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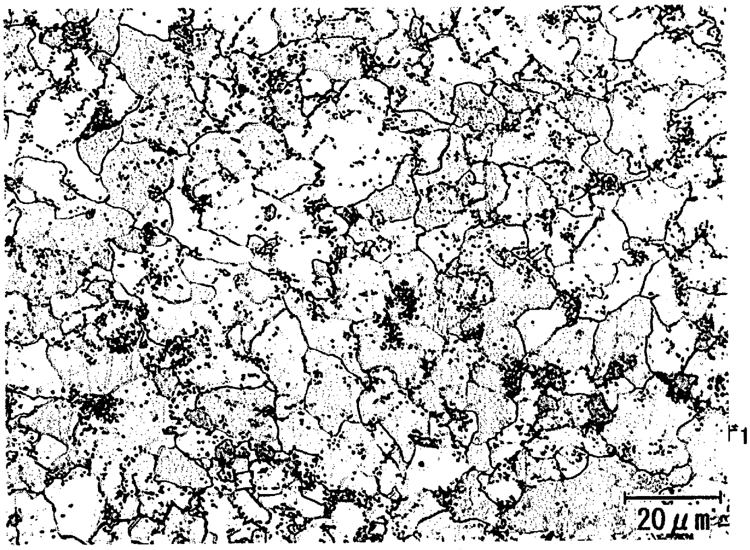
(54) **CASE-HARDENED STEEL PIPE EXCELLENT IN WORKABILITY AND PROCESS FOR PRODUCTION THEREOF**

(57) A case hardening steel tube which has a hardness of 72 - 80 HRB and which gives a carburized layer with a high strength and high wear resistance and adequate resistance to impact fracture when it is formed into a final product by working and subsequent carburizing and quenching under relatively mild conditions is manufactured by forming a tube from a steel having a steel composition comprising, in mass percent, C: 0.1 - 0.25%, Si: 0.2 - 0.4%, Mn: 0.3 - 0.9%, P: at most 0.02%, S: 0.001 - 0.15%, Cr: 0.5 - 0.9%, Mo: 0.15 - 1%, Al: 0.01 - 0.1%, B: 0.0005 - 0.009%, N: less than 0.006%, and a remainder essentially of Fe, then subjecting the resulting steel tube to normalizing by soaking at a temperature of 880 - 980 °C followed by cooling at a cooling rate of at most 70 °C per minute, carrying out cold working of the normalized steel tube, and then annealing the cold worked steel tube at a temperature of 700 - 820 °C.

Fig. 1



Description

Technical Field

[0001] This invention relates to a case hardening steel tube (a steel tube made from case hardening steel) having a high strength and a high toughness and exhibiting a high fracture load after carburizing and quenching, and to a process for its manufacture. In particular, this invention relates to a case hardening steel tube having improved workability and a process for its manufacture.

Background Art

[0002] From in the past, case hardening steel has been used for the manufacture of various types of structural parts for use in automobile or industrial machinery and particularly surface-hardened parts typified by shafts, CVJs (constant velocity joints), CVTs (continuously variable transmissions), and gears. Case hardening steel which is a material to be worked is formed into a part having a desired shape by hot or cold forging and machining, for example. The part which has been formed is then subjected to surface hardening treatment such as carburizing or carbo-nitriding in order to increase its wear resistance and fatigue strength.

[0003] The level of performance demanded of such structural parts for machinery are becoming increasingly higher. Namely, they are demanded to have, in addition to high surface hardness and high bending fatigue strength after carburizing and quenching which were demanded in the past, further improvement in wear resistance and rolling fatigue properties as well as a still higher level of resistance to impact fracture and toughness when an impact load is applied.

[0004] Case hardening steel sometimes has problems such as a decrease in impact fracture strength, a decrease in fatigue properties, and a decrease in dimensional accuracy due to abnormal growth of crystal grains during carburizing and quenching treatment. In particular, if so-called high temperature carburizing which is carried out in the temperature range of 990 - 1090 °C is employed in order to shorten the carburizing time from the viewpoint of rationalization of carburizing treatment, the problem occurs that coarse grains develop, thereby making it impossible to obtain the desired fatigue properties such as rolling fatigue properties.

[0005] JP 2005-240175 A1 (Patent Document 1) proposes suppressing the formation of coarse grains during high temperature carburizing of case hardening steel by controlling the steel composition and the formation of Ti-containing precipitates.

[0006] A steel which can form a carburized layer having a high strength and good wear resistance by carburizing and quenching under relatively mild conditions without employing high temperature carburizing has also been studied. JP H09-53150 A1 (Patent Document 2) discloses a high-strength, high-toughness case hardening steel exhibiting a sufficiently high impact fracture load even when a notch is present in the carburized surface and a process of manufacturing a high-strength, high-toughness case hardening steel tube exhibiting improved workability and improved impact fracture strength after carburizing and quenching from this steel.

[0007] According to Patent Document 2, one of the causes of the problems of the prior art is the formation of an imperfect hardened structure. The major cause of the formation of this imperfect hardened structure is the precipitation of carbides along austenite grain boundaries which occurs at the time of quenching of a carburized steel. Therefore, a steel composition design is employed in which B is added in order to prevent the above-described precipitation of carbides while N is reduced as much as possible so that B can adequately exhibit its effects.

[0008] The high-strength, high-toughness case hardening steel tube disclosed in Patent Document 2 has excellent properties particularly in the form of seamless steel tube of case hardening steel. However, since it has a relatively high hardness, problems sometimes develop with respect to workability, for example, at the time of forging by a user.

[0009] With respect to a process of manufacturing a case hardening steel tube, Patent Document 2 discloses (i) a process in which a steel tube obtained by hot tube forming is subjected to cold working followed by stress relief annealing (Example 3), and (ii) a process in which a steel tube obtained by hot tube forming is subjected to initial annealing followed by cold working and subsequent stress relief annealing (secondary annealing) (Examples 4 and 5).

Patent Document 1: JP 2005-240175 A1
Patent Document 2: JP H09-53150 A1

Disclosure of Invention

[0010] The present invention provides a case hardening steel tube which has good workability or more specifically an HRB hardness (Rockwell B scale hardness) of 72 - 80 and which can form a carburized layer of high strength and good wear resistance as well as sufficiently improved resistance to impact fracture when it is formed into a final product by working for forming followed by carburizing and quenching under relatively mild conditions, along with a process for its manufacture.

[0011] The present invention is based on the following findings.

(1) By the heat treatment methods described in Patent Document 2 which are performed after hot tube forming, notwithstanding annealing which is carried out after cold working, the hardness of the tube often reaches at least 85 HRB, which is too high to enable the user to easily fabricate parts therefrom by forming or working.

(2) Particularly in above-described process (ii) disclosed in Patent Document 2 in which initial annealing is carried out prior to cold working, if the temperature at this annealing stage is around 700°C, even if secondary annealing is carried out under the conditions described in Patent Document 2 after cold working, it is difficult to soften the steel. In this case, if the secondary annealing temperature is around 730 °C, a bainite structure is formed.

(3) In the process described in (2) above, if the heat treatment temperature in the secondary annealing after cold working is increased to around 930 °C and then gradual cooling is performed, the steel can be softened to around 75 HRB.

However, under such temperature condition, the effect of cold working disappears due to the phase transformation in a region higher than the Ac_3 point. Thus, the hardness can no longer be freely controlled within the range of 72 - 80 HRB by appropriately selecting the degree of cold working and the heat treatment conditions in secondary annealing. In addition, the high temperature heating after cold working causes a decrease in dimensional accuracy and sometimes surface decarburization. The steel structure is a ferrite + pearlite structure, and coarsening of crystal grains easily occurs.

(4) Patent Document 2 gives 870 °C as a specific temperature for initial annealing before cold working. In this heat treatment condition, the steel is once heated to a temperature higher than the Ac_3 point, so the steel structure after initial annealing becomes a ferrite + pearlite structure. However, because the initial annealing temperature is low, softening of the steel cannot be expected in secondary annealing after cold working if the annealing is carried out by gradual cooling over a sufficient length of time.

(5) In contrast to the process disclosed in Patent Document 2, if heat treatment before cold working is carried out by normalizing at a temperature of at least 880 °C (with a cooling rate of 70 °C per minute or lower) followed by cold working preferably with a reduction in area of 20 - 50% and subsequent annealing at a temperature of 700 - 820 °C, pearlite is partially spheroidized. "Spheroidizing of pearlite" as used herein means that cementite phases present in pearlite are spheroidized. As a result of the spheroidizing, a desired decrease in hardness can be achieved. In addition, the hardness can be controlled by adjusting the cooling rate after heating for normalizing and the temperature of secondary annealing, and preferably by also adjusting the reduction in area during cold working.

[0012] Thus, in the present invention, a steel tube manufactured by hot tube forming and having a steel composition which makes it possible to carburizing and quenching to perform thereon is subjected initially to normalizing, then to cold working and subsequently to stress relief annealing. During the annealing, at least a portion of the pearlite in the ferrite + pearlite structure resulting from normalizing is spheroidized (namely, cementite in the pearlite is spheroidized), leading to softening of the steel, and a case hardening steel tube having excellent workability is manufactured in this manner.

[0013] In the present invention, a ferrite + pearlite structure is formed during normalizing, and this structure is subjected to subsequent steps of cold working and annealing. By adjusting the reduction ratio in cold working and the heat treatment conditions in annealing, the proportion of pearlite which is spheroidized during annealing can be varied. In this manner it is possible to perform fine adjustment of the steel hardness.

[0014] According to one aspect, the present invention is a process for manufacturing a case hardening steel tube characterized by forming a tube from a steel having a steel composition comprising, in mass percent, C: 0.1 - 0.25%, Si: 0.2 - 0.4%, Mn: 0.3 - 0.9%, P: at most 0.02%, S: 0.001 - 0.15%, Cr: 0.5 - 0.9%, Mo: 0.15 - 1%, A1: 0.01 - 0.1%, B: 0.0005 - 0.009%, N: less than 0.006%, and a remainder essentially of Fe, subjecting the resulting steel tube to normalizing by holding at a temperature of 880 - 980 °C followed by cooling at a cooling rate of at most 70 °C per minute in a temperature range of 880 - 400 °C, performing cold working on the normalized steel tube, and then annealing the cold worked steel tube at a temperature of 700 - 820 °C.

[0015] From another standpoint, the present invention is a cold finished, case hardening steel tube characterized by having a steel composition comprising, in mass percent, C: 0.1 - 0.25%, Si: 0.2 - 0.4%, Mn: 0.3 - 0.9%, P: at most 0.02%, S: 0.001 - 0.15%, Cr: 0.5 - 0.9%, Mo: 0.15 - 1%, A1: 0.01 - 0.1%, B: 0.0005 - 0.009%, N: less than 0.006%, and a remainder essentially of Fe, and having a steel structure which is a mixed ferrite + pearlite + spheroidized cementite structure or a mixed ferrite + spheroidized cementite structure.

[0016] The above-described steel composition may further contain one or more elements selected from the following (1) and (2):

(1) in mass percent, Ni: 0.3 - 4.0%

(2) in mass percent, one or more elements selected from Ti: 0.01 - 0.3%, Nb: 0.01 - 0.3%, V: 0.01 - 0.3%, and Zr: 0.01 - 0.3%.

[0017] In the above-described steel composition, the B content is preferably B: 0.0005 - 0.003%.

[0018] "Case hardening steel" and "case hardening steel tube" refer to steel and steel tube which undergo working to form a prescribed shape of a product (such as the above-described structural part of machinery) and finally carburizing and quenching to form a harder surface skin layer (carburized layer) before being used as a product. Of course, the above-described hardness is the hardness of the case hardening steel, i.e., the hardness before the steel undergoes working to be formed into the shape of a part (of course, the hardness prior to carburizing and quenching). Forming into the prescribed shape of a product and carburizing and quenching are normally carried out by the customer (by the user).

[0019] "A remainder essentially of Fe" means that the remainder may contain unavoidable impurities.

Brief Description of the Drawings

[0020]

Figure 1 is a photograph showing the microstructure of a case hardening steel tube according to the present invention produced in an example.

Best Mode for Carrying out the Invention

[0021] The reasons why the steel composition of a case hardening steel tube according to the present invention is limited as described above will be explained together with the effect of each element. In this description, percent with respect to the steel composition means mass percent.

C:

[0022]

C is a basic element for steel to develop its hardness and strength. A hardness of at least 250 Hv is necessary in order to provide steel with such a strength that it will not deform during use of a carburized and quenched product. In order to obtain this necessary hardness, the C content is made at least 0.1 %. If C is contained in excess of 0.25%, the toughness of the central portion of steel deteriorates. Accordingly, the C content is 0.1 - 0.25% and preferably 0.12 - 0.20%.

Si:

[0023]

The effect of Si of increasing the hardenability of steel is positively utilized in order to achieve a high resistance to impact fracture by hardening of a carburized layer. If the Si content is less than 0.2%, it is not possible to provide a carburized layer with the desired high hardenability. On the other hand, if Si is contained in excess of 0.4%, embrittlement of grain boundaries due to oxidation of Si in the vicinity of the grain boundaries at the time of carburizing becomes marked. Therefore, the Si content is 0.2 - 0.4%.

Mn:

[0024]

Mn is also added in order to increase the hardenability of a carburized layer and realize a high resistance to impact fracture. If the Mn content is reduced to less than 0.3%, the hardenability of a carburized layer decreases, and the desired high resistance to impact fracture cannot be achieved. It has been found that embrittlement of grain boundaries due to oxidation of Mn in the vicinity of grain boundaries at the time of carburizing is not a problem from a practical standpoint even if the Mn content exceeds 0.9%. However, if Mn is contained in excess of 0.9%, a deterioration in blankability and grindability becomes marked. Properties such as blankability and grindability are particularly important for efficient processing of CVJs and the like. Accordingly, the Mn content is 0.3 - 0.9%.

P:

[0025]

P markedly accelerates embrittlement of grain boundaries due to precipitation of cementite on austenite grain boundaries at the time of carburizing and quenching. Therefore, it is an extremely harmful impurity in case hardening steel. Accordingly, the P content is preferably reduced as much as possible. However, because reducing P increases the cost of raw materials and the cost of refining processes, the permissible level of P is determined by balancing the desired properties and cost. Taking into consideration the below-described effect of B, the upper limit on the allowable P content in the present invention is 0.02%.

S:

[0026]

S causes a deterioration in the toughness of steel, but at the same time it improves machinability (grindability and blankability). From this standpoint, it is an element which is preferably deliberately added. If the S content is less than 0.001 %, its effect on improving machinability is not significant, while if S is contained in excess of 0.15%, the deterioration in the toughness of steel becomes marked. Therefore, the S content is 0.001 - 0.15%. In applications where a high level of machinability is not required, it is advantageous to suppress the S content to a low value.

Cr:

[0027]

Cr is an indispensable element for providing the base metal of steel (the steel in the portion excluding the carburized layer on the surface) with hardenability and for achieving the carbon concentration necessary in the carburized layer in a short length of time. For this purpose, it is necessary for the Cr content to be at least 0.5%. At the same time, Cr markedly promotes embrittlement of grain boundaries due to precipitation of cementite on austenite grain boundaries at the time of carburizing and quenching. Therefore, its content is restricted to at most 0.9%. However, if the Cr content is limited to at most 0.9%, the hardenability of steel and particularly the hardenability of a carburized layer having an increased C content becomes inadequate. Therefore, in the present invention, hardenability is supplemented by adding B, Mo, and Ni which do not lead to embrittlement of grain boundaries. Thus, the Cr content is 0.5 - 0.9% but preferably it is adjusted to 0.5 - 0.65%.

Mo:

[0028]

Mo is an essential element for increasing the strength and toughness of the steel base metal and a carburized layer and for achieving a carbon concentration necessary in the carburized layer in a short length of time. The effect of Mo on increasing hardenability is almost unaffected by the C content of the steel base metal. Therefore, its effect of increasing hardenability can be stably exhibited even with a carburized layer having an increased carbon content.

[0029] As described above, in the present invention, the Cr content is limited in order to suppress embrittlement of grain boundaries resulting from carburizing, and hardenability is supplemented by the addition of B. In such a steel, hardenability markedly decreases even if the carbon content reaches a high level, so supplementing hardenability of a carburized layer by addition of Mo is extremely important. If the Mo content is less than 0.15%, not only can hardenability not be adequately supplemented, but the amount of carbon which penetrates into the surface layer during carburizing treatment performed in a short length of time also decreases. From the standpoint of imparting the above-described effect, it is preferable for the Mo content to be large. However, a sufficient effect is obtained with addition of up to 1% of Mo, and addition of Mo in excess of this amount is inadvisable from the standpoint of economy. Accordingly, the Mo content is 0.15 - 1%, preferably 0.2 - 0.7%, and more preferably 0.2 - 0.6%.

A1:

[0030]

A1 is an element which is effective for deoxidation and crystal grain refinement of steel. Its effects are inadequate if its content is less than 0.01%. On the other hand, if A1 is contained in excess of 0.1%, the amount of inclusions which are harmful to toughness increases. Accordingly, the A1 content is 0.01 - 0.1 %.

B:

[0031]

B suppresses precipitation of carbides (Cr carbides and the like) on austenite grain boundaries which form at the time of hardening of a carburized material, thereby preventing the formation of an imperfectly hardened structure in the resulting carburized layer and also preventing grain boundary embrittlement. Therefore, it is an indispensable element for achieving adequate properties in terms of resistance to impact fracture, wear resistance and rolling fatigue properties in a carburized and quenched steel. In particular, in the present invention, the Cr content is restricted in order to prevent the adverse effect of Cr of markedly promoting embrittlement in grain boundaries due to precipitation of carbides on grain boundaries at the time of carburizing and quenching. B also serves to compensate for the decrease in hardenability of the steel base metal caused by decreasing the Cr content and thereby provide the central portion of steel with sufficient hardenability.
If the B content is less than 0.0005%, the above-described desired effects of B are not achieved. On the other hand, if B is contained in excess of 0.009%, it ends up causing grain boundary embrittlement. Therefore, the B content is 0.0005 - 0.009%.

[0032] In the present invention, as described above, heat treatment (normalizing) is carried out before cold working at a temperature of at least the Ac_3 point and specifically at a temperature of at least 880 °C. This heat treatment is contemplated that B is once solutionized in order to achieve the object of decreasing hardness by annealing which is carried out after cold working. If the amount of B is too large, a long time is required for solutionize B and accordingly a long time is required in heat treatment for normalizing. Therefore, the B content is preferably on the lower side of the above-described range. Specifically, it is particularly desirable for the B content to be at most 0.003% (namely, in the range of 0.0005 - 0.003%).

N:

[0033]

As stated in Patent Document 2, the amount of N in steel is extremely important in making the effect of B significant. Namely, the effect of preventing carbide precipitation on grain boundaries during quenching of a carburized steel which is achieved by the addition of B becomes marked only when the amount of N in steel is reduced to a range of less than 0.006%. In this range, not only is a sufficient resistance to impact fracture achieved, but rolling fatigue properties are also markedly improved. The N content in steel is preferably as low as possible, but in industrial production in air, it is extremely difficult to make the N content less than 0.001 % with current steel manufacturing technology.

Ni:

[0034]

When a case hardening steel tube according to the present invention is used as an inner race or a ball cage or the like of a common drive shaft joint for automobiles, it has adequate strength and toughness even if addition of Ni or below-described Ti, Nb, V, or Zr does not take place. However, when it is used in applications having more severe conditions, addition of one or more of these elements is effective at increasing the strength and toughness of steel.
Ni is an element which is effective at increasing the strength and toughness of the steel base metal. In addition, it acts together with Mo to greatly contribute to an increase in strength and toughness of a carburized layer. If the Ni content is less than 0.3%, the above-described effects are inadequate. On the other hand, ifNi is contained in excess of 4.0%, its effects saturate. Accordingly, when Ni is added, its content is 0.3 - 4.0%.
Ti, Nb, V, and Zr:
These elements have the effect of refining the crystal grains of steel and increasing its toughness. Accordingly, preferably one or more of these elements are added when severe conditions of use are expected. If the content of any of these elements which is added is less than 0.01 %, the above-described effect is inadequate. On the other hand, if any of these elements is contained in excess of 0.3%, it leads to worsening in the toughness and rolling

fatigue properties of steel. Accordingly, the content of any of Ti, Nb, V, and Zr, when added, is 0.01 - 0.3%.
Next, the manufacturing conditions for a case hardening steel tube according to the present invention will be explained in the order in which the steps are performed.
Tube forming:

A mother tube is manufactured from steel (case hardening steel) having the above-described steel composition using a suitable tube forming process. The mother tube is preferably a seamless steel tube prepared by hot tube forming. However, as stated below, at the time of normalizing, heat treatment is performed at a temperature which is equal to or higher than the Ac_3 point of the steel, so the working history in prior steps has no influence of the tube product. Accordingly, there is no particular limitation on the tube forming process. For example, it is possible to use an electric resistance welded steel tube as a mother tube. When a seamless steel tube is used, there is no particular restriction on hot tube forming of the seamless steel tube. For example, a seamless steel tube can be manufactured from steel having the above-described steel composition by preparing a billet from a bloom by means of hot forging, and subjecting the billet sequentially to Mannesmann piercing rolling, elongation rolling with a mandrel mill, and sizing rolling.

Normalizing:

A steel tube (mother tube) which is manufactured by the above-described process or other process is subjected to normalizing prior to cold working instead of to initial annealing as disclosed in Patent Documents 1 and 2. Normalizing is carried out by, for example, heating the steel tube in a suitable heating furnace to hold it at a prescribed temperature for heat treatment (soaking or isothermal heating) followed by cooling. The object of this normalizing treatment is to transform the structure of the steel into a mixed structure of ferrite + pearlite. If the steel structure is once made ferrite + pearlite, it is possible to develop properties desirable for a case hardening steel tube by cold working and subsequent annealing in a specified temperature range.
The heat treatment temperature for normalizing is at least 880 °C and at most 980 °C. If the heat treatment temperature exceeds 980 °C, decarburization may proceed. The lower limit of 880 °C is the temperature necessary for dissolving B in solid solution (i.e., for solutionizing B) into austenite in a short period of time so as to obtain a uniform structure. The hardness of the steel base metal can be decreased by dissolving B in solid solution. If the heat treatment temperature at the time of normalizing is lower than 880 °C, adequate dissolving of B in solid solution cannot be achieved, and a decrease in the hardness of the steel base metal is not obtained even if the heat treatment temperature is maintained for a long period.
The duration of soaking may be as short as 30 seconds if the entire part of the steel tube can reach the above-described temperature. However, at least one minute is preferable from the standpoint of minimizing variations in properties. If the duration of soaking exceeds 30 minutes, decarburization may proceed, so it is preferably at most 30 minutes.
Cooling after heat treatment (soaking) may be air cooling, but in the range from the heat treatment temperature to 400 °C (and accordingly at least in the range of 800 - 400 °C), the cooling rate is made at most 70 °C per minute. A cooling rate higher than this causes bainite to form, and the effects of the present invention can no longer be obtained. There is no particular lower limit on the cooling rate as long as it is at least the rate achieved by air cooling in view of the type of heat treatment which is normalizing. Taking into consideration the efficiency such as the treatment time, the cooling rate is preferably at least 20 °C per minute.

Cold working:

The steel tube obtained by hot tube forming undergoes cold working after it has been subjected to normalizing. Cold working is generally necessary in order to provide a steel tube with prescribed dimensions and dimensional accuracy. In the present invention, cold working is also effective at causing spheroidizing of the cementite present in pearlite (and accordingly spheroidizing of pearlite) in a secondary heat treatment stage by annealing which is carried out after the cold working.
There is no particular limitation on a means for carrying out cold working, and cold drawing, cold rolling, and the like can be used. The reduction ratio at the time of cold working is preferably such that the reduction in area is 20 - 50% and more preferably 25 - 50%. If the reduction ratio is less than 20%, it becomes difficult to spheroidize a portion of pearlite in the next step. If the reduction ratio exceeds 50%, seizing may occur at the time of working between the tools used and the material being worked. In addition, due to an increase in the accumulation of strains in the steel base metal, abnormal growth of austenite crystal grains occurs at the time of carburizing heat treatment, thereby causing the resulting hardened structure to be coarsened and become a mixed grain structure. Furthermore, if the reduction ratio of cold working exceeds 50%, the steel tube after working has a

markedly increased hardness due to work hardening, and during subsequent annealing it is difficult to be softened adequately, leading to worsening in the workability.

Annealing:

Annealing after cold working is commonly carried out in order to release strains which accumulated in the steel base metal due to cold working and soften the steel base metal and achieve the workability demanded by the user. In the present invention, it also has the object of spheroidizing at least a portion of the cementite in pearlite. With this object, the annealing temperature after cold working is in the range of 700 - 820 °C. If the annealing temperature is less than 700 °C or if it exceeds 820 °C, spheroidizing of pearlite does not adequately proceed.

[0035] If all of the pearlite (the cementite in the pearlite) is spheroidized by annealing, the steel structure becomes a mixed structure of ferrite + spheroidized cementite. On the other hand, when only a portion of the pearlite is spheroidized, the steel structure becomes a mixed structure of ferrite + pearlite + spheroidized cementite. A case hardening steel tube according to the present invention can be characterized by this steel structure and the above-described steel composition.
[0036] Spheroidizing at least a portion of pearlite in this manner results in a decrease in the hardness of the steel tube. By combining this effect with the softening produced by annealing, a case hardening steel tube having good workability in the form of a hardness of 72 - 80 HRB can be manufactured according to the present invention. The hardness can be adjusted to a desired value by varying the proportion of pearlite which is spheroidized during annealing by controlling the reduction ratio at the time of cold working and the annealing conditions.
[0037] As stated above, when a part is manufactured from a case hardening steel by a user, carburizing and quenching are normally carried out by the user after fabrication of the part by working or forming. There is no restriction on the conditions for part fabrication or carburizing and quenching when manufacturing a part from a case hardening steel tube according to the present invention. However, since it is possible to employ relatively mild carburizing and quenching conditions, it is preferable to do so. By way of example, carburizing and quenching conditions are carburizing by soaking at 920 °C for 2 hours and then quenching from 870 °C.
[0038] The following examples are intended to illustrate the present invention and not intended to limit the present invention in any way. One skilled in the art can make various modifications within the scope of the present invention.

Examples

[0039] One-ton blooms having the steel compositions shown in Table 1 were produced by casting molten steel obtained by vacuum melting. The blooms underwent hot forging to obtain round billets, which were then underwent hot tube forming by piercing rolling, elongation rolling in a mandrel mill, and sizing rolling in a stretch reducer to produce mother tubes (steel tubes) with an outer diameter of 80 mm and a wall thickness of 6.1 mm.
[0040] The steel tubes were subjected to initial heat treatment (normalizing) under the conditions shown in Table 2 followed by cooling, and they then underwent cold drawing with a reduction in area of 28.4% to provide finished seamless steel tubes having dimensions of an outer diameter of 66.2 mm and a wall thickness of 5.3 mm. These steel tubes were then subjected to annealing under the conditions shown as secondary heat treatment in Table 2. Test pieces were cut from the steel tubes after the completion of the secondary heat treatment (annealing), and the Rockwell B scale hardness (HRB) of tube cross sections was measured for each tube. The results are shown in Table 2.

Table 1

	C	Si	Mn	P	S	A1	Cr	Mo	Ti	V	B	Ni	Nb	Zr
Steel A	0.16	0.27	0.53	0.012	0.013	0.020	0.56	0.34	0.027	0.01	0.0013			
Steel B	0.17	0.29	0.57	0.008	0.004	0.020	0.58	0.34	0.026		0.0027	0.33	0.02	
Steel C	0.17	0.28	0.58	0.011	0.002	0.023	0.55	0.32	0.024	0.02	0.0018			0.03

Table 2

No.	Steel	Initial heat treatment and its cooling conditions		Secondary heat treatment	Hardness HRB	Remarks
		Initial heat treatment	Cooling rate (°C/min)			
1	A	700 °C x 15 min	10	730 °C x 20 min	87	Comparative
2	A	700 °C x 15 min	55	730 °C x 20 min	88	Comparative
3	A	870 °C x 10 min	10	730 °C x 20 min	77	Comparative
4	A	870 °C x 10 min	55	730 °C x 20 min	83	Comparative
5	A	870 °C x 10 min	68	730 °C x 20 min	84	Comparative
6	A	870 °C x 10 min	80	730 °C x 20 min	88	Comparative
7	A	870 °C x 10 min	55	730 °C x 40 min	82	Comparative
8	A	880 °C x 10 min	55	730 °C x 20 min	79	Invention
9	A	880 °C x 10 min	80	730 °C x 20 min	85	Comparative
10	A	930 °C x 10 min	55	730 °C x 20 min	78	Invention
11	A	930 °C x 10 min	68	730 °C x 20 min	78	Invention
12	A	930 °C x 10 min	55	730 °C x 40 min	76	Invention
13	C	930 °C x 10 min	80	730 °C x 40 min	85	Comparative
14	C	930 °C x 10 min	55	680 °C x 20 min	87	Comparative
15	C	930 °C x 10 min	55	800 °C x 20 min	79	Invention
16	C	930 °C x 10 min	55	840 °C x 20 min	84	Comparative
17	B	930 °C x 10 min	68	730 °C x 20 min	79	Invention
18	B	930 °C x 10 min	55	800 °C x 20 min	79	Invention

[0041] No. 1 and No. 2 in Table 2 had a heat treatment temperature in normalizing before cold working of 700 °C which was lower than the Ac_1 point, and they were finished to a hardness of at least 87 HRB. In Nos. 3 - 7 for which the heat treatment temperature before cold working exceeded the Ac_3 point, when the heat treatment temperature was lower than 880 °C, except for No. 3, the hardness was at least 82 HRB, and the object of softening to a value of at most 80 HRB could not be achieved. In No. 3 for which the cooling rate after heat treatment (soaking) was made a slow value of 10 °C per minutes, the hardness was 77 HRB and the object of softening could be achieved. However, the heat treatment time including the cooling step became long, and temperature holding equipment in the case of continuous treatment would become elongated, so this cooling rate is clearly not economical.

[0042] Nos. 8 - 18 are examples in which heat treatment prior to cold working was soaking at 880 °C or 930 °C. For Nos. 9 and 13 in which the cooling rate after soaking exceeded 70 °C per minute and for Nos. 14 and 16 in which the annealing temperature after cold working was too low or high, the hardness exceeded 80 HRB and sufficient softening could not be achieved. In contrast, for the examples of the present invention in which the cooling rate after soaking was at most 70 °C per minute and the annealing temperature after cold working was in the range of 700 - 820 °C, the object of softening to a hardness of at most 80 HRB could be achieved in each case.

[0043] When the microstructure of the steel tube which had been subjected to secondary heat treatment (annealing) was observed, No. 1 and No. 2 had a bainite structure, and Nos. 3 - 7 had a ferrite + pearlite structure. In No. 3, a tendency for coarsening of grains was observed.

[0044] On the other hand, among Nos. 8 - 18, for the examples of the present invention in which the hardness was at most 80 HRB, a ferrite + pearlite + spheroidized cementite structure was obsereved, and it was ascertained that a portion of the cementite in the pearlite structure was spheroidized. However, among Nos. 8 - 18, for those in which the hardness exceeded 84 HRB, spheroidized cementite was not observed. For Nos. 9 and 13 in which the cooling rate was 80 °C per minute, bainite was observed locally.

[0045] Accordingly, it is thought that as a result of a process in which a steel tube is subjected to normalizing by previously soaking it at 880 °C or above followed by cooling at a cooling rate of at most 70 °C per minute and then annealing is carried out after cold working at a temperature of 700 - 820 °C, transformation from a mixed structure of pearlite + ferrite to a mixed structure of pearlite + ferrite + spheroidized cementite proceeds to achieve the object of softening.

[0046] When a punching test (material of punching tool: high speed steel, punch diameter: 15.7 mm, punching speed: 2.5 mm per second) was carried out on the steel tubes of examples of the present invention in Table 2, there were no particular problems with respect to surface irregularities in the punched surface or dimensional accuracy. Also satisfactory results were obtained in an impact tensile test with a test specimen simulating a ball cage. In addition, their properties after carburizing and quenching were satisfactory.

[0047] Figure 1 shows a photomicrograph of a steel tube obtained by No. 11 of Table 2. It can be seen that carbides (cementite) were spheroidized in the ferrite + pearlite structure.

Claims

1. A process for manufacturing a case hardening steel tube **characterized in that** the process comprises producing a tube from a steel having a steel composition comprising, in mass percent, C: 0.1 - 0.25%, Si: 0.2 - 0.4%, Mn: 0.3 - 0.9%, P: at most 0.02%, S: 0.001 - 0.15%, Cr: 0.5 - 0.9%, Mo: 0.15 - 1%, Al: 0.01 - 0.1%, B: 0.0005 - 0.009%, N: less than 0.006%, and a remainder essentially of Fe, subjecting the resulting steel tube to normalizing by holding at a temperature of 880 - 980 °C and then cooling at a cooling rate of at most 70 °C per minute in a temperature range of 880 - 400 °C, performing cold working of the normalized steel tube, and then annealing the cold worked steel tube at a temperature of 700 - 820 °C.

2. A process as set forth in claim 1 wherein the steel composition contains at least one element selected from the following (1) and (2):

   (1) in mass percent, Ni: 0.3 - 4.0%
   (2) in mass percent, at least one element selected from Ti: 0.01 - 0.3%, Nb: 0.01 - 0.3%, V: 0.01 - 0.3%, and Zr: 0.01 - 0.3%.

3. A process as set forth in claim 1 or claim 2 wherein the B content in the steel composition is B: 0.0005 - 0.003%.

4. A cold worked, case hardening steel tube **characterized by** having a steel composition comprising, in mass percent, C: 0.1 - 0.25%, Si: 0.2 - 0.4%, Mn: 0.3 - 0.9%, P: at most 0.02%, S: 0.001 - 0.15%, Cr: 0.5 - 0.9%, Mo: 0.15 - 1%, A1: 0.01 - 0.1 %, B: 0.0005 - 0.009%, N: less than 0.006%, and a remainder essentially of Fe, and by having a steel structure selected from (a) a mixed structure of ferrite + pearlite + spheroidized cementite and (b) a mixed structure of ferrite + spheroidized cementite.

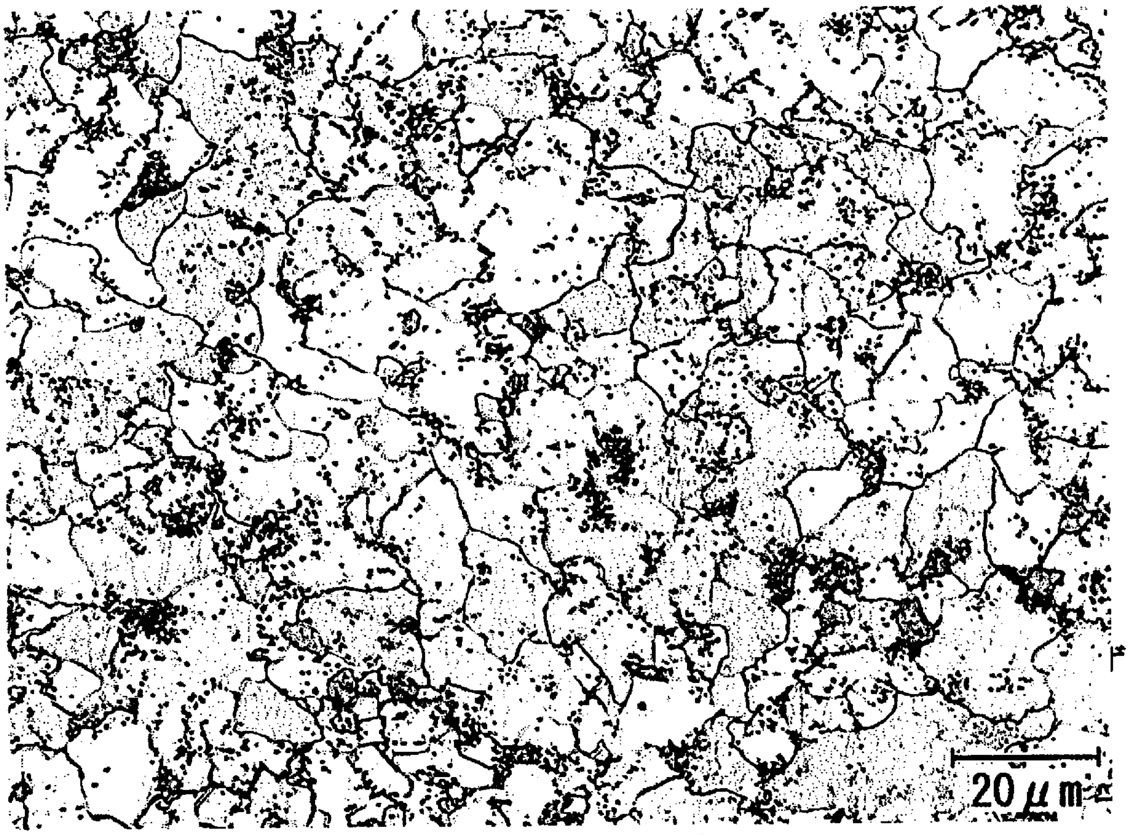
5. A case hardening steel tube as set forth in claim 4 wherein the steel composition contains at least one element selected from the following (1) and (2):

   (1) in mass percent, Ni: 0.3 - 4.0%
   (2) in mass percent, at least one element selected from Ti: 0.01 - 0.3%, Nb: 0.01 - 0.3%, V: 0.01 - 0.3%, and Zr: 0.01 - 0.3%.

6. A case hardening steel tube as set forth in claim 4 or claim 5 wherein the B content in the steel composition is B: 0.0005 - 0.003%.

7. A case hardening steel tube as set forth in any of claims 4 - 6 wherein the tube has a Rockwell B scale hardness (HRB) of 72 - 80.

Fig. 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/056016

A. CLASSIFICATION OF SUBJECT MATTER
C21D8/10(2006.01)i, *C22C38/00*(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)
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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)
WPI, Science Direct, JSTPlus(JDreamII)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 9-53150 A (Sumitomo Metal Industries, Ltd.), 25 February, 1997 (25.02.97), Claims; Par. Nos. [0001] to [0007], [0018] to [0029]; tables 1, 2, 3 & US 5853502 A & US 6126897 A	4-7
Y	JP 2003-328079 A (Nippon Steel Corp.), 19 November, 2003 (19.11.03), Claims; Par. Nos. [0001] to [0003]; table 3 (Family: none)	4-7
A	JP 2005-105379 A (Sanyo Special Steel Co., Ltd.), 21 April, 2005 (21.04.05), Claims; Par. No. [0001]; examples (Family: none)	1-7

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

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Date of the actual completion of the international search 04 June, 2008 (04.06.08)	Date of mailing of the international search report 17 June, 2008 (17.06.08)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2008/056016

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 8-20820 A (Sumitomo Metal Industries, Ltd.), 23 January, 1996 (23.01.96), Claims; Par. No. [0001]; examples (Family: none)	1-7
A	JP 2001-200313 A (Nippon Steel Corp.), 24 July, 2001 (24.07.01), Claims; Par. Nos. [0001] to [0003]; examples (Family: none)	1-7

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REFERENCES CITED IN THE DESCRIPTION

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- JP H0953150 A **[0006] [0009]**