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(54) STEEL MATERIAL WITH EXCELLENT CRASHWORTHINESS AND MANUFACTURING PROCESS THEREFOR

STAHLMATERIAL MIT AUSGEZEICHNETER BRUCHFESTIGKEIT UND HERSTELLUNGSVERFAHREN DAFÜR

MATÉRIAU D’ACIER PRÉSENTANT UNE EXCELLENTE RÉSISTANCE AU CHOC ET PROCÉDÉ DE FABRICATION DE CE DERNIER

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Description

Technical Field

[0001] The present invention relates to a steel used for large structures, e.g., ships, and a method for manufacturing the same. In particular, the present invention relates to a steel with excellent collision energy absorbability, which has high uniform elongation particularly effective in reducing a damage from a collision and the like of a ship, and a method for manufacturing the same.

Background Art

[0002] In recent years, environmental contamination due to outflow of oil because of stranding or collision of a large tanker has become a problem. In order to prevent outflows of oil because of these accidents, there has been an effort from the viewpoint of hull construction, for example, shift to double hull. However, measures with respect to a hull steel have not been studied sufficiently. Among them, as an effort from the viewpoint of the hull steel, it has been proposed that the steel in itself is allowed to absorb the energy of a collision to a large extent. However, a stage of practical use is not yet reached.

[0003] As a method for improving the energy absorbability of a collision, Patent Literature 1 proposes a technology to allow the steel plate structure to primarily contain ferrite and strengthen the ferritic phase. This technology is characterized in that the volume fraction of ferrite F is 80% or more and the lower limit of the hardness of ferrite H is specified ($H \geq 400 - 2.6 \times F$).

[0004] Meanwhile, Patent Literature 2 proposes a technology to allow the surface and back layers of a steel plate to contain a retained austenite phase. This technology specifies that C, Si, Mn, and Al are contained, an element for increasing the strength is further contained, as necessary, and 1.0% to 20% of retained gamma on an area fraction basis is contained in the surface and back layers corresponding to one-eighth or more of the plate thickness of the steel plate.

In these technologies, the energy absorbability of a collision is evaluated as a product of the strength (average of yield stress and rupture stress) and the total elongation of the steel. Therefore, an increase in the absorption energy is aimed by improving both the strength and the total elongation.

[0005] In addition to them, Patent Literature 3 discloses a technology to improve the collision energy absorbability by specifying the volume fraction of ferritic phase in the steel plate structure to be 70% or more in the plate thickness center portion and 50% or more in the plate thickness surface layer portion so as to increase the uniform elongation.

[0006] Furthermore, Patent Literature 4 proposes a technology to improve the absorbability of a collision by specifying the area fraction of ferrite occupied in the whole structure of the steel plate to be 90% or more, the average ferrite grain size thereof to be 3 to 12 μm, the maximum ferrite grain size to be 40 μm or less, and the average diameter equivalent to a circle of a second phase to be 0.8 μm or less so as to increase the product of the uniform elongation and the rupture stress.

[0007] Patent literature 5 (JP2001262272 A) refers to a steel plate having $Ceq \leq 0.36$ % (see paragraph [0012]).

Citation List

Patent Literature

[0008]

PTL 1: Japanese Patent No. 3434431
PTL 2: Japanese Patent No. 3499126
PTL 3: Japanese Patent No. 3578126
PTL 4: Japanese Unexamined Patent Application Publication No. 2007-162101

Summary of Invention

Technical Problem

[0009] The evaluation of the absorption energy on the basis of the total elongation used in Patent Literature 1 and Patent Literature 2 above is not always linked to evaluation of the safety of the hull structure and is not appropriate in the case where the collision energy absorbability is discussed. That is, the evaluation of the total elongation including a local elongation, which is influenced by a test piece shape, is not suitable for evaluation of the elongation deformation of a hull shell supported by stiffeners with a long span beyond comparison with the gauge length in a tensile test. Consequently, in the case where the absorption energy of a collision is considered, it is necessary that the evaluation be performed on the basis of the uniform elongation judged to have a high correlation to the elongation characteristics of the hull shell.

[0010] For example, in the technology of Patent Literature 1, the ferrite grain size is 5 μm or less and the hardness of ferrite is Hv 160 to 190 in the example (Patent Literature 1, Table 2) which is somewhat high. Consequently, the total elongation (EL in Table 2) is 23% to 32%. It is estimated that the uniform elongation cannot become larger than this and, therefore, becomes about one-half the total elongation at most.

[0011] Meanwhile, in the technology of Patent Literature 2, in order that the structure contains retained gamma, a little too much alloy element is added and, therefore, the steel in the example is a steel grade having a high carbon equivalent (Ceq) or a high Si content.

[0012] For example, referring to Table 1 of Patent Literature 2, the Ceq of the steel grade A is calculated to be about 0.38, and the Si contents in the steel grades B to Fare 0.55% to 1.94%, so that all of them are somewhat high. Consequently, the ductility is low on the whole, and it is estimated that even when the uniform elongation of only the surface layer is increased by the retained gamma, an improvement of the uniform elongation is difficult because the uniform elongation is constrained by a portion having low ductility.

[0013] No test results related to the toughness or the weldability of these steel grades are disclosed. In this regard, the impact absorption energy in Patent Literature 2 refers to EL × (YP + TS/2) in Table 2 and is the product of the total elongation and the strength. Then, as for the material properties of these steel grades, in consideration of the material property of a common thick steel plate, it is estimated that a steel grade having a high Si content has low toughness, and a steel grade having a somewhat high Ceq has a weldability problem.

In general, as for hull steel, a required yield stress is determined on the basis of demands of the design, and the strength rank of the steel is selected in accordance with the part where the steel is used, so that strength more than necessary is not specifically required. Meanwhile, an improvement in the strength causes an increase in cost and degradation in weldability due to, for example, addition of alloy elements, so that an improvement in the absorption energy due to an increase in the strength is not preferable.

[0014] On the other hand, in the technology of Patent Literature 3, an improvement in the uniform elongation is aimed by reducing the amount of addition of alloy element to a somewhat low level and increasing the structure fraction of ferritic phase having a low hardness and high ductility. However, development of a manufacturing method in which the volume fraction of ferritic phase in the plate thickness surface layer portion is increased to the same level of that in the plate thickness center portion has not yet been reached. Also, only the examples in which the plate thicknesses are relatively small 25 mm or less are disclosed. As the plate thickness increases, the amount of water and the time of controlled cooling in the production increase and, therefore, it becomes very difficult to ensure the fraction of ferrite in the plate thickness surface layer portion.

[0015] Patent Literature 4 discloses the information of the chemical composition and the metallurgical structure of the steel, but there are many practically uncertain points in the manufacturing method. That is, in the manufacturing method described in the detailed explanations in the specification, hot rolling and reheating after cooling are recommended. However, inexpensiveness and mass production are indispensable to a shipbuilding steel plate, and there is a fear for commercialization of the process, e.g., reheating, from the viewpoint of the production cost and the term of construction. Meanwhile, Patent Literature 3 indicates that differences in characteristics in the plate thickness direction occur easily in the cooling after rolling. However, there is no consideration of the above indication in Patent Literature 4, evaluation of the characteristics in the example is performed only in the area at one-quarter the plate thickness, and the characteristics of the plate thickness surface layer portion are not disclosed.

[0016] In view of these described above, it is considered that in a steel with excellent energy absorbability of a collision of a ship, there is need of a further improvement in the performance and, in addition, there is room for increase in a producible plate thickness. In particular, establishment of an ideal metal microstructure in consideration of the whole plate thickness of the steel plate including the plate thickness surface layer portion and a breakthrough in the manufacturing method therefor are necessary.

[0017] It is an object of the present invention to provide a steel with excellent collision energy absorbability and a method for manufacturing the same, wherein the energy absorbability of a collision can be enhanced without increasing the cost due to, for example, addition of alloy elements to the steels now in practical use and changing the hull structure design, as compared with those of the steels which have been proposed at the present.

Solution to Problem

[0018] The features of the present invention to solve the above-described problems are as described below.

[0019] A steel according to the present invention is specified to be a steel having a structure composed of at least two phases of ferrite which is a soft phase and pearlite, bainite, martensite, and the like which are hard phases in order to improve the uniform elongation without reducing the strength. In this regard, this structure of the steel was obtained by performing studies under the basic policy to optimize the mechanical properties of the individual phases and, in addition, optimize the combination thereof and is on the basis of the findings described below.

[0020] In general, in a steel having a structure composed of at least two phases, the soft phase plays a role mainly in improving the ductility and toughness and the hard phase plays a role mainly in improving the strength. Then, initially, the properties of a ferritic phase serving as a soft phase were studied in order to improve the uniform elongation. It is clear that a softer phase is more excellent in the uniform elongation. However, in the case where a hard phase is further present, concentration of strain on the soft phase increases and contribution of the soft phase to the uniform elongation increases as the difference between the two phases is large to some extent. In the case where the hard phase is a bainitic phase having relatively low strength, it is necessary that the hardness of the ferritic phase is specified to be Hv 160 or less to increase concentration of strain on the ferritic phase. In this regard, Hv 140 or more is required to allow the tensile strength to become 490 MPa or more.

[0021] Meanwhile, the uniform elongation decreases as the grain size decreases and, therefore, an influence of ferrite grain size on a dual-phase steel was examined. As a result, it was ascertained that the uniform elongation was reduced sharply when the average grain size became less than 2 μm. Here, it was also ascertained that the local elongation was relatively not influenced by the grain size and, therefore, reduction in the total elongation due to a decrease in grain size was relatively small as compared with the reduction in the uniform elongation. Consequently, from this fact as well, it is necessary that a distinction be made between the uniform elongation and the total elongation in the case where the ductility is evaluated.

[0022] Furthermore, the relationship between the proportions of the soft phase and the hard phase and the uniform elongation was examined. As a result, an improvement in the uniform elongation was observed as the volume fraction of ferritic phase increased. In particular, it was found that the uniform elongation was excellent when the volume fraction of ferritic phase was 75% or more in the whole plate thickness. It was found that, in the case where the hardness of the ferritic phase was Hv 140 or more and 160 or less, an influence of, in particular, the plate thickness surface layer portion was large. Therefore, it was made clear that an increase in the volume fraction of ferritic phase in the whole plate thickness was important.

[0023] In order to ensure a predetermined proportion of the volume fraction of ferritic phase, as described above, appropriate control of the cooling condition is necessary. That is, the cooling step is roughly divided into two parts of a former part which is aimed principally at transforming an austenitic phase structure when rolling is finished to a ferritic phase and a latter part which induces transformation to a hard phase.

[0024] As for the cooling in the former part, it is ideal that a steel plate average temperature is lowered promptly from the temperature of (Ar_3 - 50) °C or higher at which the ferrite transformation does not proceed relatively easily to the steel plate average temperature of (Ar_3 - 150) °C or higher to (Ar_3 - 50) °C or lower at which the ferrite transformation proceeds easily from the viewpoint of ferrite phase transformation based on the phase equilibrium and kinetics. However, as the cooling rate increases, a difference in the cooling rate in the steel plate thickness direction increases. Consequently, in the plate thickness surface layer portion in which the cooling rate is large, transformation to the hard phase, e.g., bainite and martensite, occurs instead of the ferrite transformation. So, it is necessary to suppress this transformation to the hard phase. In the case where the cooling rate of the steel plate surface is specified to be 100°C/sec or more, generation of the hard phase can be suppressed by controlling the temperature of the steel plate surface in such a way as not to become lower than 400°C.

[0025] Meanwhile, after the cooling, a ferritic phase is generated in the process of recuperation of the temperature of the steel plate surface due to the heat of the plate thickness center portion. In this regard, the average cooling temperature of the steel plate may not reach (Ar_3 - 150) °C or higher to (Ar_3 - 50) °C or lower by one run of cooling because of a large plate thickness or the like. In that case, cooling is repeated a plurality of times.

[0026] On the other hand, a method of control in which the cooling rate is reduced and, thereby, generation of the hard phase is suppressed in the steel plate surface layer portion is also considered. However, the cooling takes a time so much that it reduces the production efficiency. At the same time, in the case where the cooling rate is less than 100°C/sec, the relationship between the cooling rate and the upper limit temperature of the hard phase generation is changed complicatedly, so that the control is difficult. In the case where the cooling rate is 100°C/sec or more, the control is easy because transformation to the hard phase can be suppressed unless the temperature does not become 400°C or lower.

[0027] After cooling to a predetermined temperature is performed by the above-described cooling method, the ferrite transformation in the plate thickness center portion is allowed to proceed promptly. A time of 10 seconds or more is required until the volume fraction of the ferritic phase becomes 75% or more.

[0028] Next, the cooling in the latter part to generate the hard phase was studied from the viewpoint of an influence of the structure on the strength. The strength is influenced by the strength and the volume fraction of the hard phase significantly. However, it was ascertained that, under a constant chemical composition of the steel, even when the structure was changed, control to obtain optional strength was possible by selecting a production condition.

[0029] That is, in the case where the volume fraction of hard phase is relatively large, predetermined strength can be obtained by specifying the cooling stop temperature after rolling to be somewhat high and specifying the cooling rate to be somewhat small so as to specify the strength of the hard phase to be somewhat low.

[0030] On the other hand, in the case where the volume fraction of hard phase is relatively small, predetermined strength can be obtained by specifying the cooling stop temperature after rolling to be somewhat low and specifying the cooling rate to be somewhat large so as to specify the strength of the hard phase to be somewhat high.

[0031] In this regard, such control of the strength is achieved relatively easily on the basis of the principle that, in the case where the volume fraction of hard phase is small, the concentration of carbon concentrated from the ferritic phase to the hard phase at the time of transformation increases and, thereby, the hard phase is hardened more easily.

[0032] Meanwhile, the method for controlling the cooling rate may be air cooling insofar as predetermined conditions are satisfied. In the case where the temperature is necessary to be held, a heat insulating cover is disposed on the steel, and in the case where the cooling rate is necessary to be increased, water cooling is performed.

[0033] Finally, the toughness is also one of the most important mechanical properties of the steel used for ships and the like. As for the steel, having a structure primarily containing ferrite, which is the subject of the present invention, the toughness is influenced mainly by the ferrite grain size and, therefore, it is necessary that the grain size is specified to be desirably 40 μm or less. The grain size can be controlled by, for example, specifying the reduction ratio to be a predetermined value or more in a rolling step.

[0034] The features of the present invention on the basis of the above-described findings are as described below.

[0035] A first invention is a steel with excellent collision energy absorbability, with a steel composition consisting of, on a percent by mass basis, C: 0.05% to 0.16%, Si: 0.1% to 0.5%, Mn: 0.8% to 1.6%, Sol. Al: 0.002% to 0.07%, and optionally further Ti: 0.003% to 0.03%, and/or Nb: 0.005% to 0.05%, and/or at least one type selected from the group consisting of Cr: 0.1% to 0.5%, Mo: 0.02% to 0.3%, V: 0.01% to 0.08%, and Cu: 0.1% to 0.6%; and/or Ni: 0.1% to 0.5%, and the remainder being iron and incidental impurities and satisfying Ceq ≤ 0.36%, wherein Ceq is represented by Formula (1) below

$$Ceq = C + Mn / 6 + (Cu + Ni) / 15 + (Cr + Mo + V) / 5 \qquad (1)$$

where the symbols of elements express percent by mass of the respective elements,
the structure of this steel including a ferritic phase and a hard phase with a higher hardness than the ferritic phase composed of pearlite and/or bainite and/or martensite, the volume fraction of the ferritic phase being 75% or more in the whole plate thickness, the hardness of the ferritic phase being Hv 140 or more and 160 or less, the average ferrite grain size being 2 μm or more, wherein the ferrite grain size is 40 μm or less,
wherein a ratio of a volume fraction of a ferritic phase in the plate thickness surface layer portion to a volume fraction of a ferritic phase in the plate thickness center portion is 0.925 or more and 1.000 or less, and wherein the plate thickness surface layer portion is specified to be a region from the plate surface to the depth of one tenth the plate thickness, and wherein the steel plate has a thickness of 12 to 50 mm.

[0036] A second invention is a method for manufacturing a steel with excellent collision energy absorbability according to claim 1, characterized by comprising the steps of heating a raw material steel having the steel composition according to claim 1, then performing rolling in the temperature range of the Ar3 point or higher and 850°C or lower at a cumulative reduction ratio of 50% or more and 80% or less, subsequently starting 1st stage cooling from a steel average temperature of (Ar3- 50) °C or higher, performing at least one run of cooling to a steel surface temperature range of 400°C or higher and (Ar3- 50) °C or lower at a steel surface cooling rate of 100°C/sec or more until the steel average temperature becomes (Ar3- 150) °C or higher and (Ar3- 50) °C or lower, subsequently performing air cooling for 10 seconds or more, and performing 2nd stage cooling from the steel average temperature of (Ar3- 150) °C or higher at a steel average cooling rate of 10°C/sec or more until the steel average temperature becomes 300°C or higher and 600°C or lower, wherein the Ar3 point is represented by Formula (2) below

$$Ar_3 = 910 - 310C - 80Mn - 20Cu - 15Cr - 55Ni - 80Mo \qquad (2)$$

where the symbols of elements express percent by mass of the respective elements.

Advantageous Effects of Invention

[0037] According to the present invention, a steel with high uniform elongation and excellent collision energy absorbability can be obtained by using a steel having substantially the same components as those of a common hull steel and a structure composed of 2 or more phases comprising ferrite which is a soft phase and a hard phase, optimizing the mechanical properties of the individual phases, and optimizing the combination thereof. Meanwhile, as for the manufacturing method, the efficiency is not reduced and the controllability is not specifically difficult as compared with the common method for manufacturing a hull steel, so that production can be performed efficiently and stably.

[0038] As a result, a steel with excellent energy absorbability of a collision of a ship can be provided without increasing the cost due to, for example, addition of alloy elements to the steels now in practical use and adding specific production equipments, so that an industrial effect thereof is very large. Also, an environmental protection effect is very large from the viewpoint of prevention of outflow of oil because of stranding or collision of a large tanker.

Description of Embodiments

[0039] The reasons for limiting the individual constituent features of the present invention will be described below.

1. Metal structure

[0040] A steel according to the present invention is a steel with excellent collision energy absorbability, that is, excellent uniform elongation, which has substantially the same components as those of a common hull steel. That is, in order to improve the uniform elongation without reducing the strength, a steel having a structure composed of at least two phases of ferrite which is a soft phase and pearlite, bainite, martensite, and the like which are hard phases is used, the mechanical properties of the individual phases are optimized and, in addition, the combination thereof is optimized.

[0041] The structure of the steel according to the present invention includes a ferritic phase and a hard phase. The hard phase is composed of structures, e.g., pearlite, bainite, and martensite, which have hardness higher than the hardness of the ferritic phase.

Volume fraction of ferritic phase: 75% or more in whole plate thickness

[0042] As the volume fraction of ferritic phase increases, the uniform elongation is improved. Although the metallographic structure changes to some extent in the plate thickness direction, it is necessary that the volume fraction of ferritic phase be 75% or more in the whole plate thickness in order to obtain sufficient uniform elongation. Meanwhile, in the present invention, the plate thickness surface layer portion is specified to be a region from the plate surface to the depth of about one tenth the plate thickness. This plate thickness surface layer portion is a region in which, in the cooling, the cooling rate is relatively large as compared with that in the plate thickness center portion, the hard phase is generated easily, and the uniform elongation is reduced easily. In the case where the whole plate thickness is considered, the fraction is not so large, and an influence thereof on the characteristics is allowable to some extent. However, the influence becomes not negligible if differences in characteristics from the plate thickness center portion increase. Consequently, it is required to ensure the volume fraction of ferritic phase in the same manner also in the plate thickness surface layer portion.

[0043] In this regard, as described above, the main factor which has an influence on the volume fraction of ferritic phase is the cooling rate. Therefore, in order to examine whether the volume fraction of ferritic phase in the whole plate thickness is within the scope of the present invention or not, the volume fractions of ferritic phase in the plate thickness center portion, in which the cooling rate is the smallest in the plate thickness direction, and the plate thickness surface layer portion, in which the cooling rate is the largest in the plate thickness direction, may be measured and examined.

[0044] Ratio of volume fraction of ferritic phase in plate thickness surface layer portion to volume fraction of ferritic phase in plate thickness center portion: 0.925 or more and 1.000 or less

[0045] In addition to the above-described specification of the volume fraction of ferritic phase in the whole plate thickness, it is preferable that the ratio of the volume fraction of ferritic phase in the plate thickness surface layer portion to the volume fraction of ferritic phase in the plate thickness center portion (hereafter may be simply referred to as volume fraction ratio) is specified to be 0.925 or more and 1.000 or less. It is preferable from the viewpoint of collision energy absorbability to specify the volume fraction ratio to be 0.925 or more because a difference in material, in particular a difference in uniform elongation, between the plate thickness surface layer portion and the plate thickness center portion becomes small sufficiently, so that the structure can be assumed to be substantially homogeneous in the plate thickness direction. It is further preferable that the volume fraction ratio is specified to be 0.935 or more. In this regard, the plate thickness surface layer portion is a region in which, in the cooling, the cooling rate is relatively large as compared with that in the plate thickness center portion, the hard phase is generated easily and, thereby, the volume fraction of ferritic phase in the plate thickness center portion becomes larger than that in the plate thickness surface layer portion. Consequently, the upper limit of the volume fraction ratio is specified to be 1.000.

Hardness of ferritic phase: Hv 140 or more and 160 or less

[0046] As the hardness of the ferritic phase decreases, the uniform elongation is improved. The hardness of the ferritic phase is specified to be Hv 160 or less because the uniform elongation is excellent when the hardness is Hv 160 or less. On the other hand, the hardness is specified to be Hv 140 or more in order to obtain the strength of TS 490 MPa or more.

Average grain size of ferritic phase: 2 μm or more

[0047] As the average grain size of the ferritic phase becomes small, the uniform elongation is reduced. In particular, if the average grain size becomes less than 2 μm, the uniform elongation is degraded sharply, so that the average grain size is specified to be 2 μm or more. In the case where the average grain size of the ferritic phase is specified to be 2 μm or more, high uniform elongation can be obtained stably. The average grain size of the ferritic phase is preferably 4 μm or more. In this regard, in the case where the ferrite structure is too large, the steel may become soft, so that the average grain size of the ferritic phase is preferably 40 μm or less to obtain a tensile strength of 490 MPa or more stably.

2. Chemical composition

[0048] The reasons for specifying the chemical composition of the steel according to the present invention will be described. In this regard, every component % represents percent by mass.

Ceq: 0.36 or less

[0049] As the Ceq becomes high, the strength increases and the strength of ferrite also increases, so that the uniform elongation is reduced, and if 0.36 is exceeded, the uniform elongation is reduced significantly. Meanwhile, the Ceq is an indicator of the toughness of a welding heat affected zone (HAZ). If 0.36 is exceeded, the HAZ toughness of the large-heat-input-welding is reduced. Consequently, the Ceq is specified to be 0.36 or less. Here, the Ceq is determined on the basis of Formula (1) below.

$$Ceq = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo + V)/5 \quad (1)$$

where the symbols of elements express percent by mass of the respective elements.

C: 0.05% to 0.16%

[0050] Carbon is contained to ensure the strength. If the amount is less than 0.05%, an effect thereof is not sufficient, and if 0.16% is exceeded, a structure primarily including ferrite is not obtained and the uniform elongation is reduced. Therefore, the amount of C is specified to be within the range of 0.05% to 0.16%.

Si: 0.1% to 0.5%

[0051] Silicon is contained as a deoxidizing agent at a steel making stage and an element to enhance the strength. If the amount is less than 0.1%, an effect thereof is not sufficient, and if 0.5% is exceeded, the ductility is reduced. Therefore, the amount of Si is specified to be within the range of 0.1% to 0.5%.

Mn: 0.8% to 1.6%

[0052] Manganese is contained to ensure the strength. If the content is less than 0.8%, an effect thereof is not sufficient, and if more than 1.6% is contained, a structure primarily including ferrite is not obtained. Therefore, the amount of Mn is specified to be 0.8% to 1.6%.

Sol. Al: 0.002% to 0.07%

[0053] Aluminum is contained for deoxidation. If the amount of Sol. Al is less than 0.002%, an effect thereof is not sufficient, and if more than 0.07% is contained, a surface flaw of the steel is generated easily. Therefore, the amount of Sol. Al is specified to be within the range of 0.002% to 0.07%, and preferably within the range of 0.01% to 0.05%.

[0054] The basic chemical components in the present invention are as described above, and the remainder is composed of iron and incidental impurities. Furthermore, in order to improve the strength and the toughness, Ti and Nb can be contained as optional elements.

Ti: 0.003% to 0.03%

[0055] In order to further improve the toughness, Ti can be contained. At heating in rolling or at welding, Ti generates TiN, makes austenite grains finer, and improves the base material toughness and the welding HAZ toughness. If the content thereof is less than 0.003%, an effect thereof is not sufficient, and if the content is more than 0.03%, the welding HAZ toughness is reduced. Therefore, in the case where Ti is contained, the amount thereof is preferably within the range of 0.003% to 0.03%, and is further preferably within the range of 0.005% to 0.02%.

Nb: 0.005% to 0.05%

[0056] In order to enhance the strength, Nb can be contained. If the content thereof is less than 0.005%, an effect thereof is not sufficient, and if the content is more than 0.05%, the welding HAZ toughness is reduced. Therefore, in the case where Nb is contained, the amount thereof is preferably within the range of 0.005% to 0.05%, and is further preferably within the range of 0.005% to 0.03%.

[0057] Furthermore, in order to enhance the strength, at least one type of Cr, Mo, V, and Cu can be contained.

Cr: 0.1% to 0.5%

[0058] If Cr is less than 0.1%, an effect thereof is insufficient, and if 0.5% is exceeded, the weldability and the welding heat affected zone toughness are reduced. Therefore, in the case where Cr is contained, the content is preferably within the range of 0.1% to 0.5%.

Mo: 0.02% to 0.3%

[0059] If Mo is less than 0.02%, an effect thereof is insufficient, and if 0.3% is exceeded, the weldability and the welding HAZ toughness are reduced significantly. Therefore, in the case where Mo is contained, the content is preferably within the range of 0.02% to 0.3%.

V: 0.01% to 0.08%

[0060] If V is less than 0.01%, an effect thereof is insufficient, and if 0.08% is exceeded, the toughness is reduced significantly. Therefore, in the case where V is contained, the content is preferably within the range of 0.01% to 0.08%.

Cu: 0.1% to 0.6%

[0061] If Cu is less than 0.1%, an effect thereof is not sufficient, and if more than 0.6% of Cu is added, concern about Cu cracking increases. Therefore, in the case where Cu is contained, the content is preferably within the range of 0.1% to 0.6%, and is further preferably within the range of 0.1% to 0.3%.

[0062] Furthermore, in order to improve the toughness, Ni can also be contained.

Ni: 0.1% to 0.5%

[0063] If the content of Ni is less than 0.1%, an effect thereof is not sufficient, and if 0.5% is exceeded, the steel cost increases significantly. Therefore, in the case where Ni is contained, the content is preferably within the range of 0.1% to 0.5%.

3. Production condition

[0064] The steel with excellent collision energy absorbability according to the present invention can be produced under the production condition described below.

[0065] Initially, a molten steel having the above-described composition is produced in a converter or the like and is made into a raw material steel (slab) by continuous casting or the like. Subsequently, the raw material steel is heated to a temperature of 900°C to 1,150°C and is subjected to hot rolling.

[0066] In order to obtain good toughness, it is effective to specify the heating temperature to be low and reduce the grain size before rolling. If the heating temperature is lower than 900°C, a rolling load becomes too large, and if 1,150°C is exceeded, not only austenite grains are coarsened so as to reduce the toughness but also an oxidation loss becomes considerable so as to reduce the yield. The heating temperature is specified to be preferably 900°C to 1,150°C because stable rolling can be performed and good toughness is obtained. A more preferable heating temperature range is 1,000°C to 1,100°C from the viewpoint of the toughness.

[0067] Rolling condition: cumulative reduction ratio of 50% or more in temperature range of Ar_3 point or higher and 850°C or lower

[0068] A steel plate having a predetermined plate thickness is produced by hot-rolling the raw material steel. The start temperature of the hot rolling is not specifically limited. Also, the rolling condition is not specifically limited except the rolling condition in an unrecrystallization temperature range of austenite described later. Meanwhile, for the purpose of grain size reduction grain size regulation of the austenite recrystallized structure prior to the rolling in the unrecrystallization temperature range of austenite described later, it is preferable that rolling be performed at a cumulative reduction ratio of 30% or more in an austenite recrystallization temperature range.

[0069] In the rolling, in order to improve the toughness, a forming strain is introduced in a temperature range of the Ar_3 point or higher and 850°C or lower, which is the unrecrystallization temperature range of austenite. In the case where the cumulative reduction ratio is 50% or more, the ferrite grain size after transformation becomes small sufficiently and the toughness is improved. Therefore, the cumulative reduction ratio during rolling is specified to be 50% or more in a temperature range of the Ar_3 point or higher and 850°C or lower, and preferably be 55% or more. The upper limit of the cumulative reduction ratio is not necessarily specified, although 80% or less is industrially preferable. In this regard, the Ar_3 point is determined on the basis of Formula (2) below,

$$Ar_3 = 910 - 310C - 80Mn - 20Cu - 15Cr - 55Ni - 80Mo \quad (2)$$

where the symbols of elements express percent by mass of the respective elements.

The rolling finishing temperature is preferably the Ar_3 point or higher. If the rolling finishing temperature is lower than the Ar_3 point, a rolled ferrite structure remains and, thereby, the elongation of a finally obtained steel may be reduced. Therefore, the finish rolling temperature is preferably the Ar_3 point or higher.

[0070] In the present invention, the steel plate after hot rolling is subjected to former part cooling serving as the first step cooling, air cooling and, subsequently, latter part cooling serving as the second step cooling.

[0071] The former part cooling serving as the first step cooling before the air cooling is aimed principally at transforming an austenitic phase structure when rolling is finished to a ferritic phase and is performed to ensure predetermined volume fraction, hardness, and grain size of the ferritic phase by the air cooling following the former part cooling. Therefore, the former part cooling is started from the temperature of (Ar_3 - 50)°C or higher on a steel plate average temperature basis and is performed to the temperature range of (Ar_3 - 150)°C or higher to (Ar_3 - 50)°C or lower, so that ferrite transformation may proceed easily during the air cooling from the viewpoints of phase equilibrium and kinetics and the transformation may be controlled easily.

[0072] In the former part cooling, it is ideal that the temperature of (Ar_3 - 50)°C or higher on a steel plate average temperature basis is cooled to the steel plate average temperature of (Ar_3 - 150)°C or higher to (Ar_3 - 50)°C or lower promptly. Therefore, the cooling rate is specified to be 100°C/sec or more on a steel surface cooling rate basis. However, as the cooling rate increases, a difference in the cooling rate in the steel plate thickness direction increases and, thereby, transformation to a hard phase, e.g., bainite and martensite, occurs instead of the ferrite transformation in the plate thickness surface layer portion in which the cooling rate is large. Consequently, it is necessary that this transformation to the hard phase be suppressed. In the case where the steel plate surface cooling rate is specified to be 100°C/sec or more, generation of the hard phase in the former part cooling step can be suppressed by controlling the temperature of the steel plate surface at the time of finishing of the former part cooling in such a way as not to become lower than 400°C. If the cooling rate is less than 100°C/sec on a steel surface cooling rate basis, the ferrite transformation and the transformation of the hard phase proceed complicatedly, so that control of the transformation during the air cooling becomes difficult. Therefore, 100°C/sec or more is employed. In the case where the cooling rate of 100°C/sec or more on a steel surface cooling rate basis is ensured and cooling to a predetermined temperature range is performed in one stroke, the driving force of the ferrite transformation in the air cooling step after the former part cooling can be increased and the volume fraction, the hardness, and the grain size of the ferritic phase generated in the air cooling step concerned can be met the specifications according to the present invention.

[0073] In the cooling method of the former part cooling, at least one run of cooling is performed until the steel plate surface temperature reaches the temperature range of 400°C or higher and (Ar_3 - 50)°C or lower.

[0074] This is because if the steel plate surface temperature is lower than 400°C, transformation to the hard phase proceeds rapidly, so that a predetermined volume fraction of ferritic phase is not obtained and, on the other hand, if (Ar_3 - 50)°C is exceeded, an effect of cooling the whole plate thickness is hardly exerted. Therefore, as for the condition of the steel plate surface temperature in the former part cooling, in the case where cooling to the temperature range of

400°C or higher and (Ar_3 - 50)°C or lower on a steel plate surface temperature basis is performed, a predetermined volume fraction of ferritic phase can be obtained in the steel plate surface layer portion as well while an effect of cooling the whole plate thickness is ensured. In this regard, when the steel plate average temperature do not reach a predetermined temperature by one run of cooling, the steel plate surface is recuperated by the heat of the plate thickness center portion and, thereafter, cooling can be repeated under the same condition. Here, the cooling for the second and subsequent runs are performed after the steel plate surface is recuperated for the purpose of preventing excessive cooling of the steel plate surface layer portion only. According to this, balance between the cooling behavior of the whole steel plate including the plate thickness center portion and the cooling behavior of the steel plate surface layer portion can be achieved.

[0075] The air cooling after the former part cooling is performed in a temperature range of (Ar_3 - 150)°C to (Ar_3 - 50)°C on a steel average temperature basis for 10 seconds or more.

[0076] The air cooling after the former part cooling is performed to ensure predetermined volume fraction, hardness, and grain size of the ferritic phase. As for the air cooling temperature range, if the steel average temperature is lower than (Ar_3 - 150)°C, it takes a long time to allow ferrite transformation to proceed, and if the temperature is higher than (Ar_3 - 50)°C, the transformation ratio of ferrite does not reach a predetermined fraction. Therefore, the air cooling temperature range is specified to be (Ar_3 - 150)°C or higher to (Ar_3 - 50)°C or lower on a steel average temperature basis. If the air cooling time is less than 10 seconds, the ferrite transformation does not proceed sufficiently, predetermined dispersion control of ferritic phase (volume fraction of ferritic phase: 75% or more, average grain size: 2 μm or more) cannot be achieved and, in addition, diffusion of C from the ferritic phase to the austenitic phase does not proceed sufficiently, so that the hardness of ferritic phase does not become Hv 160 or less. Therefore, the air cooling time is specified to be 10 seconds or more. In this manner, predetermined volume fraction, hardness, and grain size of the ferritic phase can be ensured by performing air cooling in the cooling temperature range of (Ar_3 - 150)°C to (Ar_3 - 50)°C on a steel average temperature basis for 10 seconds or more.

[0077] In this regard, in the case where the shape and the surface temperature of the steel, the cooling condition, and the like are provided, the steel average temperature determined on the basis of simulation calculation or the like can be used.

[0078] In the latter part cooling serving as the second step cooling, cooling is performed from a temperature of (Ar_3 - 150)°C or higher on a steel average temperature basis to 300°C to 600°C at a cooling rate of 10°C/sec or more.

[0079] In the latter part cooling serving as the second step cooling, the cooling start temperature-cooling rate-cooling finishing temperature are controlled in order to ensure the predetermined strength by inducing transformation from an austenitic phase to a hard phase. As the cooling start temperature becomes low, the strength is reduced, and if the steel average temperature becomes lower than (Ar_3 - 150)°C, the predetermined strength is not obtained. Therefore, the cooling start temperature is specified to be (Ar_3 - 150)°C or higher for the purpose of ensuring the predetermined strength.

[0080] As the steel average cooling rate becomes large, the strength is enhanced, and if the steel average cooling rate is less than 10°C/sec, the predetermined strength is not obtained. Therefore, the steel average cooling rate is specified to be 10°C/sec or more for the purpose of ensuring the predetermined strength.

As the cooling finishing temperature becomes low, the strength is enhanced, and if cooling to lower than 300°C is performed, the ductility and toughness is degraded. Conversely, if cooling is stopped at a temperature higher than 600°C, the predetermined strength is not obtained. Therefore, the cooling finishing temperature is specified to be 300°C or higher and 600°C or lower on a steel average temperature basis from the viewpoint of optimization of the strength and the ductility and toughness.

EXAMPLE 1

[0081] Examples will be described below. Table 1 shows components of sample steels used in the examples. The remainder not indicated was composed of iron and incidental impurities. The steel grades A to H shown in Table 1 are steels having chemical compositions satisfying the present invention and the steel grade I exhibits a Ceq out of the scope of the present invention (over the upper limit of 0.36%)

[Table 1]

[0082]

Table 1

Steel grade	C	Si	Mn	P	S	Sol.Al	N	Cu	Ni	Cr	Mo	V	Ti	Nb	Ceq	Remarks
A	0.15	0.26	1.06	0.009	0.005	0.027	0.0031	-	-	-	-	-	-	-	0.33	Invention example
B	0.14	0.23	1.15	0.007	0.003	0.022	0.0028	-	-	-	-	-	-	-	0.33	Invention example
C	0.12	0.32	1.33	0.010	0.003	0.030	0.0034	-	-	-	-	-	-	-	0.34	Invention example
D	0.11	0.24	1.41	0.009	0.003	0.047	0.0022	-	-	-	-	-	0.011	-	0.35	Invention example
E	0.15	0.28	1.11	0.008	0.001	0.020	0.0031	-	-	-	-	-	0.009	0.010	0.34	Invention example
F	0.08	0.25	1.36	0.004	0.003	0.032	0.0032	0.19	0.20	-	-	-	0.008	-	0.33	Invention example
G	0.08	0.20	1.34	0.007	0.001	0.029	0.0032	-	-	-	0.16	0.047	-	0.009	0.34	Invention example
H	0.06	0.18	1.17	0.006	0.002	0.028	0.0018	0.27	0.28	0.12	0.11	0.043	-	0.016	0.35	Invention example
I	0.15	0.31	1.29	0.011	0.002	0.027	0.0031	-	-	-	-	-	-	-	0.37	Comparative example

Note: Underlined data is out of the scope of the present invention.
Ceq=C+Mn/6+(Cu+Ni)/15+(Cr+Mo+V)/5 (symbols of elements express contents (percent by mass) of the respective elements)

[0083] Cast slabs having these steel compositions were heated and, thereafter, were rolled into steel plates having plate thicknesses of 12 to 50 mm, followed by cooling with various cooling patterns. Table 2 shows production conditions. Steel Nos. 1 to 10 are invention examples satisfying the chemical composition and the production condition according to the present invention. Steel Nos. 11 to 16 are comparative examples in which the production condition or the chemical composition is out of the scope of the present invention.

[Table 2]

[0084]

Table 2

Steel No.	Steel grade	Plate thickness (mm)	Reduction ratio at to 850°C (%)	Formar part cooling					Air cooling time between former part cooling and latter part cooling (sec)	Latter part cooling			Ar_3 (°C)	Remarks
				Start temperature (steel plate average) (°C)	Cooling rate (steel plate surface) (°C/sec)	The number of cooling runs (run)	Surface temperature at stop of cooling* (°C)	Finishing temperature (steel plate average) (°C)		Start temperature (steel plate average) (°C)	Cooling rate (steel plate average) (°C/sec)	Finishing temperature (steel plate average) (°C)		
1	A	12	70	780	135	1	600	680	30	650	80	550	779	Invention example
2	B	16	65	770	180	1	450	670	12	650	60	520	775	Invention example
3	C	25	60	750	225	3	530-590	660	20	640	40	500	766	Invention example
4	D	30	60	750	210	2	420-520	670	25	650	20	510	763	Invention example
5	E	19	50	770	135	I	540	690	40	660	60	570	775	Invention example
6	F	35	60	740	190	3	530-610	670	30	650	20	500	762	Invention example
7	G	50	50	750	270	4	460-520	680	70	660	10	430	765	Invention example
8	H	50	50	750	200	5	600-630	690	50	680	10	340	766	Invention example
9	B	19	65	760	210	3	590-630	660	15	640	50	540	775	Invention example
10	C	20	65	750	220	3	540-640	650	20	630	50	510	766	Invention example
11	I	19	65	760	210	3	600-620	660	30	640	50	500	760	Comparative example

(continued)

Steel No.	Steel grade	Plate thickness (mm)	Reduction ratio at to 850°C (%)	Formar part cooling					Air cooling time between former part cooling and latter part cooling (sec)	Latter part cooling			Ar_3 (°C)	Remarks
				Start temperature (steel plate average) (°C)	Cooling rate (steel plate surface) (°C/sec)	The number of cooling runs (run)	Surface temperature at stop of cooling* (°C)	Finishing temperature (steel plate average) (°C)		Start temperature (steel plate average) (°C)	Cooling rate (steel plate average) (°C/sec)	Finishing temperature (steel plate average) (°C)		
12	A	12	70	720	100	1	610	640	30	630	80	540	779	Comparative example
13	B	16	65	770	80	1	630	670	12 -	650	60	500	775	Comparative example
14	C	25	60	740	180	1	340	660	20	640	40	510	766	Comparative example
15	E	19	50	730	300	3	450-500	610	40	590	60	540	775	Comparative example
16	F	35	60	740	190	3	540-600	670	8	660	20	510	762	Comparative example

Underlined data are out of the scope of the present invention.

*: In the case of a plurality of cooling runs, temperatures in the lowest temperature run and the highest temperature run are shown.

Ar_3(°C) = 910 - 310C - 80Mn - 20Cu - 15Cr - 55Ni - 80Mo (symbols of elements express contents (percent by mass) of the respective elements)

[0085] The microstructures of these steel plates were observed with an optical microscope, and the volume fractions of ferrite in the plate thickness center portion and the plate thickness surface layer portion and the ferrite grain sizes (average grain sizes) were measured. As for the hardness of the ferritic phase, that of the plate thickness center portion and that of the plate thickness surface layer portion were measured with a micro Vickers hardness meter (load: 25 gf) and the average value thereof was determined as the hardness of the ferritic phase.

[0086] Meanwhile, the strength, the uniform elongation, and the toughness were determined as mechanical characteristics. In the tensile test, a JIS No. 1B test piece of the whole thickness was taken in the direction at a right angle to the rolling direction of the steel plate and was tested. The uniform elongation was evaluated as the elongation at a maximum stress. In the impact test, a JIS No. 4 standard test piece was taken parallel to the rolling direction and close to the surface layer (distance between the surface of the steel and an end surface of the test piece was 2 mm or less) and was used for the test. The toughness was evaluated on the basis of vTrs (brittle-ductile transition temperature).

[0087] Table 3 shows the test results of the microstructures, the mechanical characteristics, and the like of the steel plates.

[Table 3]

[0088]

Table 3

Steel No.	Steel grade	Plate thickness (mm)	Ferritic phase					YS (MPa)	TS (MPa)	Uniform elongation (%)	vTrs (°C)	Remarks
			Fraction of phase (%)			Hardness (Hv)	Average grain size (μm)					
			Plate thickness center	Plate thickness surface layer	Surface layer/ center							
1	A	12	78	77	0.987	142	7	419	523	23.4	-46	Invention example
2	B	16	78	75	0.962	145	8	404	532	23.7	-42	Invention example
3	C	25	80	79	0.988	148	11	398	529	23.0	-51	Invention example
4	D	30	80	78	0.975	151	13	407	536	23.1	-60	Invention example
5	E	19	77	75	0.974	143	12	401	525	22.9	-45	Invention example
6	F	35	81	80	0.988	152	11	421	538	22.5	-63	Invention example
7	G	50	82	80	0.976	155	14	407	545	22.3	-54	Invention example
8	H	50	85	84	0.988	159	12	392	540	22.3	-62	Invention example
9	B	19	78	76	0.974	146	9	408	525	23.2	-46	Invention example
10	C	20	81	76	0.938	147	10	399	520	23.6	-52	Invention example
11	I	19	75	69	0.920	147	7	451	548	19.4	-50	Comparative example
12	A	12	70	63	0.900	141	8	401	525	19.5	-29	Comparative example

(continued)

Steel No.	Steel grade	Plate thickness (mm)	Ferritic phase					YS (MPa)	TS (MPa)	Uniform elongation (%)	vTrs (°C)	Remarks
			Fraction of phase (%)			Hardness (Hv)	Average grain size (μ m)					
			Plate thickness center	Plate thickness surface layer	Surface layer/ center							
13	B	16	72	53	0.736	145	10	399	534	18.9	-44	Comparative example
14	C	25	70	33	0.429	146	11	384	530	18.3	-47	Comparative example
15	E	19	70	71	1.014	151	11	392	528	19.2	-40	Comparative example
16	F	35	63	72	1.143	153	12	405	544	18.5	-53	Comparative example

Underlined data are out of the scope of the present invention.

As shown in Table 3, all of Steel Nos. 1 to 10 which are invention examples have excellent characteristics, where TS (tensile strength) is 520 MPa or more and the uniform elongation is 22% or more. Also, all of Steel Nos. 1 to 10 have YS (yield strength) of 390 MPa or more and vTrs of lower than -40°C and, therefore, satisfy YS $\geq$ 355 MPa, TS $\geq$ 490 MPa, uniform elongation $\geq$ 20%, and vTrs $\leq$ 0°C which are aimed characteristics.

[0089] On the other hand, Steel Nos. 11 to 16 are comparative examples. As for Steel No. 11, the Ceq is high, and even when the production condition is devised, predetermined characteristics cannot be obtained, the volume fraction of ferritic phase in the plate thickness surface layer portion is small, and the uniform elongation is poor. As for the Steel No. 12, the cooling start temperature of the former part cooling is too low, so that both the volume fractions of ferritic phase in the plate thickness center portion and the plate thickness surface layer portion are small and the uniform elongation is poor. As for the Steel No. 13, the cooling rate is small relative to the specified cooling rate (100°C/s or more) of the former part cooling, so that the volume fraction of ferritic phase is small and the uniform elongation is poor.

[0090] As for the Steel No. 14, the stop temperature of the former part cooling is too low, so that the volume fraction of ferritic phase is small and the uniform elongation is poor. As for the Steel No. 15, the finishing temperature of the former part cooling is too low, so that the volume fraction of ferritic phase is small and the uniform elongation is poor. As for the Steel No. 16, the air cooling time between the former part cooling and the latter part cooling is small, so that the volume fraction of ferritic phase is small and the uniform elongation is poor.

Claims

1. A steel with excellent collision energy absorbability, with a steel composition consisting of, on a percent by mass basis, C: 0.05% to 0.16%, Si: 0.1% to 0.5%, Mn: 0.8% to 1.6%, Sol. Al: 0.002% to 0.07%,
   and optionally further Ti: 0.003% to 0.03%, and/or
   Nb: 0.005% to 0.05%, and/or
   at least one type selected from the group consisting of Cr: 0.1% to 0.5%, Mo: 0.02% to 0.3%, V: 0.01% to 0.08%, and Cu: 0.1% to 0.6%; and/or
   Ni: 0.1% to 0.5%,
   and the remainder being iron and incidental impurities and satisfying Ceq $\leq$ 0.36%, wherein Ceq is represented by Formula (1) below

   $$Ceq = C + Mn / 6 + (Cu + Ni) / 15 + (Cr + Mo + V) / 5 \quad (1)$$

   where the symbols of elements express percent by mass of the respective elements,
   the structure of this steel including a ferritic phase and a hard phase with a higher hardness than the ferritic phase composed of pearlite and/or bainite and/or martensite, the volume fraction of the ferritic phase being 75% or more in the whole plate thickness, the hardness of the ferritic phase being Hv 140 or more and 160 or less, the average ferrite grain size being 2 μm or more,wherein the ferrite grain size is 40 μm or less,
   wherein a ratio of a volume fraction of a ferritic phase in the plate thickness surface layer portion to a volume fraction of a ferritic phase in the plate thickness center portion is 0.925 or more and 1.000 or less, and wherein the plate thickness surface layer portion is specified to be a region from the plate surface to the depth of one tenth the plate thickness, and wherein the steel plate has a thickness of 12 to 50 mm.

2. A method for manufacturing a steel with excellent collision energy absorbability according to claim 1, **characterized by** comprising the steps of heating a raw material steel having the steel composition according to Claim 1, then performing rolling in the temperature range of the Ar3 point or higher and 850°C or lower at a cumulative reduction ratio of 50% or more and 80% or less, subsequently starting 1st stage cooling from a steel average temperature of (Ar3- 50) °C or higher, performing at least one run of cooling to a steel surface temperature range of 400°C or higher and (Ar3- 50)°C or lower at a steel surface cooling rate of 100°C/sec or more until the steel average temperature becomes (Ar3- 150) °C or higher and (Ar3- 50) °C or lower, subsequently performing air cooling for 10 seconds or more, and performing 2nd stage cooling from the steel average temperature of (Ar3- 150) °C or higher at a steel average cooling rate of 10°C/sec or more until the steel average temperature becomes 300°C or higher and 600°C or lower,
   wherein the Ar3 point is represented by Formula (2) below

   $$Ar3 = 910 - 310C - 80Mn - 20Cu - 15Cr - 55Ni - 80Mo \quad (2)$$

where the symbols of elements express percent by mass of the respective elements.

Patentansprüche

1. Stahl mit ausgezeichneter Absorptionsfähigkeit für Kollisionsenergie mit einer Stahlzusammensetzung, die auf Massenprozentbasis, aus Folgendem besteht: C: 0,05 % bis 0,16 %, Si: 0,1 % bis 0,5 %, Mn: 0,8 % bis 1,6 %, Sol. Al: 0,002 % bis 0,07 %,
und optional des Weiteren aus Ti: 0,003 % bis 0,03 %, und/oder Nb: 0,005 % bis 0,05 %, und/oder
mindestens einem Typ, der aus der Gruppe gewählt wird, die aus Folgendem besteht: Cr: 0,1 % bis 0,5 %, Mo: 0,02 % bis 0,3 %, V: 0,01 % bis 0,08 %, und Cu: 0,1 % bis 0,6 %; und/oder
Ni: 0,1 % bis 0,5 %,
und wobei der Rest Eisen und unvermeidbare Verunreinigungen sind, und Ceq ≤ 0,36 % erfüllt, wobei Ceq durch die unten stehende Formel (1) repräsentiert ist

$$\mathrm{Ceq} = \mathrm{C} + \mathrm{Mn} / 6 + (\mathrm{Cu} + \mathrm{Ni}) / 15 + (\mathrm{Cr} + \mathrm{Mo} + \mathrm{V}) / 5 \qquad (1)$$

wobei die Symbole der Elemente Massenprozent der jeweiligen Elemente ausdrücken,
wobei die Struktur dieses Stahls eine Ferritphase und eine Hartphase mit einer höheren Härte als die Ferritphase beinhaltet, die aus Perlit und/oder Bainit und/oder Martensit besteht, wobei der Volumenanteil der Ferritphase 75 % oder mehr in der gesamten Plattendicke beträgt, die Härte der Ferritphase Hv 140 oder mehr und 160 oder weniger beträgt, die mittlere Ferritkorngröße 2 μm oder mehr beträgt, wobei die Ferritkorngröße 40 μm oder weniger beträgt,
wobei ein Verhältnis eines Volumenanteils einer Ferritphase in dem Abschnitt der Plattendicken-Oberflächenschicht zu einem Volumenanteil einer Ferritphase in dem mittleren Abschnitt der Plattendicke 0,925 oder mehr und 1,000 oder weniger beträgt, und wobei der Abschnitt der Plattendicken-Oberflächenschicht als eine Region von der Plattenoberfläche bis zu der Tiefe von einem Zehntel der Plattendicke spezifiziert ist, und wobei die Stahlplatte eine Dicke von 12 bis 50 mm aufweist.

2. Verfahren zur Herstellung eines Stahls mit ausgezeichneter Absorptionsfähigkeit für Kollisionsenergie nach Anspruch 1, **dadurch gekennzeichnet, dass** es die Schritte zum Erwärmen eines Stahlausgangsmaterials mit der Stahlzusammensetzung nach Anspruch 1 umfasst, das anschließende Durchführen von Walzen im Temperaturbereich des Ar3-Punktes oder höher und 850 °C oder niedriger bei einem kumulativen Reduktionsverhältnis von 50 % oder mehr und 80 % oder weniger, anschließend das Beginnen des Abkühlens der ersten Stufe von einer mittleren Stahltemperatur von (Ar3- 50) °C oder höher, Durchführen von mindestens einem Durchlauf des Abkühlens auf einen Stahloberflächen-Temperaturbereich von 400 °C oder höher und (Ar3- 50)°C oder niedriger bei einer Stahloberflächen-Abkühlungsgeschwindigkeit von 100 °C/Sek oder mehr, bis die mittlere Stahltemperatur (Ar3- 150)°C oder höher und (Ar3- 50)°C oder niedriger wird, anschließend Durchführen von Luftkühlung für 10 Sekunden oder mehr und Durchführen des Abkühlens der zweiten Stufe von der mittleren Stahltemperatur von (Ar3-150)°C oder höher bei einer durchschnittlichen Stahlabkühlungsgeschwindigkeit von 10 °C/Sek oder mehr, bis die mittlere Starttemperatur 300 °C oder höher und 600 °C oder niedriger wird,
wobei der Ar3-Punkt durch die unten stehende Formel (2) präsentiert ist

$$\mathrm{Ar3} = 910 - 310\mathrm{C} - 80\mathrm{Mn} - 20\mathrm{Cu} - 15\mathrm{Cr} - 55\mathrm{Ni} - 80\mathrm{Mo} \qquad (2)$$

wobei die Symbole der Elemente Massenprozent der jeweiligen Elemente ausdrücken.

Revendications

1. Acier ayant une excellente capacité d'absorption d'énergie de collision, ayant une composition d'acier constituée, sur une base de pourcentage en masse, de C : 0,05 % à 0,16 %, Si : 0,1 % à 0,5 %, Mn : 0,8 % à 1,6 %, Al sol. : 0,002 % à 0,07 %,
et éventuellement également Ti : 0,003 % à 0,03 %, et/ou Nb : 0,005 % à 0,05 %, et/ou
au moins un type choisi dans le groupe constitué de Cr : 0,1 % à 0,5 %, Mo : 0,02 % à 0,3 %, V : 0,01 % à 0,08 % et Cu : 0,1 % à 0,6 % ; et/ou

Ni : 0,1 % à 0,5 %,
le reste étant du fer et des impuretés inévitables et satisfaisant Ceq ≤ 0,36 %, où Ceq est représentée par la formule (1) ci-dessous

$$Ceq = C + Mn/6 + (Cu + Ni)/15 + (Cr + Mo V)/5 \qquad (1)$$

dans laquelle les symboles des éléments expriment un pourcentage en masse des éléments respectifs,
la structure de cet acier incluant une phase ferritique et une phase dure ayant une dureté supérieure à la phase ferritique constituée de perlite et/ou de bainite et/ou de martensite, la fraction volumique de la phase ferritique étant de 75 % ou plus dans l'épaisseur totale de la plaque, la dureté de la phase ferritique étant de Hv 140 ou plus et 160 ou moins, la grosseur moyenne des grains de ferrite étant de 2 μm ou plus, la taille des grains de ferrite étant de 40 μm ou moins,
où un rapport d'une fraction volumique d'une phase ferritique dans la partie de couche de surface de l'épaisseur de la plaque à une fraction volumique d'une phase ferritique dans la partie centrale de l'épaisseur de la plaque est de 0,925 ou plus et 1,000 ou moins, et où la partie de couche de surface de l'épaisseur de la plaque est spécifiée comme étant une région depuis la surface de la plaque jusqu'à la profondeur d'un dixième de l'épaisseur de la plaque, et où la plaque d'acier a une épaisseur de 12 à 50 mm.

2. Procédé de fabrication d'un acier ayant une excellente capacité d'absorption d'énergie de collision selon la revendication 1, **caractérisé en ce qu'**il comprend les étapes consistant à chauffer un acier de départ ayant la composition d'acier selon la revendication 1, puis à effectuer un laminage dans la plage de température du point Ar3 ou plus et de 850 °C ou moins à un taux de réduction cumulé de 50 % ou plus et 80 % ou moins, à commencer ensuite un refroidissement de premier stade depuis une température d'acier moyenne de (Ar3 - 50) °C ou plus, à effectuer au moins une opération de refroidissement jusqu'à une plage de température de surface d'acier de 400 °C ou plus et (Ar3 - 50) °C ou moins à une vitesse de refroidissement de surface d'acier de 100 °C/s ou plus jusqu'à ce que la température moyenne d'acier devienne (Ar3 - 150) °C ou plus et (Ar3 - 50) °C ou moins, puis à effectuer un refroidissement à l'air pendant 10 secondes ou plus, et à effectuer un refroidissement de second stade depuis la température d'acier moyenne de (Ar3 - 150) °C ou plus à une vitesse de refroidissement d'acier de 10 °C/s ou plus jusqu'à ce que la température moyenne d'acier devienne 300 °C ou plus et 600 °C ou moins, où le point Ar3 est représenté par la formule (2) ci-dessous

$$Ar3 = 910 - 310C - 80Mn - 20Cu - 15Cr - 55Ni - 80Mo \qquad (2)$$

dans laquelle les symboles des éléments expriment un pourcentage en masse des éléments respectifs.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- JP 2001262272 A **[0007]**
- JP 3434431 B **[0008]**
- JP 3499126 B **[0008]**
- JP 3578126 B **[0008]**
- JP 2007162101 A **[0008]**