be easily manufactured in steelmaking and continuous casting processes. An eco-friendly non-leaded free-cutting steel, which has an excellent hot-rolling ability as well as cuttability that is greatly increased by crystallizing a large amount of spherically shaped MnS in a steelmaking step, can be also provided.

[0050] While the present invention has been shown and described in connection with the exemplary embodiments, it will be apparent to those skilled in the art that modifications and variations can be made without departing from the spirit and scope of the invention as defined by the appended claims.

Claims

1. A lead-free free-cutting steel comprising:

0.03-0.13 wt% of carbon (C); 0.1 wt% or less of silicon (Si); 0.7-2.0 wt% of manganese (Mn); 0.05-0.15 wt% of phosphorous (P); 0.2-0.5 wt% of sulfur (S); 0.001-0.01 wt% of boron (B); 0.1-0.5 wt% of chromium (Cr); 0.003-0.2 wt% of titanium (Ti); 0.005-0.015 wt% of nitrogen (N);
0.03 wt% or less of oxygen (O); residual iron (Fe); and other unavoidable impurities.

2. The lead-free free-cutting steel of claim 1, wherein the number of manganese sulfide (MnS) inclusions having a particle size of 5 μm^2 or more is in the range of 300-1000 per mm^2 of a material in a section of a wire rod rolling direction.

3. The lead-free free-cutting steel of claim 1, wherein the weight ratio of Mn to S (Mn/S) is 3.5 or more.

4. A method of manufacturing a lead-free free-cutting steel, the method comprising:

a converter refining step of ending an oxygen blowing when a free oxygen concentration is in the range of 400-1000 ppm by blowing oxygen with a supersonic speed in a molten metal in a converter;
a tapping step of tapping the molten metal after the ending of the oxygen blowing into a teaming ladle in a non-deoxidation state;
a molten steel heating step of performing a ladle furnace (LF) refining until the free oxygen concentration is in the range of 100-200 ppm after transporting the teaming ladle to the LF;
a continuous casting step of casting the molten steel into a billet when the free oxygen concentration is in the range of 50-150 ppm at a point of time of 10-50% of total casting time; and
a wire rod rolling step of rolling the billet into a wire rod while the billet is maintained at a temperature of 1200-1350°C in a heating furnace for 2-5 hours,
wherein the lead-free free-cutting steel comprises 0.03-0.13 wt% of carbon (C), 0.1 wt% or less of silicon (Si), 0.7-2.0 wt% of manganese (Mn), 0.05-0.15 wt% of phosphorous (P), 0.2-0.5 wt% of sulfur (S), 0.001-0.01 wt% of boron (B), 0.1-0.5 wt% of chromium (Cr), 0.003-0.2 wt% of titanium (Ti), 0.005-0.015 wt% of nitrogen (N), 0.03 wt% or less of oxygen (0), residual iron (Fe) and other unavoidable impurities.

5. The method of claim 4, wherein the number of manganese sulfide (MnS) inclusions having a particle size of 5 μm^2 or more is in the range of 300-1000 per mm^2 of a material in the section of the wire rod rolling direction.

6. The method of claim 4, wherein the continuous casting step comprises:

a step of casting the molten steel into a bloom; and
a bloom rolling step of rolling the bloom into a billet while maintaining at a heating furnace temperature of 1250°C or more for 4-10 hours.

7. The method of claim 4 or 6, wherein the continuous casting step uses a mold electromagnetic stirrer device, a soft reduction device or the mold electromagnetic stirrer device and the soft reduction device.

8. The method of claim 4, wherein the weight ratio of Mn to S (Mn/S) is 3.5 or more.

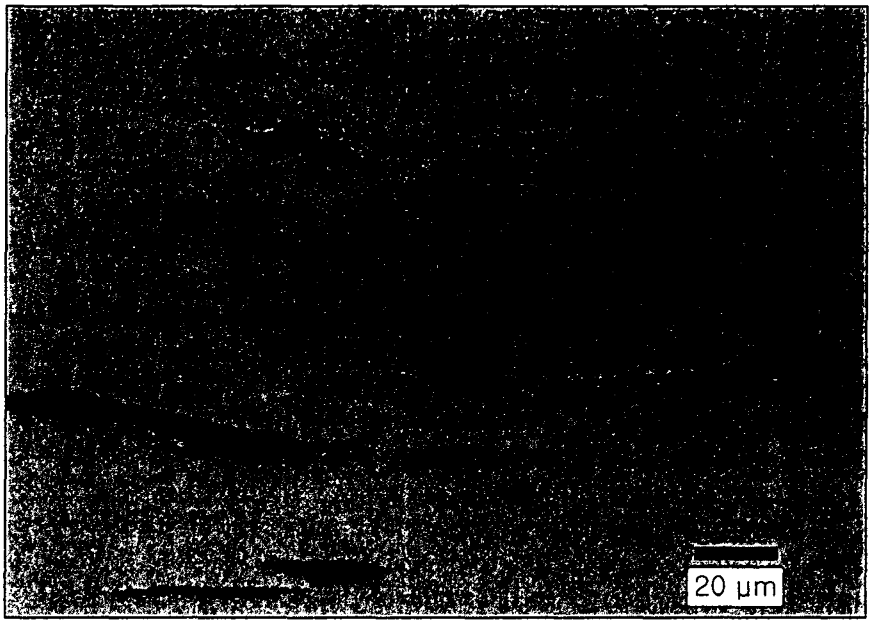

FIG. 1

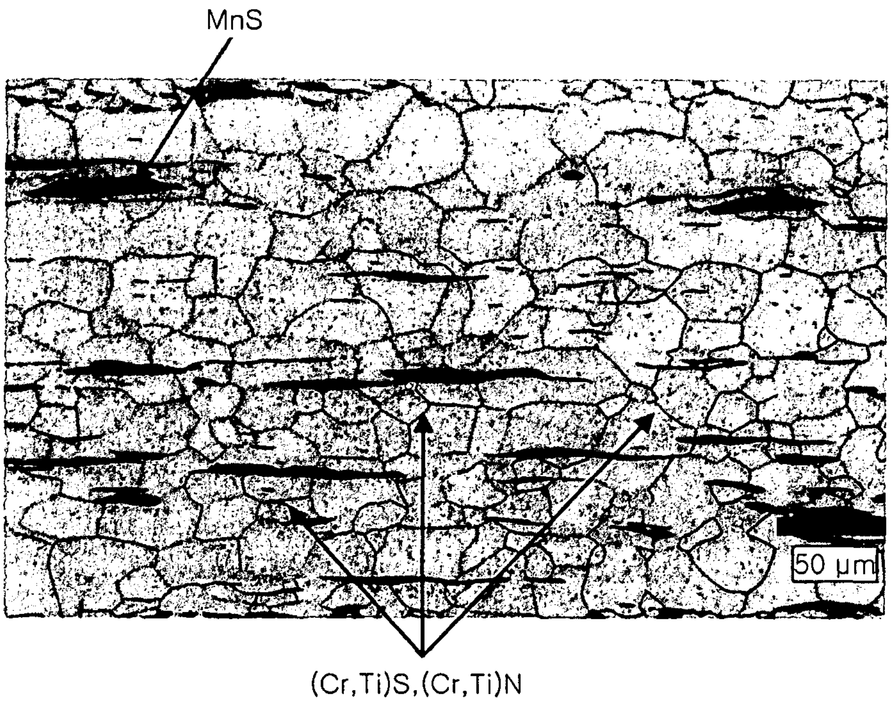

FIG. 2

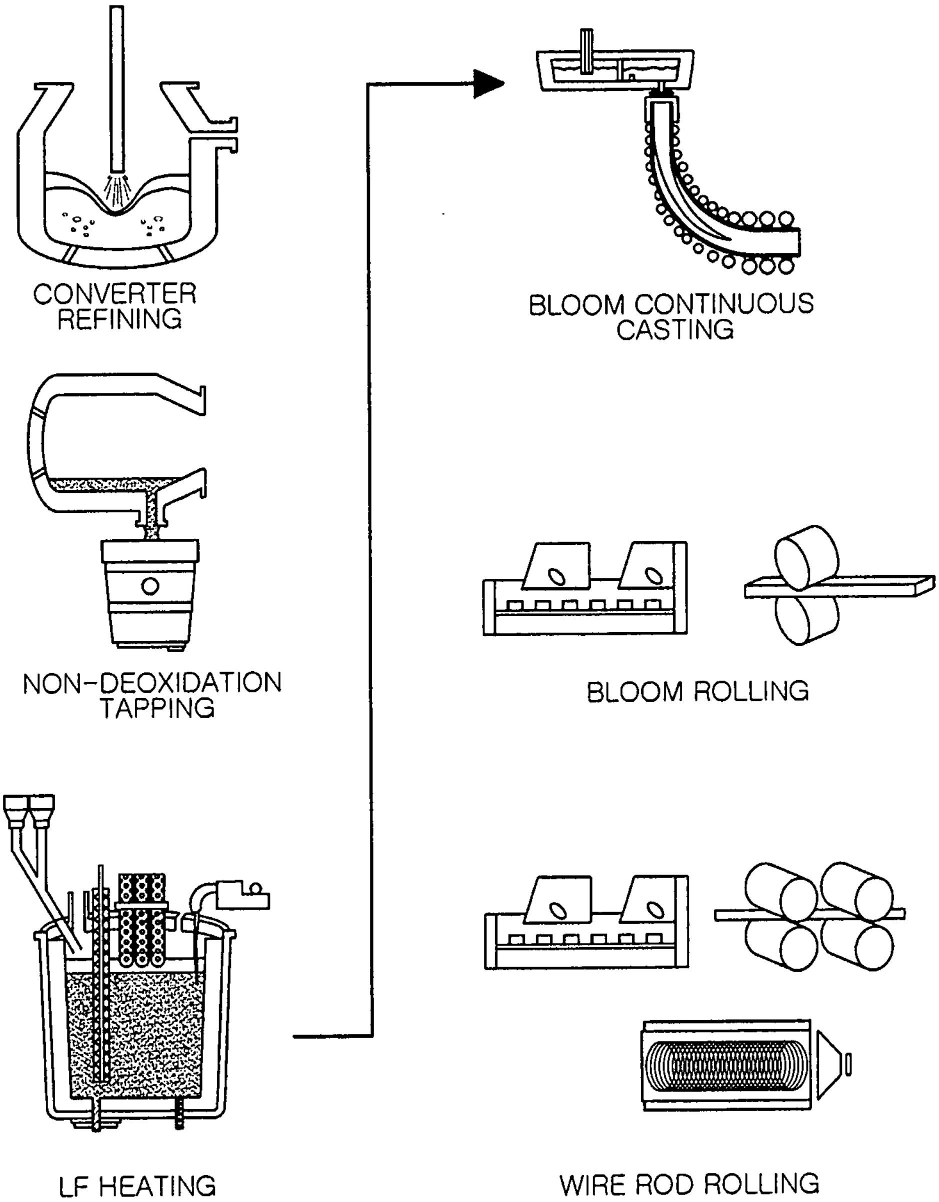
CONVERTER
REFINING
NON-DEOXIDATION
TAPPING
LF HEATING
BLOOM CONTINUOUS
CASTING
BLOOM ROLLING
WIRE ROD ROLLING

FIG. 3

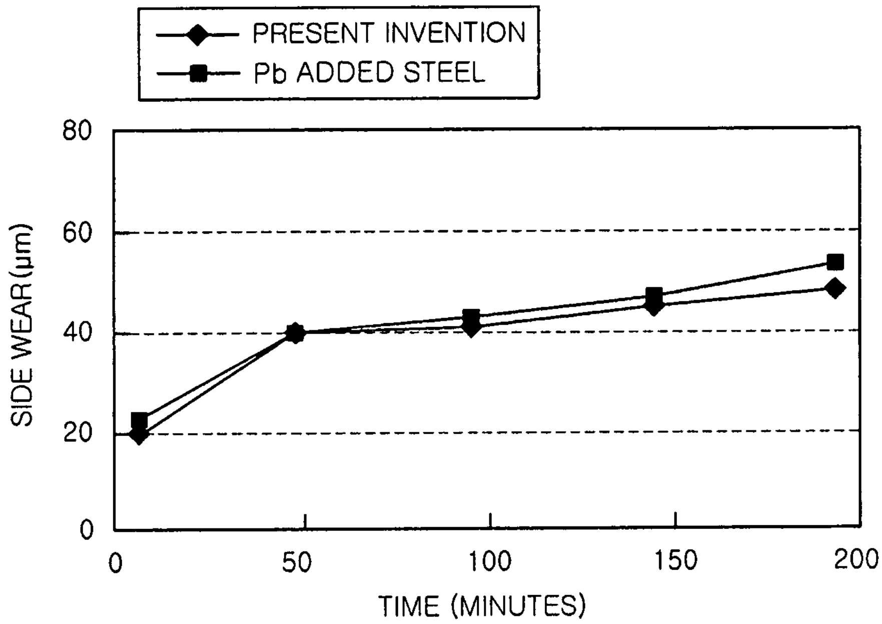
PRESENT INVENTION
Pb ADDED STEEL
SIDE WEAR (μm)
80
60
40
20
0
0
50
100
150
200
TIME (MINUTES)

FIG. 4

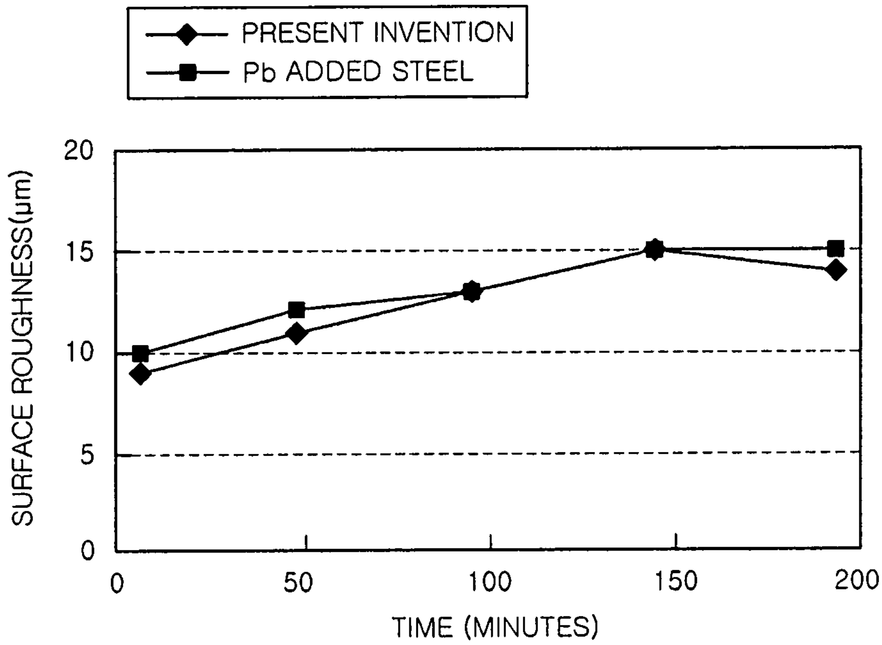
PRESENT INVENTION
Pb ADDED STEEL
SURFACE ROUGHNESS(μm)
20
15
10
5
0
0
50
100
150
200
TIME (MINUTES)

FIG. 5