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(54) A free machining steel bearing bismuth and sulfur with superior high temperature ductility, and manufacturing method therefor

(57) A bismuth-sulfuric (to be called "Bi-S" below) free-machinable steel showing a superior high temperature ductility, and a manufacturing method therefor, are disclosed, in which surface defects do not occur at a low rolling temperature. The Bi-S free-machinable steel with a superior high temperature ductility includes: in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, and a balance of Fe and other unavoidable impurities; an MnS inclusion with MnS and Bi absorbed into it; and a metallic Bi inclusion. In another aspect, the free machinable steel includes 0.02-0.1% of Ti and 0.0030-0.0100% of N in addition to the above elements. In still another aspect, the free machinable steel includes 0.0050-0.0150% of B and 0.0070% or less of N in addition to the above elements.

EP 1 054 074 A2

Description

BACKGROUND OF THE INVENTION

1. Field of the invention

[0001] The present invention relates to a bismuth-sulfur (to be called "Bi-S" below) free machining steel showing a superior high temperature ductility, and a manufacturing method therefor, in which surface defects do not occur at a low rolling temperature.

2. Description of the prior art

[0002] The free machining steel is widely used in manufacturing small parts such as cameras, watches and the like, in which a high machinability is required. Further, recently, in accordance with the increase in the production of automobiles, watches and cameras, a lead-sulfuric free-machinable steel has been developed in which machinability-improving elements such as Pb and the like are added, thereby improving the machinability. However, Pb is toxic to the human body, and therefore, in order to solve the problem, the Bi-S free-machinable steel has been developed.

[0003] Generally, the Bi-S free machining steel contains metallic or non-metallic inclusions to improve the machinability. The typical one of the non-metallic inclusions is MnS, while the metallic inclusions are low melting point metals such as Bi and the like which show almost no solid-solubility within the steel. Theme inclusions act as the stress-concentration centers during the machining to facilitate the formation of voids and cracks, thereby decreasing the force required for the machining. Further, they are softened or dissolved by the machining heat so as to act as a lubricant at the boundary surface between the tool and the chips. Thus the wear of the tool is inhibited, and the machining force is required in a smaller degree.

[0004] Sulphur which is added to form MnS may be over-saturated if the content of Mn is not sufficient, or even if the content of Mn is sufficient, if the solidification or the cooling occur abruptly. In a continuous casting, a solidified structure is formed on the surface of it in a certain thickness, and dendrites are formed within it, with the result that MnS are formed among the dendrites. However, in abruptly solidified crystals which are also called "chill crystals", S cannot be farmed into MnS, but is over-saturated. Thus during a cooling or reheating, the over-saturated S are partly precipitated in the form of MnS, and are partly segregated on the grain boundaries to be formed into FeS which causes the hot rolling brittleness. Further, in this steel, not only S, but also gas pores which are not dissolved in the steel are over-saturated. These gas pores which exceed the solid solubility at the solid phase of the steel remain as pin holes.

[0005] Meanwhile, Bi which facilitates the machining shows almost no solid-solubility, and has a low melting point. Therefore, in the general carbon steels in which MnS is not intentionally formed, MnS is segregated on the grain boundaries in the form of thin films to cause a grain boundary embrittlement. On the other hand, in the free machining steel in which MnS is intentionally formed, MnS is absorbed into the MnS inclusions, and therefore, MnS is segregated on the austenite boundary surface between the MnS inclusions and the matrix structure or on the austenite grain boundary surface, thereby causing a hot rolling shortness. The liquid phase Bi which is present on the austenite boundaries between the MnS inclusions and the matrix structure causes the lowering of the ductility at about 900 - 1000°C, while the liquid phase Bi which is present on the austenite grain boundaries causes the lowering of the ductility at about 800 - 900°C. Thus if the ductility is steeply lowered daring the hot rolling, defects occur on the surface of the hot rolled steel. This is particularly significant in the case where the ductility is lowered at 800 - 900°C.

[0006] Meanwhile, these surface defects can be classified into two kinds. One of them is large scale defects caused by the scab, with their length being 5-10 mm. Their distribution intervals are not uniform, but usually are more than several mm. Another of them is fine cracks formed in a skew form in the lengthwise direction, with their length being 1 mm or less. Their distribution intervals are several μm scale, and are somewhat regular. These defects are numerous cracks which are formed on the surface boundaries between the matrix structure and MnS (with Bi absorbed into it), or in the pin holes, or on the grain boundaries after starting from a part of fine cracks among the numerous fine cracks. Therefore, conventionally, either the fine cracks as the starting point of the defects are inhibited, or even if the fine cracks have been already formed, in order to inhibit their further growth, the rolling temperature was maintained at above 1000°C. Thus the formation of the defects was inhibited based on the method of improving the ductility. However, the high rolling temperature is accompanied by a difficulty of the maintenance of the rolling facility and by a lowering of the productivity. For this reason, there is demanded a method in which the formation of the surface defects can be inhibited at a relatively low rolling temperature, thereby ensuring a superior ductility,

SUMMARY OF THE INVENTION

[0007] After long time studies and researches, the present inventor found that the growth of the grains could be inhibited by maintaining the reheating temperature at a low level, or that, even if the reheating temperature was high, the migrations of the grain boundaries could be impeded by utilizing the fine non-resolved precipitates by adding Ti and N, thereby improving the high temperature ductility. Further, the present inventor studied on the segregation behaviors of S and Bi at the austenite grain boundaries of the Bi-S free machining steel, and found that if a proper amount of B (which is diffused faster than S and Bi) is added, the hot rolling brittleness could be effectively prevented, and the high temperature ductility could be improved. Thus the present inventor came to propose the present invention.

[0008] Therefore it is an object of the present invention to provide a free machining steel with a superior high temperature ductility, and a manufacturing method therefor, in which the reheating temperature is maintained at a low level to inhibit the growth of grains and to make the grains fine, thereby preventing the formation at surface defects even at a relatively low rolling temperature.

[0009] It is another object of the present invention to provide a free machining steel with a superior high temperature ductility, and a manufacturing method therefor, in which Ti and N are added, and thus even if the reheating temperature is high, the fine precipitates (which are not resolved at a high temperature) are utilized to impede the migration of the grain boundaries and to make the grains fine, thereby preventing the formation of the surface defects even at a relatively low rolling temperature.

[0010] It is still another object of the present invention to provide a free-machinable steel with a superior high temperature ductility, and a manufacturing method therefor, in which B and N are added, and thus B (which shows a faster diffusion speed than S and Bi) is preferably segregated on the austenite grain boundaries, thereby preventing the formation of the surface detects due to FeS and due to a dissolved Bi at a relatively low rolling temperature.

[0011] In achieving the above objects, the Bi-S free machining steel with a superior high temperature ductility according to the present invention includes: in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, and a balance of Fe and other unavoidable impurities; an MnS inclusion with MnS and Bi absorbed into it; and a metallic Bi inclusion.

[0012] In another aspect of the present invention, the method for manufacturing a Bi-S free machining steel with a superior high temperature ductility according to the present invention includes the steps of: preparing a bloom having a composition of (in wt%) 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, and a balance of Fe and other unavoidable impurities; reheating the bloom to 850 - 1000°C so as to make austenite grain size not exceed 60 μm; carrying out a billet-rolling to form a billet; reheating the billet to 850 - 1000°C again so as to make austenite grain size not exceed 60 μm; and carrying out a wire rod rolling.

[0013] In still another aspect of the present invention, the Bi-S free machining steel with a superior high temperature ductility according to the present invention includes; in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, 0.02-0.1% of Ti, 0.0030-0.0100% of N, and a balance of Fe and other unavoidable impurities; an MnS inclusion with MnS and Bi absorbed into it; and a metallic Bi inclusion.

[0014] In still another aspect of the present invention, the method for manufacturing a Bi-S free-machinable steel with a superior high temperature ductility according to the present invention includes the stops of: preparing a bloom having a composition of (in wt%) 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or loss of Al, 0.02-0.1% of Ti, 0.0030-0.010% of N and a balance of Fe and other unavoidable impurities; reheating the bloom to carry out a billet-rolling at 850 - 1200°C so as to form a billet; and reheating the billet to carry out a wire rod rolling at 850 - 1200°.

[0015] In still another aspect of the present invention, the Bi-S free machining steel with a superior high temperature ductility according to the present invention includes: in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, 0.0070% or less of N, 0.0050-0.0150% of B, and a balance of Fe and other unavoidable impurities; an MnS inclusion with MnS and Bi absorbed into it; and a metallic Bi inclusion.

[0016] In still another aspect of the present invention, the method for manufacturing a Bi-S free machining steel with a superior high temperature ductility according to the present invention includes the steps of: preparing a bloom composed of in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% at P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, 0.0070% or less of N, 0.0050-0.0150% of B, and a balance of Fe and other unavoidable impurities; reheating the bloom to carry out a billet-rolling at 800 - 1200°C so as to form a billet; and reheating the billet to carry out a wire rod rolling at 800 - 1200°C.

<u>DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT</u>

[0017] The Bi-S free machining steel can be hot-rolled at above 950°C, but if an 60% or more of the high temperature ductility is to be secured, the hot rolling should be carried out at a high temperature of above 1000°C, this being the general practice. That is, if the rolling temperature is lowered to below 1000°C, then the high temperature ductility may be dropped to below 60%, and therefore, there is a possibility that surface defects may occur during the hot rolling. However, in the present invention, even at a relatively low temperature of below 1000°C, a superior high temperature ductility is ensured, thereby preventing the formation of surface defects.

[0018] First, such a superior high temperature ductility can be achieved by making the grains fine. That is, making the grains fine results in an increase of the total grain boundary area. This in turn decreases the proportion of the grain boundary area on which Bi is segregated, and therefore, the grain boundary brittleness due to Bi can be inhibited. Further, only making the grains fine decreases the size of the voids which are generated at the triple points of the grain boundaries. Further, it facilitates the recrystallization, and therefore, the ductility can be improved. Making the grains fine for improving the high temperature ductility is made possible by inhibiting the growth of the grains during the reheating.

[0019] Therefore, in the present invention, the reheating temperature is maintained as low as 850 - 1000°C to inhibit the growth of the grains so as to impede the migration of the grain boundaries. Thus the austenite grain size is controlled to lens than 60 μm, and in this way, a free machining steel with a superior high temperature ductility is realized,

[0020] Further, in the present invention, even if the reheating temperature is high, the precipitates such as TiN which are finely existing without being solid-solved at a high temperature are utilized to impede the migration of the grain boundaries. Thus the austenite grain size becomes as small as 60 μm or less, and therefore, there is obtained a Ti-N-added free machining steel with a superior high temperature ductility.

[0021] Second, the superior high temperature ductility can be achieved by adding B. That is, boron (B) which shown a faster diffusion speed than S and Bi is preferably segregated on the grain boundaries. Thus a B-N-added free machining steel is obtained in which the problem of the decrease of the high temperature ductility due to FeS and due to a dissolved Bi is solved.

[0022] Now the reasons for limiting the amounts of the ingredients will be described.

[0023] The content of C has to be 0.05% or more to secure a proper surface roughness and mechanical properties. If the amount of C is more than 0.15%, hard pearlite structures are increased to aggravate the machinability. Therefore the content of C should be preferably limited to a range of 0.05-0.15%.

[0024] The content of Mn should be 0.5% or more, so that a necessary amount of the MnS inclusion can be secured, and that the hot rolling brittleness due to the formation of FeS on the grain boundaries during the hot rolling can be inhibited. However, if its content exceeds 2.0%, the hardness of thus steel increases, and therefore, the machinability is aggravated. Therefore, the Mn content should be preferably limited to 0.5-2.0%.

[0025] The content of P should be 0.01% or more to improve the surface roughness. If its content exceeds 0.1%, the mechanical properties and the cold rollability are aggravated, and therefore its content should be preferably limited to 0.01-0.1%.

[0026] The content of S should be 0.15% or more to form an MnS inclusion, so that the surface roughness can he improved through a growth inhibition of BUE (built-up edge). However, if its content exceeds 0.4%, then the hot rollability and the cold rollability are aggravated. Therefore its content should be preferably limited to 0.15-0.4%.

[0027] The content of O should be 0.003% or more to prevent the dropping of the machinability due to the extension of the MnS inclusions. However, if its content exceeds 0.020%, the plastic deformation of the MnS inclusions cannot be ensured during the machining. Therefore its content should be preferably limited to 0.003-0.020%.

[0028] Bi exists within the steel independently or by being absorbed into MnS. Therefore, during a machining, it acts as a stress concentrating center to decrease the radius of curvature of the chips, and therefore, it improves the handlability of chips. Further, Bi increases the surface areas of the MnS inclusions to ultimately improve the surface roughness of the metal to be machined. Further, Bi is melted by the machining heat, with the result that the frictions between the chips and the tool are decreased, and that the wear of the machining tool is alleviated. Thus, if the content of Bi is less than 0.02%, the machinability is aggravated, while if its content exceeds 0.30%, the hot rollability is aggravated.

[0029] Si forms SiO_2 which in turn forms MnS inclusions and composite inclusions. The plastic deformation of such a composite inclusion is very undesirable. That is, the formation of an MnS inclusion layer on the tip of the tool is impeded, and therefore, a BUE is easily formed, with the result that the surface roughness of the object to be machined is aggravated. Therefore, the content of Si should be maintained as low as possible, such that it should not exceed 0.001%.

[0030] Al forms Al_2O_3, and therefore, MnS inclusions and composite inclusions are apt to be formed. These composite inclusions give very bad influence to the plastic deformation like the SiO_2 composite inclusion, of MnS. Therefore, the formation of an MnS inclusion layer on the tip of a tool is impacted, and thus, a BUE is liable to be formed, with the ultimata result that the surface roughness of the object to be machined is aggravated. Further, Al_2O_3 is very hard, and therefore, it prompts the wearing of the tool. Accordingly, the content of Al should preferably not exceed 0.0009%.

[0031] Ti is solid-dissolved in the steel, or it is bonded with N and C to be precipitated in the form of TiN, Ti(CN) and TiC. They are precipitated at a high temperature in the order of TiN, Ti(CN) and TiC. In other words, TIN is solid-solved at the highest temperature. The exact solid resolution temperature is decided by the solubility product of Ti and N, but it is known that it remain oven at above 1200°C. Therefore, if the growth of the austenite grains in to be inhibited during the reheating, it is advantageous to use TiN which is stable at oven a higher temperature. If the Ti content is loss than 0.02%, it is not effective for the inhibition of the grain growth, because TiN has a low solid resolution temperature. If its content is more than 0.1%, the grains are hardened by TiN although TiN is effective for inhibiting the grain growth. Consequently, the grain boundaries become weak, thereby rather aggravating the high temperature ductility.

[0032] The purpose for adding B is to make B segregated on the grain boundaries so as to delay the speed of the formation of ferrite, thereby improving the hardenability. Therefore, in the plain carbon steel in which MnS is contained not as much as the free-machinable steel, if B is added by 0.0020-0.0030% for the grain boundary segregation, then the quenchability can be improved. However, in the free machining steel which contains 1.6-1.8 vol% of MnS, boron (B) is also segregated on the boundaries between MnS and the matrix structure besides on the grain boundaries. Therefore, B should be contained more in the Bi-S free machining steel compared with the plain carbon steel. That is, if the content of B is less than 0.0050%, the amount of B segregated on the grain boundaries is too insufficient, and therefore, the segregation of Bi and S on the austenite grain boundaries cannot be effectively inhibited. On the other hand, it B is added more than 0.0150%, the B precipitates are formed on the austenite grain boundaries. Therefore, even if Bi, S and the like are not segregated, the austenite grain boundaries become weak, with the result that the high temperature ductility is aggravated.

[0033] In a steel containing Ti, nitrogen (N) is precipitated in the form of TiN and Ti(CN), and therefore it makes the grains fine at a high temperature, while it precipitation-hardens the steel at the normal temperature. Therefore, if TiN is to be utilized to make the grain, fine, a proper amount of N is required. However, if it is too much added, the steel is age-hardened because of potential interactions, and therefore a normal temperature brittleness can be caused. Therefore, the N content should be preferably 0.0030-0.0100%. Meanwhile, in a steel containing B, the added N is precipitated in the form of BN to diminish the effective amount of B which is segregated on the grain boundaries. Therefore, in this case, N should be preferably limited to 0.0070% or less.

[0034] In the steel composed as described above, there are formed metallic Bi inclusions and MnS inclusions with MnS and Bi absorbed into them. Here, the area fraction of the MnS inclusion in which MnS and Bi are absorbed should be preferably 0.5-2.0%. The reason is as follows. That is, if the area fraction of the inclusion is less than 0.5%, the machinability is lowered, and the high temperature brittleness mechanism is shifted from the boundary brittleness between the matrix structure and MnS to a grain boundary brittleness. If it is more than 2.0%, the hot rollability is aggravated. Meanwhile, the area fraction of the metallic Bi inclusion should be preferably 0.030-0.30%, and the reason is as follows. That is, if the area fraction is less than 0.030%, the machinability is lowered, while if it is more than 0.30%, the hot rollability is aggravated. The above mentioned two kinds of inclusions should preferably have a length of 5-20 μm, and a width of 1-10 μm, and the reason is as follows. That is, if the inclusions are too fine, the role as a stress concentration center is diminished so as to deteriorate the machinability. If they are too coarse, the machinability and hot rollability are aggravated. Meanwhile, if the shape ratio (length/width) of the inclusions is too small, the machinability is lowered, while if it is too large, there is the possibility that the stock may be cleaved in the hot rolling direction during the hot temperature deformation. Therefore, the shape ratio should be preferably 1-2.

[0035] Now the manufacturing method for the free machining steel will be described.

[0036] First, the free machining steel manufacturing method based on the adjustment of the reheating temperature will be described.

[0037] First, a free machining steel bloom is prepared in which Ti, B and N are not added. Then a reheating temperature is adjusted to 850 - 1000°C for a hot rolling. If the reheating temperature is below 850°C, the rolling temperature is too low, and therefore, the ductility is lowered. If it exceeds 1000°C, the grains grow too much. Through this temperature adjustment, the austenite grain size is made not to exceed 60 μm. Accordingly, a superior high temperature ductility of over 60% can be secured, and therefore, during the pillet rolling and wire rod rolling later, the surface defects can be prevented. Meanwhile, the above reheating temperature should be preferably maintained for 1 minute or more.

[0038] Now the free machining steel manufacturing method with Ti and N added will be described.

[0039] A free machining steel bloom is prepared in which 0.02-0.1% of Ti and 0.0030-0.0100% of N are added. The bloom is reheated to the usual temperature. Here, even at above 1000°C, it is possible that the austenite grain site can be adjusted to 60 μm or less by the help of precipitates such as insoluble TiN. Therefore, a high temperature ductility of 60% or more can be secured. Accordingly, the rolling temperature for the billet rolling and wire rod rolling to be carried out can be expanded to a range of 850 - 1200°C. The reason for setting the rolling temperature to 850 - 1200°C is as follows. If the rolling temperature is below 850°C, surface defects may be formed during the hot rolling, while if it is above 1200°C, the grain boundaries are partly melted, and therefore, surface defects stay be formed due to the weakness of the grain boundaries.

[0040] Now the free machining steel manufacturing method with B and N added will be described.

[0041] A free machining steel bloom is prepared in which 0.0050-0.015% of B and 0.0070% or less of N are added. Then the bloom is reheated in the usual method, and a billet rolling is carried out at 800 - 1200°C. Then the billet thus obtained is reheated, and a wire rod rolling is carried out at 800 - 1200°C. Thus a free machining steal is obtained in which the high temperature ductility is superior and surface defects are not found. The reason why the billet rolling and the wire rod rolling are carried out at 800 - 1200°C is as follows. That is, if it is below 800°C, then surface defects are liable to occur during the hot rolling, and the rolling load is large so as to require a large scale rolling machine, thereby losing the practicality. If it is above 1200°C, the grain boundaries are partly melted, and therefore, surface detects may be formed due to the weakness of the grain boundaries.

[0042] Now the present invention will be described in detail based on actual examples.

〈Example 1〉

[0043] Test pieces having the compositions am shown in Table 1 below were prepared. Here, the volume fraction of MnS inclusions with MnS and Bi absorbed therein was 1.5-2.0%, while the volume fraction of Bi inclusions was 0.15-0.2%. The inclusions had a length of 5-15 µm and a width of 5-15 µm. The ratio of the width to the length was about 1-2. The area fraction of the Bi inclusions was calculated from a display (200 times-magnified) of a scanning electronic microscope (SEM).

〈Table 1〉

Steel	Chemical composition(wt%)							Area fraction of inclusions(%)		Length(L) and width(W) of inclusions (µm)
	C	Si	Mn	P	S	Bi	T[0]	MnS+Bi	Bi	
	0.084	0.01 or less	1.20	0.08	0.32	0.10	0.011	1.5-2.0	0.15-0.2	L=5-15 W=5-15 L/W=1-2

[0044] A test piece A of Table 1 was reheated at the reheating conditions of Table 2, and tensile strength tests were carried out. The area reductions for the respective temperature were calculated, and the results are shown in table 2 below. Further, the austenite grain sizes were measured, and the results are shown in Table 2 below.

〈Table 2〉

Steel	Reheating conditions		Austenite grain size µm	Area reduction ratio(%)				
	Temp(°C)	Time(min)		800°C	900°C	950°C	1000°C	1100°C
A	1250	3	121	49	38	67	72	83
	1150	3	86	-	46	-	-	-
	1050	3	79	-	47	-	-	-
	900	3	54	-	67	-	-	-
	900	1	52	-	75	-	-	-
	900	10	55	-	68	-	-	-

[0045] As shown in Table 2 above, if the austenite grain size was 121 µm, the area reduction was 60% at 900°C or below. Therefore, if a hot rolling was carried out at 900°C, then surface defects occurred. However, if the reheating temperature was controlled to make the austenite grain sizes as fine as 60 µm or less, then the area reduction was increased to over 60%. Therefore$_1$ surface defects did not occur upon hot-rolling at 900°C, That is, if the austenite grain sizes were controlled according to the present invention, the hot rolling could be carried out at a relatively low temperature of 900°C without causing surface defects.

[0046] In this example, the area reduction was used as the criterium for the quantitative evaluation at the high temperature ductility, and the reason for this will be described below.

[0047] In the case where the area reduction of the high temperature tensile strength test pieces was measured for predicting the hot rolling brittleness, if the fractured stock showing an area reduction of 60% or more was observed, it was found that voids were formed on the boundaries between the matrix structure and the MnS inclusions with Bi and MnS absorbed in them. Further, the voids were accompanied by plastic deformations to be merged with the adjacent other voids, with the result that a ductile fracture occurred. On the other hand, if the fractured stock with an area reduction of 60% or less is observed, there are also formed voids on the austenite grain boundaries between the matrix structure and the MnS inclusions with Bi absorbed therein. However, these voids were not accompanied by plastic deformations, bat directly was led to cracks. These cracks were merged into adjacent other cracks, with the result that brittleness fractures occurred. Further, in the fractured stock showing an area reduction of 60% or less, as the area reduction was diminished, so much the grain boundary fracture ratio was increased. Therefore, the temperature level at which the tensile test piece shows an area reduction of 60% can be adopted as the criterium for the hot rolling brittleness at which surface defects occur. Further, the area reduction can be adopted as the criterium for the quantitative evaluation of the high temperature ductility.

〈Example 2〉

[0048] Test pieces having the compositions as shown in Table 3 below were prepared. Here, the volume fraction of the MnS inclusions with MnS and Bi absorbed therein was 1.5-2.0%, and the volume fraction of the Bi inclusions was 0.10.2%. The length of the inclusions was 5-15 μm, and their width was 5-15 μm, while the ratio of the length to the width was about 1-2. The area fraction of the Bi inclusions was calculated from a display (200 times-magnified) of a scanning electronic microscope (SEM).

[0049] Test pieces of the steels of Table 3 below were subjected to tensile tests at condition. of Table 4 below, The stocks having different austenite grain sizes were put to tensile tests, and thus the area reductions were measured. The results are shown in Table 4 below. As can be seen in Table 4 below, even if the reheating temperature was as high as 1250°C, the growth of the austenite grains was inhibited during the reheating of the steels (with Ti and N adjusted) (steel No. T1, T2 and T4), and therefore, the austenite grain size was 60 μm or less. The area reductions of these steels at 850 - 1000°C were 60% or more. Therefore there is no apprehension that surface defects may occur during a hot rolling. However, even in the steels with Ti added therein, the steel with a low content of N (steel No. T3) does not show the precipitation of TiN which inhibits the growth of the austenite grains. Therefore, in this steel, the austenite grain size was 85 μm, and the area reduction at 850 - 1000°C was 60% or lees, with the result that surface defects should occur in this temperature range.

<Table 3>

Steel	Chemical composition(wt%)									Area fraction (%)		Length(L) and width(W) of inclusion (μm)
	C	Si	Mn	P	S	Bi	T[O]	Ti	N	MnS+Bi	Bi	
T0	0.084	0.01 or less	1.20	0.08	0.32	0.10	0.0110	-	-	1.5-2.0	0.15-0.2	L = 5-15 W = 5-15 L/W = 1-2
T1	0.099	"	1.25	0.08	0.27	0.099	0.0100	0.021	0.0048			
T2	0.095	"	1.24	0.06	0.29	0.10	0.0095	0.025	0.0050			
T3	0.10	"	1.24	0.08	0.28	0.096	0.0097	0.034	0.0005			
T4	0.091	"	1.25	0.09	0.30	0.11	0.0105	0.050	0.0056			
T5	0.091	"	1.27	0.08	0.29	0.10	0.0102	0.12	0.0060			

〈Table 4〉

Steel	Reheating conditions		Austenite grain size (μm)	Area reduction ratio(%)					
	Temp(°C)	Time (min)		800°C	850°C	900°C	950°C	1000°C	1100°C
T0	1250	3	121	49	45	38	67	72	83
T1			59	44	63	81	87	88	90
T2			60	43	60	77	84	86	87
T3			85	42	40	43	50	56	75
T4			55	45	60	75	80	82	85
T5			54	41	39	40	45	55	60

[0050] Even if the N concentration was adjusted, and even if the TiN precipitates make the austenite grains fine to as low as 54 μm in the steel with an excessive content of Ti (steel No. T5), the strength of the grains is too high as against the grain boundaries due to the excessive precipitation of TiN. Therefore, the area reduction at 850 - 1000°C was 60% or less, and therefore, surface defects should occur during a hot rolling. Further, in the case of the steels without any addition of Ti and N (Steel No. T0), the area reduction at 850 - 950°C was 60% or less, and therefore, surface defects should occur during a hot rolling. Accordingly, it can be seen that only the steels (steel No. T1, T2 and T4) with proper amount of Ti and N added therein can retain a superior high temperature ductility not only above 1000°C but also in a relatively low temperature range of 850 - 1000°C.

〈Example 3〉

[0051] Steel test pieces having compositions of Table 5 below were subjected to tensile tests. Then the area reductions were measured, and the results are entered in Table 6 below.

[0052] As can be seen in Tables 5 and 6, in the case of the inventive steels (1-3), B was segregated on the grain boundaries to inhibit the segregation of Bi and S. Therefore, the area reduction was more than 70%, and thus the high temperature ductility was superior. Therefore, There is no apprehension that there will formed surface defects. On the other hand, in the case of the comparative steel (1) without any content of B, the area reduction at 800 - 950°C was 60% or less, and thus a hot rolling brittleness occurred, with the result that the high temperature ductility was aggravated. Even if B was added, in the case of the comparative steels (2-3) with a low content of B, the amount of B segregated on the austenite grain boundaries was very small, and therefore, the area reduction at 800 - 900°C was 60% or less. Therefore, a high temperature ductility could not be secured as much as to inhibit the hot rolling brittleness. Meanwhile, in the case of the comparative steel (4) with too high a B concentration, B was segregated too much on the grain boundaries, and therefore, the area reduction at 900°C or above was 60% or less, thereby aggravating the high temperature ductility. Thus the inventive steels with a proper content of B showed a more superior high temperature ductility at 800 - 1000°C compared with the comparative steels with no content of B, thereby excluding the possibility of occurrence of surface defects during a hot rolling.

[0053] Meanwhile, the inventive steels (1-3) with B added therein will be compared with the comparative steel (1) without addition of B. It can be seen that the inventive steels (1-3) have a far more superior high temperature ductility compared with the comparative steel(1) even at a relatively high rolling temperature. For example, within a hot rolling temperature range of 1000 - 1100°C, the area reduction of the inventive steels (1-3) was 90% or mare whereas the comparative steel (1) shows 90% or less.

[0054] Thus compared with the comparative steel without a B content, the inventive steels with a proper content of B are superior in the high temperature ductility not only at a high temperature of above 1000°C but also at a relatively low rolling temperature of 800 -1000°C.

<Table 5>

Steels		Chemical compositions(wt%)										Area fraction of inclusions		Length(L) and width (W) of inclusions
		C	Si	Mn	P	S	Bi	T[O]	Al	B	N	MnS+Bi	Bi	
Compara-tive Steels	1	0.084	0.009	1.20	0.08	0.32	0.10	0.0110	0.0007	-	0.0062			
	2	0.099	0.008	1.25	0.08	0.27	0.10	0.0100	0.0007	0.0031	0.0048			
	3	0.108	0.007	1.24	0.06	0.29	0.10	0.0095	0.0007	0.0040	0.0050			
Inven-tive Steels	1	0.099	0.007	1.24	0.08	0.28	0.10	0.0097	0.0007	0.0050	0.0005	1.5-2.0	1.15-0.2	L:5-15 W:5-15 L/W:1-2
	2	0.10	0.008	1.25	0.09	0.30	0.11	0.0105	0.0007	0.0086	0.0056			
	3	0.07	0.007	1.28	0.08	0.29	0.10	0.0102	0.0007	0.0121	0.0060			
Compara-tive Steels	4	0.1	0.005	1.28	0.07	0.28	0.13	0.0098	0.0007	0.0190	0.0054			
The area fractions of inclusions were calculated from a display(200 times-magnified) of a scanning electronic microscope(SEM).														

〈Table 6〉

Steels		Reheating conditions		Area reduction at different temp(%)				
		Temp(°C)	Time(min)	800°C	900°C	950°C	1000°C	1100°C
Comparative Steels	1	1250	3	49	38	67	72	83
	2			44	39	65	70	85
	3			45	66	81	86	88
Inventive Steels	1			78	86	90	92	90
	2			75	90	92	93	92
	3			70	86	91	90	93
Comparative Steels	4			30	20	25	20	40

〈Example 4〉

[0055] Steel pieces having compositions as shown in Table 5 of Example 3 were reheated at 1250°C for 3 hours. Then a hot rolling was carried out at the temperatures of Table 5, then the presence degree of the surface defects were checked, and the results are shown in Table 7 below.

[0056] As shown in Table 7 below, when the comparative steels (1-2) were hot-rolled at 800 - 950°C, surface defects were found. In the case of the inventive steels (1-3), however, no surface defects were found even at a low temperature of about 800°C.

⟨Table 7⟩

Steels		Reheating conditions		Presence of surface defects				
		Temp (°C)	Time (min)	800°C	900°C	950°C	1000°C	1100°C
Comparative Steels	1	1250	3	X	X	○	○	○
	2			X	X	○	○	○
	3			X	○	○	○	○
Inventive Steels	1			○	○	○	○	○
	2			○	○	○	○	○
	3			○	○	○	○	○
Comparative Steels	4			X	X	X	X	X

○:surface defects absent,
X:surface defects present

[0057] According to the present invention as described above, a free machining Bi-S steel with a superior high temperature ductility is provided. This free machining steel can be rolled even at a relatively low temperature without causing surface defects, and therefore, the productivity is improved,

Claims

1. A Bi-S free machining steel with a superior high temperature ductility, comprising: in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, and a balance of Fe and other unavoidable impurities; an MnS inclusion with MnS and Bi absorbed into it; and a metallic Bi inclusion.

2. The Bi-S free machining steel as claimed in claim 1, wherein the MnS inclusion with MnS and Bi absorbed therein has an area fraction of 0.5-2.0%, the metallic Bi inclusion has an area fraction of 0.030-0.30%, and the two inclusions have a length of 5-20 μm and a width of 1-10 μm.

3. A method for manufacturing a Bi-s free machining steel with a superior high temperature ductility, comprising the steps of:

   preparing a bloom having a composition of (in wt%) 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, and a balance of Fe and other unavoidable impurities;
   reheating the bloom to 850 - 1000°C so as to make austenite grain size not exceed 60 μm;
   carrying out a billet-rolling to form a billet;
   reheating the billet to 850 - 1000°C again so as to make austenite grain size not exceed 60 μm; and
   carrying out a wire rod rolling.

4. A Bi-S free machining steel with a superior high temperature ductility, comprising: in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, 0.02-0.1% of Ti, 0.0030-0.0100% of N, and a balance of Fe and other anavoidable impurities; an MnS inclusion with MnS and Bi absorbed into it; and a metallic Bi inclusion.

5. The Bi-S free machining steel as claimed in claim 4, wherein the MnS inclusion with MnS and Bi absorbed therein has an area fraction of 0.5-2.0%, the metallic Bi inclusion has an area fraction of 0.030-0.30%, and the two inclusions have a length of 5-20 μm and a width of 1-10 μm.

6. A method for manufacturing a Bi-S free-machinable steel with a superior high temperature ductility, comprising the steps of:

preparing a bloom having a composition of (in wt%) 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, 0.02-0.1% of Ti, 0.0030-0.010% of N and a balance of Fe and other unavoidable impurities;

reheating the bloom to carry out a billet-rolling at 850 - 1200°C so as to form a billet; and
reheating the billet to carry out a wire rod rolling at 850 - 1200°C.

7. The method as claimed in claim 6, wherein the billet rolling and the wire rod rolling are carried out at 850 - 1000°C to prevent surface defects.

8. A Bi-S free machining steel with a superior high temperature ductility, comprising: in wt%, 0.05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% at S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, 0.0070% or less of N, 0.0050-0.0150% of B, and a balance of Fe and other unavoidable impurities; an MnS inclusion with MnS and Bi absorbed into it; and a metallic Bi inclusion.

9. The Bi-S free-machinable steel as claimed in claim 8, wherein the MnS inclusion with MnS and Bi absorbed therein has an area fraction of 0.5-2.0%, the metallic Bi inclusion has an area fraction at 0.030-0.30%, and the two inclusions have a length of 5-20 μm and a width of 1-10 μm.

10. A method for manufacturing a Bi-S free machining steel with a superior high temperature ductility, comprising the steps of:

preparing a bloom composed of in wt%, 0,05-0.15% of C, 0.5-2.0% of Mn, 0.15-0.40% of S, 0.01-0.10% of P, 0.003-0.020% of O, 0.03-0.30% of Bi, 0.01% or less of Si, 0.0009% or less of Al, 0.0070% or less of N, 0.0050-0.0150% of B, and a balance of Fe and other unavoidable impurities;
reheating the bloom to carry out a billet-rolling at 800 - 1200°C so as to form a billet; and
reheating the billet to carry out a wire rod rolling at 800 - 1200°C.

11. The method as claimed in claim 10, wherein the billet rolling and the wire rod rolling are carried out at 800 - 1000°C to prevent surface defects.

12. The method as claimed in claim 10, wherein the billet rolling and the wire rod rolling are carried out at 1000 - 1100°C to increase an area reduction to 90% or more.