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(71) Applicant: **Nippon Steel & Sumitomo Metal Corporation**
Tokyo 100-8071 (JP)

(72) Inventors:
- **KAWAMOTO Takuma**
Osaka-shi
Osaka 541-0041 (JP)
- **ARAI Yuji**
Osaka-shi
Osaka 541-0041 (JP)
- **TAKANO Takashi**
Osaka-shi
Osaka 541-0041 (JP)

(74) Representative: **Zimmermann & Partner**
Josephspitalstr. 15
80331 München (DE)

(54) **PROCESS FOR PRODUCING STEEL PIPE FOR AIR BAG**

(57) In a process for manufacturing a steel tube for air bags having a high strength and high toughness which can simplify cold drawing and reduce the alloy cost, a seamless steel tube is formed from a steel comprising, in mass percent, C: 0.04 - 0.20%, Si: 0.10 - 0.50%, Mn: 0.10 - 1.00%, P: at most 0.025%, S: at most 0.005%, Al: at most 0.10%, Cr: 0.01 - 0.50%, Cu: 0.01 - 0.50%, Ni: 0.01 - 0.50%, and a remainder of Fe and unavoidable impurities, and the seamless steel tube is subjected to cold drawing at least one time with a working ratio such that the reduction in area is greater than 40% to obtain predetermined dimensions, then to quench hardening by heating to a temperature of at least the Ac_3 point at a rate of temperature increase of at least 50° C per second followed by cooling at a cooling rate of at least 50° C per second at least in a temperature range of 850 - 500° C, and to tempering at a temperature of at most the Ac_1 point.

EP 2 578 705 A1

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Description

Technical Field

[0001] This invention relates to a process for inexpensively manufacturing a seamless steel tube which is suitable as a steel tube for air bags (air bag systems) and of which are required a high strength as expressed by a tensile strength of at least 900 MPa and a high level of toughness as expressed by a value of vTrs 100 (the lowest Charpy fracture appearance transition temperature at which the percent ductile fracture is 100%) of -60° C or below.

Background Art

[0002] In recent years, the automotive industry has actively promoted the introduction of safety equipment. One example of such equipment which has been developed is an air bag system, which has been installed in many automobiles. At the time of a collision, an air bag system inflates an air bag with a gas or the like between a passenger and the steering wheel, the instrument panel, or the like before the passenger impacts these objects and reduces injuries of the passenger by absorbing the kinetic energy thereof. Air bag systems were initially of a type which used explosive chemicals, but in recent years, a type which uses a high-pressure filling gas has been developed and is being increasingly widely used.

[0003] In air bag systems which use a high-pressure filling gas, an inflating gas such as an inert gas (such as argon) which is blown into an air bag at the time of a collision is always maintained at a high pressure inside an accumulator connected to the air bag, and at the time of a collision, the gas is blown all at once from the accumulator into the air bag in order to inflate the air bag. An accumulator is typically manufactured by welding a lid to both ends of a steel tube which has been cut to a suitable length and if necessary subjected to diameter reduction.

[0004] Accordingly, a stress at a high strain rate is applied to a steel tube used for an accumulator of an air bag system (referred to below as an air bag accumulator or simply as an accumulator) in an extremely short length of time. Therefore, unlike structures such as conventional pressure cylinders or line pipes, this type of steel tube requires high dimensional accuracy, workability, and weldability as well as a high strength and excellent bursting resistance.

[0005] Recently, there are increasing demands for decreases in the weight of automobiles. From this standpoint, there is also a desire to decrease the wall thickness and the weight of steel tubes for air bags for mounting on automobiles. In order to guarantee a high bursting pressure even with a decreased wall thickness, accumulators are now manufactured from high-strength seamless steel tubes having a tensile strength of at least 900 MPa or even at least 1000 MPa. Taking an accumulator manufactured from a seamless steel tube having an outer diameter of 60 mm and a wall thickness of 3.55 mm as an example, if its tensile strength is 800 MPa, its bursting pressure is at most around 100 MPa, but if its tensile strength is 1000 MPa, its bursting pressure increases to 130 MPa. At the same time, when the outer diameter of an air bag accumulator and the required bursting pressure are constant, it is possible to decrease the wall thickness by around 20%.

[0006] An accumulator also needs to have excellent low-temperature toughness so that even in cold regions, the accumulator does not undergo brittle fracture at the time of a collision which can lead to secondary accidents.

[0007] For this reason, a seamless steel tube for an accumulator has been imparted a high strength and a high toughness by carrying out quench hardening and tempering thereon. Specifically, it is desired that an accumulator have low-temperature toughness such that fracture in a Charpy impact test at -60° C is ductile (namely, vTrs100 is -60° C or below) and preferably such that fracture in a Charpy impact test at -80° C is ductile (vTrs100 is -80° C or below).

[0008] Concerning a seamless steel tube for air bag systems having a high strength and high toughness, Patent Document 1, for example, proposes a process for manufacturing a seamless steel tube for air bags comprising forming a seamless steel tube by hot working using a steel material having a chemical composition in a prescribed range, cold drawing the seamless steel tube so as to give predetermined dimensions, heating the steel tube to a temperature in the range of at least the Ac_3 point to at most 1050° C followed by quenching, and then tempering it at a temperature in the range of at least of 450° C to at most the Ac_1 point.

[0009] It is purported that this process provides a seamless steel tube which has excellent workability and weldability at the time of manufacture of an air bag inflator, which has a tensile strength of at least 900 MPa when used as an inflator, and which has high toughness such that it exhibits ductility in a dropping test performed at -60° C on a steel tube cut in half. However, the fact that it exhibits ductility in a dropping test at -60° C does not necessarily mean that it is ductile in a bursting test at -60° C.

[0010] Patent Document 2 proposes a process for manufacturing a steel tube for air bag systems having a tensile strength exceeding 1000 MPa by carrying out quench hardening by high-frequency induction heating to achieve grain refinement by rapid heating. When using a seamless steel tube as a mother tube, the seamless steel tube is prepared by hot tube forming using a steel material having a chemical composition in a prescribed range, and the seamless steel tube is subjected to cold drawing to obtain a steel tube having predetermined dimensions. After the steel tube is heated, it is quenched and then tempered at a temperature of at most the Ac_1 transformation point. By carrying out tempering after quench hardening, the steel tube is given a desirable high toughness so as to exhibit ductility in a bursting test even at -80° C or below.

[0011] However, in the processes disclosed in Patent Documents 1 and 2, as specifically disclosed therein, in order to obtain a steel tube having a tensile strength of at least 1000 MPa and a high toughness, it was necessary to contain a large amount of expensive alloying metals such as Cr and Mo. In Patent Document 1, the (Cr + Mo) content is from 1.0 to 2.5 mass %, and in Patent Document 2, a steel material is employed for which in many cases the (Cr + Mo) cotent is 0.92 mass %. If large amounts of Cr and Mo are contained, in addition to a high material cost particularly due to expensive Mo, after forming a seamless steel tube in a hot state, the resulting steel tube tends to have a high strength which makes the subsequent cold drawing difficult. Therefore, softening treatment becomes necessary before cold drawing, thereby making the manufacturing process complicated and manufacturing costs high.

[0012] Patent Document 3, which utilizes a steel in which the (Cr + Mo) content is 1.0 - 1.18 mass %, has the same problems as Patent Documents 1 and 2.

[0013] Patent Document 4 discloses a steel composition for a seamless steel tube having excellent bursting resistance and which contains Cr, Mo, Cu, and Ni. However, its properties are evaluated with respect to a seamless steel tube in which the (Cr + Mo) content is at least 0.76 mass %, and the tensile strength of that tube is at most 947 MPa.

Prior Art Documents

Patent Documents

[0014]

Patent Document 1: JP 2004-76034 A1
Patent Document 2: WO 2004/104255 A1
Patent Document 3: US 2005/0076975 A1
Patent Document 4: WO 2002/079526 A1

Summary of the Invention

[0015] In a conventional steel tube for air bags, in order to provide it with a high strength and a high toughness, strengthening was achieved by adding Cr and Mo. However, that technique not only increases the alloy cost but also makes it difficult to carry out cold drawing after tube forming. Therefore, when there is a large difference between the size of a seamless steel tube used as a mother tube and the size of a steel tube for air bags as a final product, it becomes necessary to repeat cold drawing multiple times in a cold drawing step. In this case, the steel tube is finished to a product with desired dimensions while carrying out softening between successive times of cold drawing, so the overall manufacturing costs increase.

[0016] An object of the present invention is to provide a process for manufacturing a steel tube for air bags having a high strength and high toughness by less expensive means than the prior art techniques and which is less expensive than conventional products by simplifying a drawing step or decreasing the alloy cost.

[0017] From another standpoint, an object of the present invention is to provide a process for manufacturing a steel tube for air bags having a wall thickness and diameter which are the same as or smaller than those of conventional products using a starting material and a manufacturing process with lower costs than in the past.

[0018] The present inventors noted that as a result of relying on strengthening by Cr and Mo in a conventional high-strength steel tube for air bags, the strength after the completion of hot tube forming becomes high, thereby leading to a decrease in productivity during cold drawing, and the alloy cost increases. Therefore, they investigated an alloy composition and a manufacturing process which suppress the use of these alloy elements as much as possible and which can guarantee a high strength as expressed by a tensile strength of at least 900 MPa and excellent low-temperature toughness as expressed by vTrs100 of -60° C or below.

[0019] As a result, they obtained the following knowledge and completed the present invention.

(a) In the manufacture of a steel tube for air bags by carrying out cold drawing followed by quench hardening and tempering, if the heating conditions and cooling conditions at the time of quench hardening are appropriately set, it is possible to guarantee a high strength and low-temperature toughness even if the steel tube does not contain a large amount of Cr and Mo. It is particularly effective for the steel to contain Cu and Ni in place of Cr and Mo.

(b) A steel having a reduced content of Cr and Mo and in place containing Cu and Ni easily undergoes cold drawing after hot tube forming. As a result, it is possible to increase the working ratio (reduction in area) in one time of cold drawing operation in a cold drawing step, thereby simplifying the cold drawing step.

[0020] The present invention is a process for manufacturing a steel tube for air bags characterized by including a tube forming step in which a seamless steel tube is produced by hot tube forming from a steel comprising, in mass %, C: 0.04 - 0.20%, Si: 0.10 - 0.50%, Mn: 0.10 - 1.00%, P: at most 0.025%, S: at most 0.005%, Al: at most 0.10%, Cr: 0.01 - 0.50%, Cu: 0.01 - 0.50%, Ni: 0.01 - 0.50%, and a remainder of Fe and unavoidable impurities, a cold drawing step in which the resulting seamless steel tube is subjected to cold drawing at least one time with a reduction in area of at least 40% in one time of cold drawing operation to obtain a steel tube having predetermined dimensions, and a heat treatment step in which the cold drawn steel tube is subjected to quench hardening by heating it to a temperature of at least the Ac_3 point at a rate of temperature increase of at least 50° C per second followed by cooling at a cooling rate of at least 50° C per second at least in a temperature range of 850 - 500° C and then to tempering at a temperature of at most the Ac_1 point.

[0021] Preferred embodiments of a process for manufacturing a steel tube for air bags according to the present invention are as follows.

[0022] The steel may optionally further contain one or more of the following elements:

Mo: less than 0.10%,
at least one of Nb: at most 0.050%, Ti: at most 0.050%, and V: at most 0.20%; and
at least one of Ca: at most 0.005% and B: at most 0.0030%.

[0023] The contents of Cu, Ni, Cr, and Mo in the steel preferably satisfy the following Equation (1).

$$\mathrm{Cu} + \mathrm{Ni} \geq (\mathrm{Cr} + \mathrm{Mo})^2 + 0.3 \quad \cdots \quad (1)$$

[0024] The symbols for elements in Equation (1) indicate the values of the content of those elements in mass percent. When Mo is not contained, Mo = 0.

[0025] The wall thickness of the steel tube after completion of the cold drawing step is preferably at most 2.0 mm.

[0026] The cold drawing step is preferably carried out by performing cold drawing a single time.

[0027] The heating for quench hardening in the heat treatment step is preferably carried out by high-frequency induction heating. In this case, before being heated for quench hardening, the steel tube obtained in the cold drawing step preferably undergoes straightening.

[0028] According to the present invention, it is possible to manufacture a steel tube for air bags having a high strength as expressed by a tensile strength of at least 900 MPa and excellent low-temperature toughness as expressed by vTrs100 of -60° C or below, while the content of expensive Mo is restricted to 0 or a low level. In addition, the strength of the seamless steel tube obtained by hot tube forming is not too high, so the working ratio in the subsequent cold drawing step can be increased compared to a conventional process, and the number of times that cold drawing operation must be carried out with intervening softening between cold rolling operations can be decreased. Therefore, according to the present invention, it is possible to decrease both the alloy cost and the manufacturing cost of a steel tube for air bags compared to the prior art.

Modes for Carrying Out the Invention

[0029] The chemical composition and the manufacturing process for a steel tube for air bags according to the present invention will be explained more specifically below.

(A) Chemical composition of the steel

[0030] In this description, percent with respect to the chemical composition of a steel means mass percent. The remainder of the chemical composition of a steel other than the elements described below is Fe and unavoidable impurities.

C: 0.04 - 0.20%

[0031] C is an element which is effective at inexpensively increasing the strength of steel. If its content is less than 0.04%, it is difficult to obtain a high strength (tensile strength), and if it exceeds 0.20%, workability and weldability decrease. Accordingly, the C content is made at least 0.04% and at most 0.20%. A preferred range for the C content is at least 0.07% to at most 0.20%, and a more preferred range is at least 0.12% to at most 0.17%. When it is desired to obtain a tensile strength of at least 1000 MPa, it is preferable to contain at least 0.06% of C.

Si: 0.10 - 0.50%

[0032] Si is an element which has a deoxidizing action and which also increases the strength of steel by increasing its hardenability. With this object, the Si content is made at least 0.10%. However, if its content exceeds 0.50%, toughness decreases, so the Si content is made at most 0.50%. A preferred range for the Si content is at least 0.20% to at most 0.45%.

Mn: 0.10 - 1.00%

[0033] Mn is an element which has a deoxidizing action and which is also effective at increasing the strength and toughness of steel by increasing its hardenability. If its content is less than 0.10%, a sufficient strength and toughness are not obtained. If its content exceeds 1.00%, coarsening of MnS takes place, the coarse MnS being elongated at the time of hot rolling, leading to a decrease in toughness. Therefore, the Mn content is made at least 0.10% and at most 1.00%. A preferred Mn content is at least 0.30% and at most 0.80%.

P: at most 0.025%

[0034] P, which is contained in steel as an impurity, produces a decrease in toughness due to grain boundary segregation. In particular, if the P content exceeds 0.025%, toughness is markedly decreased. Accordingly, the P content is made at most 0.025%. The P content is preferably at most 0.020% and more preferably at most 0.015%.

S: at most 0.005%

[0035] S, which is contained in steel as an impurity, also decreases toughness particularly in the T direction of a steel tube (the direction perpendicular to the rolling direction (the lengthwise direction) of a steel tube). If the S content exceeds 0.005%, there is a marked decrease in the toughness in the T direction of a steel tube, so the S content is made at most 0.005%. A preferred S content is at most 0.003%.

Al: at most 0.10%

[0036] Al is an element which has a deoxidizing action and which is effective at increasing the toughness and workability of steel. However, if Al is contained in an amount exceeding 0.10%, there is marked occurrence of sand marks. Accordingly, the Al content is made at most 0.10%. The Al content may be on the level of an impurity, so there is no particular lower limit, but it is preferably at least 0.005%. The Al content in the present invention is expressed as the content of acid-soluble Al (so-called sol. Al).

Cr: 0.01 - 0.50%

[0037] Cr has the effect of increasing the strength and toughness of steel by increasing the hardenability and resistance to temper softening. This effect appears when the Cr content is at least 0.01%. However, because Cr is an element which improves hardenability, it causes hardening of steel in the cooling stage after hot tube forming, thereby limiting the working ratio in a single time of cold drawing operation, so there is an increased necessity to perform cold drawing a plurality of times in a cold drawing step with intervening softening treatment. Furthermore, an increase in the Cr content leads to an increase in the alloy cost. For the above reasons, the Cr content is made at least 0.01 % and at most 0.50%. A preferred Cr content is at least 0.15% to at most 0.45%, and a more preferred content is at least 0.18% to at most 0.35%.

Mo: 0% to less than 0.10 mass %

[0038] Mo has the effect of increasing the strength and toughness of steel by increasing the hardenability and resistance to temper softening. This effect appears when its content is at least 0.01%. However, in the present invention, the necessary strength and toughness are achieved by Ni and Cu, and it is not essential to add Mo. Namely, Mo may be 0%.

[0039] When Mo is added, its content is made less than 0.10%. If the Mo content is higher, even if a seamless steel tube obtained by hot tube forming is air cooled, there is a tendency for the strength of the seamless steel tube to become too high. As a result, in the subsequent cold drawing step, it becomes necessary to carry out softening before working, and the working ratio (reduction in area) in cold drawing is limited. Therefore, the number of times of cold drawing and softening prior to cold drawing necessary to obtain a steel tube having predetermined dimensions increases. This tendency becomes marked when Mo is 0.10% or greater. Mo is an extremely expensive metal, so an increase in the Mo content is tied to a marked increase in the alloy cost. Namely, an Mo content of 0.10% or higher is an impediment to achieving the objects of the present invention. Accordingly, when Mo is contained, its content is made less than 0.10%, and a preferred content of Mo is at least 0.01% and at most 0.05%.

Cu: 0.01 - 0.50%

[0040] Cu has the effect of increasing the strength and toughness of steel by increasing its hardenability. This effect is exhibited if the Cu content is at least 0.01% and preferably at least 0.03%. However, a Cu content in excess of 0.50% leads to an increase in the alloy cost. Accordingly, the Cu content is made at least 0.01% and at most 0.50%. A preferred Cu content is at least 0.03% and particularly at least 0.05%, and more preferably at least 0.15%. The upper limit on the Cu content is preferably 0.40% and more preferably 0.35%.

Ni: 0.01 - 0.50%

[0041] Ni has the effect of increasing the strength and toughness of steel by increasing its hardenability. This effect appears if the Ni content is at least 0.01% and preferably at least 0.03%. However, an Ni content exceeding 0.50% leads to an increase in the alloy cost. Accordingly, the Ni content is made at least 0.01% and at most 0.50%. The Ni content is preferably at least 0.03%, more preferably at least 0.05%, and most preferably at least 0.15%. The upper limit on the Ni content is preferably 0.40% and more preferably 0.35%.

[0042] The sum of the contents of Cu and Ni (Cu + Ni) is preferably at least 0.20% and at most 0.65%, and more preferably at least 0.28% and at most 0.60%.

[0043] In a preferred embodiment of the present invention, the contents of Cu, Ni, Cr, and Mo in steel are adjusted so as to satisfy the following Equation (1).

$$\mathrm{Cu} + \mathrm{Ni} \geq (\mathrm{Cr} + \mathrm{Mo})^2 + 0.3 \quad \cdots \quad (1)$$

[0044] The symbols for elements in Equation (1) indicate the value of the content of each element in mass percent. When the steel does not contain Mo, Mo is 0.

[0045] Cr and Mo interfere with spheroidization of cementite which precipitates during tempering. Particularly in a steel containing B, they easily form compounds with B (borides) at grain boundaries, so they easily cause a decrease in toughness particularly in a high-strength steel. By suppressing Cr and Mo and containing Cu and Ni so as to satisfy Equation (1), it becomes easy to manufacture a steel tube for air bags having a high strength and a high toughness.

[0046] In a preferred embodiment of the present invention, at least one element selected from one or both of the following groups (i) and (ii) can be further contained.

(i) Nb, Ti, V
(ii) Ca, B

Nb: at most 0.050%

[0047] Nb, which is finely dispersed in steel as carbides, has an effect of strongly pinning grain boundaries. As a result, it refines crystal grains and increases the toughness of steel. However, if Nb is contained in an amount exceeding 0.050%, carbides coarsen and toughness ends up decreasing. Accordingly, when Nb is added, its content is made at most 0.050%. The above-described effect of Nb appears even with an extremely small content, but in order to adequately obtain this effect, the Nb content is preferably at least 0.005%.

Ti: at most 0.050%

[0048] Ti has the effect of fixing N in steel and thereby increasing toughness. Finely-dispersed Ti nitrides strongly pin grain boundaries and refine crystal grains, thereby increasing the toughness of steel. However, if Ti is contained in an amount larger than 0.050%, nitrides coarsen and toughness ends up decreasing. Accordingly, the content of Ti when it is added is made at most 0.050%. The effect of Ti appears even when it is added in a minute amount, but in order to adequately obtain its effect, its content is preferably at least 0.005%. A preferred Ti content is 0.008 - 0.035%.

V: at most 0.20%

[0049] V has the effect of ensuring toughness and increasing strength by precipitation strengthening. However, a V content exceeding 0.20% leads to a decrease in toughness. Accordingly, the content of V when it is added is made at most 0.20%. The effect of V appears even when it is added in a minute amount, but in order to obtain an adequate effect, its content is preferably at least 0.02%. A preferred range for the V content is 0.03 - 0.10%.

Ca: at most 0.005%

[0050] Ca has the effect of fixing S, which is present in steel as an unavoidable impurity, as sulfides and improving the anisotropy of toughness, thereby increasing the toughness in the T direction of a steel tube and hence increasing the resistance to bursting thereof. However, if Ca is contained in excess of 0.005%, inclusions increase and toughness ends up decreasing. Accordingly, the content of Ca when it is added is made at most 0.005%. The above-described effect of Ca is observed even when it is added in an extremely small amount, but in order to obtain an adequate effect, its content is preferably at least 0.0005%.

B: at most 0.0030%

[0051] When B is added in a minute amount, it segregates at grain boundaries in steel and markedly increases the hardenability of steel. However, if the B content is 0.0030% or higher, coarse borides precipitate at grain boundaries and a tendency for toughness to decrease is observed. Accordingly, when B is added, its content is made at most 0.0030%. The effect of B is observed even when it is added in a minute amount, but in order to guarantee an adequate effect, its content is preferably made at least 0.0005%.
[0052] In the present invention, when it is desired to obtain a tensile strength of at least 1000 MPa, it is preferable to add B in order to increase strength by improving hardenability.
[0053] B does not segregate at grain boundaries unless it is present in solid solution in steel. Accordingly, N, which easily forms a compound with B, is preferably fixed by Ti, and B is preferably contained in at least an amount which is fixed by N. For this reason, the B content preferably satisfies the relationship given by the following Equation (2) based on the stoichiometric ratios of B, Ti, and N.

$$B - (N - Ti/3.4) \times (10.8/14) \geq 0.0001 \quad \cdots \quad (2)$$

[0054] In Equation (2), B, N, and Ti represent the values of the contents of those elements in mass percent.

(B) Tube forming step

[0055] A steel ingot of a steel having its chemical composition adjusted as set forth above in (A) is used as a starting material to obtain a seamless steel tube by hot tube forming.
[0056] There are no particular limitations on the form or the method for the preparation of a steel ingot which is used as a starting material for hot tube forming. For example, it may be a cast member (a round CC billet) obtained by casting using a continuous casting machine having a cylindrical mold, or it may be an ingot which is cast into a rectangular mold and then hot forged to obtain a cylindrical shape. As a result of suppressing the addition of ferrite-stabilizing elements such as Cr and Mo and adding austenite-stabilizing elements such as Cu and Ni, even when continuous casting is employed into a round shape to form a round CC billet, the effect of preventing center cracks is sufficiently obtained, so the applicability of the present invention to a round CC is sufficiently high. As a result, it is possible to eliminate a step of working to form a round billet by blooming or the like which is necessary when casting into a rectangular mold.
[0057] There are no particular limitations on a hot tube forming method for obtaining a seamless steel tube. For example, the mandrel-Mannesmann method can be used. Cooling after hot tube forming is preferably cooling with a low cooling rate such as air cooling in order to facilitate cold drawing. There are no particular limitations on the shape of the resulting seamless steel tube, but a diameter of 32 - 50 mm and a wall thickness of around 2.5 - 3.0 mm, for example, are suitable.

(C) Cold drawing step

[0058] A seamless steel tube which is obtained by hot tube forming generally has a large wall thickness and a large diameter with an inadequate dimensional accuracy. In order to obtain predetermined dimensions (the outer diameter and wall thickness of a steel tube) and good surface condition, the seamless steel tube which is used as a mother tube is subjected to cold drawing. In the present invention, in order to exploit the characteristics of the steel being used, the working ratio (reduction in area) in at least one time of cold drawing operation which is performed in the cold drawing step is made greater than 40%. If the working ratio in one time of cold drawing operation exceeds 50%, inner surface wrinkles and cracks easily develop, so the working ratio is preferably 42 - 48% and more preferably 43 - 46%. When cold drawing is carried out two or more times in the cold drawing step, the working ratio in at least one of the times should be at least 40%, and it is possible to combine cold drawing having a working ratio of at least 40% with cold drawing having a working ratio of less than 40%.

[0059] The working ratio in cold drawing is synonymous with the reduction in area (decrease in cross section) defined by the following formula.

$$\% \text{ reduction in area} = (S_0 - S_f) \times 100/S_0$$

where, So is the cross-sectional area of the steel tube before cold drawing, and S_f is the cross-sectional area of the steel tube after the completion of cold drawing.

[0060] The cross-sectional area of a steel tube is the cross-sectional area of just the tube wall and excludes the hollow portion of the tube cross section.

[0061] The working ratio (or reduction in area) in one time of cold drawing operation can be the total working ratio when cold drawing is performed a plurality of times with no softening intervening between occurrences of cold drawing. Using a steel according to the present invention, the working ratio in one time of cold drawing can exceed 40%, so if the finished dimensions of a seamless steel tube obtained by hot tube forming are suitably selected, it is possible to manufacture a thin-walled steel tube of predetermined dimensions in a single occurrence (one time) of cold drawing. Manufacture can thus be greatly simplified compared to the conventional process for manufacturing a thin-walled steel tube, which requires two occurrences of cold drawing and requires intervening softening between them.

[0062] Methods of cold drawing are well known, and cold drawing can be carried out in a conventional manner. For example, when a seamless steel tube prepared by the mandrel-Mannesmann method as described above is used as a mother tube, the resulting tube may be allowed to cool to room temperature and then subjected to drawing with a die and a plug to reduce the diameter and wall thickness of the tube. A steel tube for air bags preferably has a diameter of at most 30 mm and a wall thickness of at most 2 mm, for example. As long as a steel tube having the necessary dimensions can be obtained from the seamless steel tube used as a mother tube by cold drawing, there are no particular limitations on the working method, but the above-described drawing method is preferable.

[0063] With a steel composition used in the present invention, it is possible to perform working with a reduction in area of 46%, for example, by single occurrence of cold drawing. Therefore, when the final dimensions of a steel tube for air bags are a wall thickness of 1.7 mm and an outer diameter of 25 mm, if the dimensions of a mother tube to undergo cold drawing are, for example, an outer diameter of 31.8 mm and a wall thickness of 2.5 mm, it is possible to obtain a product having predetermined dimensions by performing cold drawing a single time.

(D) Straightening

[0064] Since a steel tube for air bags manufactured in the present invention has a tensile strength of at least 900 MPa and has undergone cold drawing with a reduction in area of at least 40%, there is a tendency for the strength of the steel tube after cold drawing to be higher than for a conventional steel, and in some cases, there is the possibility of the steel tube developing bending such as springback after cold drawing.

[0065] As explained below, in order to achieve a high strength and high toughness, a steel tube which is given predetermined dimensions by cold drawing is heated to at least the Ac_3 transformation point by rapid heating for the purpose of quench hardening. This rapid heating is typically carried out by high-frequency induction heating. If there are bends in a steel tube which is to undergo quench hardening, the problem may occur that the steel tube is unable to pass straight through the high-frequency coils used for high-frequency induction heating. Accordingly, in a preferred embodiment, straightening is carried out after cold drawing to remove bends in the steel tube.

[0066] There are no particular limitations on the straightening method, and straightening can be carried out in a conventional manner. For example, a preferred method is one in which four 2-roll stands having an adjusted roll gap are provided with the center of the roll gap in each stand being slightly deviated or offset with respect to each other and a steel tube is passed through the rolls to apply working in the form of bending forth and back. The higher the working ratio in bending forth and back at this time, the higher is the effect of straightening. From this standpoint, the amount of offset (the amount of deviation of the roll axis between adjacent roll pairs) is made at least 1% of the outer diameter of the steel tube, and the roll gap is preferably made at most 1% smaller than the outer diameter of the steel tube. In order to avoid problems such as cracking of the steel tube, the amount of offset is preferably made at most 50% of the outer diameter of the steel tube, and the roll gap is preferably made at least 5% smaller than the outer diameter of the steel tube.

(E) Heat Treatment

[0067] After carrying out the straightening described above in (D) as required, the steel tube is subjected to heat treatment in order to impart the required tensile strength to the steel tube and increase the toughness in the T direction, thereby guaranteeing bursting resistance. In order to give a steel tube a high strength as expressed by a tensile strength of at least 900 MPa and excellent low temperature toughness or bursting resistance, heat treatment is carried out by quench hardening after heating to a temperature of at least the Ac_3 (transformation) point and subsequent tempering at a temperature of at most the Ac_1 (transformation) point.

[0068] If the heating temperature before quenching is lower than the Ac_3 point at which an austenite single phase forms, it is not possible to guarantee good toughness in the T direction (and accordingly good bursting resistance). On the other hand, if the heating temperature is too high, austenite grains abruptly start to grow and become coarse grains, and toughness decreases. Therefore, the heating temperature is preferably made at most 1050° C. More preferably it is at most 1000° C.

[0069] Heating to at least the Ac_3 point for quench hardening is carried out by rapid heating at a heating rate of at least 50° C per second. This heating rate can be the average heating rate in a temperature range from at least 200° C to the heating temperature. If the heating rate is lower than 50° C per second, it is not possible to achieve refinement of austenite grain diameters, and the tensile strength and low-temperature toughness or bursting resistance decrease. In order to obtain a steel tube with a tensile strength of at least 1000 MPa and vTrs100 of -80° C or below, the heating rate is preferably at least 80° C per second and more preferably at least 100° C per second. This rapid heating can be achieved by high-frequency induction heating. In this case, the heating rate can be adjusted by the feed speed of a steel tube passing through high-frequency coils.

[0070] A steel tube which has been heated to a temperature of at least the Ac_3 point by rapid heating is held for a short period at a temperature of at least the Ac_3 point, and then it is rapidly cooled to carry out quench hardening. The holding time is preferably in the range of 0.5 - 8 seconds. More preferably it is 1 - 4 seconds. If the holding time is too short, the uniformity of mechanical properties is sometimes inferior. If the holding time is too long, particularly if the holding temperature is on the high side, it easily leads to coarsening of the austenite grain diameter. Refinement of grain diameter is necessary to guarantee extremely high toughness.

[0071] The cooling rate for quench hardening is controlled so as to be at least 50° C per second at least in a temperature range of 850 - 500° C. This cooling rate is preferably at least 100° C per second. In order to make the tensile strength at least 1000 MPa and make vTrs100 a value of -80° C or below, the cooling rate is preferably made at least 150° C per second. If the cooling rate is too low, quench hardening becomes incomplete, and the proportion of martensite decreases, so a sufficient tensile strength is not obtained.

[0072] A steel tube which has undergone the above-described rapid cooling and cooled to the vicinity of room temperature is then subjected to tempering at a temperature of at most the Ac_1 point in order to impart a tensile strength of at least 900 MPa and sufficient bursting resistance. If the tempering temperature exceeds the Ac_1 point, it becomes difficult to stably obtain the desired tensile strength and low-temperature toughness with certainty.

[0073] There are no particular limitations on a method for tempering, and it can be carried out by, for example, soaking in a heat treatment furnace such as a hearth roller type continuous furnace or by using high-frequency induction heating or the like followed by cooling. Preferred soaking conditions in a heat treatment furnace are a temperature of 350 - 500° C and a holding time of 20 - 30 minutes. After tempering, bends can be straightened using a suitable straightener or the like in the manner described in (D).

[0074] In order to form an air bag accumulator from a steel tube for air bags manufactured in this manner, the steel tube is cut to a predetermined length to obtain a short tube, and if necessary at least one end of the cut tube is subjected to diameter reduction by press working or spinning (this is referred to as bottling) for final working to a shape necessary for mounting of an initiator or the like. Accordingly, the predetermined dimensions and dimensional accuracy for a steel tube for air bags referred to in this description mean the dimensions and dimensional accuracy with respect to the tube thickness and diameter. Finally, a lid is mounted on each end of the steel tube by welding.

Examples

[0075] Steels having the chemical compositions shown in Table 1 with Ac_1 points in the range of 720 - 735° C and Ac_3 points in the range of 835 - 860° C were prepared in a converter, and cylindrical billets having an outer diameter of 191 mm were manufactured by continuous casting (round CC). Each round CC billet was cut to a desired length and heated to 1250° C, and then it underwent piercing and rolling by the usual Mannesmann piercer-mandrel mill type technique to obtain a first mother tube having an outer diameter of 31.8 mm and a wall thickness of 2.5 mm and a second mother tube having an outer diameter of 42.7 mm and a wall thickness of 2.7 mm.

[0076] The two types of mother tubes which were obtained in this manner underwent cold drawing one or two times by a usual method which carries out drawing using a die and a plug and were finished to form steel tubes with an outer diameter of 25.0 mm and a wall thickness of 1.7 mm. For comparative steels G and H in Table 1, when it was attempted to manufacture a steel tube having the above-described shape by performing cold drawing one time on the first mother tube having an outer diameter of 31.8 mm and a wall thickness of 2.5 mm, fracture developed and manufacture could not be carried out.

[0077] In Comparative Examples 9 and 10, the second mother tubes were used. A steel tube having an outer diameter of 32.0 mm and a wall thickness of 2.2 mm was formed by performing drawing a first time, then it underwent softening at 630° C for 20 minutes, and then it was finished to an outer diameter of 25.0 mm and a wall thickness of 1.7 mm by performing drawing a second time.

[0078] Each steel tube which underwent cold drawing was straightened using a straightener, and then it was subjected to water quenching by heating to 920° C at an average heating rate of 300° C per second (the average value in the temperature range of 200 - 900° C) using a high-frequency induction heating apparatus, holding at 920° C for 2 seconds, and water cooling (at an average cooling rate of 150° C per second in the temperature range of 850 - 500° C). Subsequently, in order to temper the steel tube, it was soaked for 30 minutes at 350 - 500° C in a bright annealing furnace and then cooled to room temperature by natural cooling initially in the furnace and then outside the furnace to obtain a steel tube for air bags.

[0079] A tube of a fixed length was cut from each resulting steel tube, and it was cut in the lengthwise direction of the tube at room temperature and unrolled. A rectangular member having a length of 55 mm, a height of 10 mm, and a width of 1.7 mm which was taken in the T direction from the unrolled tube and which had a 2-mm V-notch was used as a test piece for a Charpy impact test which was carried out at various temperatures of -40° C and below. By means of this test, the lowest temperature at which the percent ductile fracture was 100% (vTrs100) was obtained.

[0080] Using a No. 11 test piece prescribed by JIS Z 2201 which was taken from the L direction of each steel tube, a tensile test in accordance with the tensile test method for metals prescribed by JIS Z 2241 was carried out. The results of the above tests and the manufacturing conditions of a steel tube are compiled in Table 2.

Table 1

Steel	Steel composition (mass %, remainder of Fe and impurities)														Cu+Ni	$(Cr+Mo)^2+0.3$	Remark
	C	Si	Mn	P	S	Cr	Mo	Cu	Ni	Nb	Ti	V	sol.Al	Ca	B			
A	0.14	0.29	0.50	0.012	0.003	0.30	0.01	0.25	0.26	0.025	0.024	-	0.031	0.0016	0.0014	0.51	0.40	This invention
B	0.15	0.28	0.48	0.012	0.002	0.29	-	0.26	0.28	0.024	0.024	-	0.035	0.0011	0.0013	0.54	0.38	
C	0.14	0.26	0.52	0.013	0.002	0.30	0.01	0.27	0.25	0.024	0.026	-	0.042	0.0015	0.0014	0.52	0.40	
D	0.13	0.25	0.47	0.011	0.002	0.36	0.04	0.26	0.06	-	0.023	0.018	0.042	0.0013	0.0015	0.32	0.46	
E	0.13	0.26	0.48	0.012	0.002	0.22	-	0.26	0.25	-	-	-	0.034	-	-	0.51	0.35	
F	0.15	0.26	0.40	0.013	0.003	0.35	0.02	0.29	0.30	-	0.022	-	0.040	-	0.0010	0.59	0.44	
G	0.12	0.25	1.29*	0.014	0.003	0.61*	0.28*	0.27	0.25	0.023	0.024	-	0.036	0.0015	0.0003	0.52	1.09	Compparative
H	0.15	0.23	0.54	0.013	0.002	0.74*	0.35*	0.29	0.31	0.024	0.008	-	0.033	0.0022	0.0002	0.60	1.49	

*Outside the range defined herein.

Table 2

Run No.	Steel	Dimensions of mother tube	First cold rolling			Second cold rolling			Total working ratio	Heating conditions for quench hardening	Cooling rate (°C/s)	TS (MPa)	vTrs100 (°C)	Remark
			Dimensions (mm)	% area reduction	Result	Dimensions (mm)	% area reduction	Result						
1	A	0D:31.8mm x2.5mm t	0D:25. 0mm x1.7mm t	46	○	-	-	-	46	920°Cx2s (high frequency induction heating)	150	1098	-120	This invention
2	B				○	-	-	-				1070	-120	
3	C				○	-	-	-				1101	-120	
4	D				○	-	-	-				1022	-75	
5	E				○	-	-	-				1028	-100	
6	F				○	-	-	-				1053	-110	
7	G				×	***	***	***		***	***	***	***	Comparative
8	H				×	***	***	***		***	***	***	***	
9	G	0D-42. 7mm x2.7mm t	0D:32. 0mm x2.2mm t	39.3	○	0D:25. 0mm x1. 7mm t	39. 6	○	63. 3	920°Cx2s (HF-IH)	150	1075	-110	
10	H				○			○				1040	-110	

***Due to cracking which occurred during cold drawing, subsequent steps could not be preformed. HF-IH = high frequency inducition heating

[0081] As is apparent from Table 2, when steels A - F having the chemical composition of a steel according to the present invention were used, in spite of a low alloy cost due to the amount of expensive Mo which was zero or a small amount of less than 0.10%, it was possible to perform working to predetermined product dimensions by one time of cold drawing even with a working ratio as expressed by a reduction in area of 46%. Furthermore, by carrying out rapid heating and rapid cooling in the subsequent quench hardening step, it was possible to achieve a high level of product performance as a steel tube for air bags. In particular, when using steels A - C, E, and F having a composition which satisfies above-described Equation (1), vTrs100 was -100° C or below, so it is apparent that the low-temperature toughness is extremely high and excellent bursting resistance in a low-temperature environment can be expected.

[0082] Steels F and G, which were comparative examples, contained a large amount of Mo, so the alloy cost was high. Furthermore, cracks developed when cold drawing was carried out with a reduction in area of at least 40%. Therefore, it is necessary to carry out cold drawing at least 2 times with a reduction in area of less than 40%, and softening between cold drawing is necessary, so the manufacturing costs of a steel tube for air bags also increase.

Claims

1. A process for manufacturing a steel tube for air bags **characterized by** including:

a tube forming step in which a seamless steel tube is produced by hot tube forming from a steel comprising, in mass %, C: 0.04 - 0.20%, Si: 0.10 - 0.50%, Mn: 0.10 - 1.00%, P: at most 0.025%, S: at most 0.005%, Al: at most 0.10%, Cr: 0.01 - 0.50%, Cu: 0.01 - 0.50%, Ni: 0.01 - 0.50%, and a remainder of Fe and unavoidable impurities,
a cold drawing step in which the resulting seamless steel tube is subjected to cold drawing at least one time with a reduction in area of at least 40% in one time of cold drawing to obtain a steel tube having predetermined dimensions, and
a heat treatment step in which the cold drawn steel tube is subjected to quench hardening by heating it to a temperature of at least the Ac_3 point at a rate of temperature increase of at least 50° C per second followed by cooling at a cooling rate of at least 50° C per second at least in a temperature range of 850 - 500° C and then to tempering at a temperature of at most the Ac_1 point.

2. A process for manufacturing a steel tube for air bags as set forth in claim 1 wherein the steel further contains less than 0.10% of Mo.

3. A process for manufacturing a steel tube for air bags as set forth in claim 1 or claim 2 wherein the steel contains at least one of Nb: at most 0.050%, Ti: at most 0.050%, and V: at most 0.20%.

4. A process for manufacturing a steel tube for air bags as set forth in any of claims 1 - 3 wherein the steel contains at least one of Ca: at most 0.005% and B: at most 0.0030%.

5. A process for manufacturing a steel tube for air bags as set forth in any of claims 1 - 4 wherein the contents of Cu, Ni, Cr and Mo in the steel satisfy the following Equation (1):

$$Cu + Ni \geq (Cr + Mo)^2 + 0.3 \quad \cdots \quad (1)$$

wherein the symbols for elements in Equation (1) mean the values of the content of the respective elements in mass percent, and Mo = 0 when the steel does not contain Mo.

6. A process for manufacturing a steel tube for air bags as set forth in any of claims 1 - 5 wherein the wall thickness of the steel tube after completion of the cold drawing step is at most 2.0 mm.

7. A process for manufacturing a steel tube for air bags as set forth in claim 6 wherein the cold drawing step is carried out by performing cold drawing one time.

8. A process for manufacturing a steel tube for air bags as set forth in any of claims 1 - 7 wherein heating for quench hardening in the heat treatment step is carried out by high-frequency induction heating.

9. A process for manufacturing a steel tube for air bags as set forth in claim 8 wherein the steel tube obtained in the cold drawing step is straightened before heating for the quench hardening.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/062583

A. CLASSIFICATION OF SUBJECT MATTER
C21D8/10(2006.01)i, *C21D9/08*(2006.01)i, *C22C38/00*(2006.01)i, *C22C38/42*(2006.01)i, *C22C38/54*(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)
C21D8/10, C21D9/08, C22C38/00-38/60

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	1996-2011
Kokai Jitsuyo Shinan Koho	1971-2011	Toroku Jitsuyo Shinan Koho	1994-2011

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2007/091585 A1 (Sumitomo Metal Industries, Ltd.), 16 August 2007 (16.08.2007), & CA 2630797 A1 & CN 101374966 A & EP 1983065 A1 & TW 200801207 A & KR 10-2008-0068737 A & MX 2008008790 A1 & US 2007/0246130 A1	1-9
A	WO 2004/104255 A1 (Sumitomo Metal Industries, Ltd.), 02 December 2004 (02.12.2004), & CA 2525062 A1 & CN 1791694 A & EP 1637619 A1 & TW 200426224 A & KR 10-2006-0012310 A & MX 2005012511 A1 & US 2005/0000601 A1	1-9

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

* Special categories of cited documents:
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 August, 2011 (16.08.11)	23 August, 2011 (23.08.11)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 2009)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2011/062583

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	JP 2010-132999 A (Sumitomo Metal Industries, Ltd.), 17 June 2010 (17.06.2010), paragraphs [0043]; examples (Family: none)	4,5,7-9

Form PCT/ISA/210 (continuation of second sheet) (July 2009)

REFERENCES CITED IN THE DESCRIPTION

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- JP 2004076034 A **[0014]**
- WO 2004104255 A1 **[0014]**
- US 20050076975 A1 **[0014]**
- WO 2002079526 A1 **[0014]**