US 20170002436A1

(19) United States

(12) Patent Application Publication

KIM et al.

(10) Pub. No.: US 2017/0002436 A1

(43) Pub. Date: Jan. 5, 2017

(54) **FERRITIC LIGHTWEIGHT STEEL SHEET HAVING EXCELLENT STRENGTH AND DUCTILITY AND METHOD FOR MANUFACTURING THE SAME**

(71) Applicants: **POSCO**, Pohang-si (KR); **POSTECH ACADEMY-INDUSTRY FOUNDATION**, Pohang-si (KR)

(72) Inventors: **Han Soo KIM**, Pohang-si (KR); **Nack Joon KIM**, Pohang-si (KR); **Alireza ZARGARAN**, Pohang-si (KR); **Chang Young SON**, Pohang-si (KR); **Min Seo KOO**, Pohang-si (KR)

(21) Appl. No.: **15/199,616**

(22) Filed: **Jun. 30, 2016**

(30) **Foreign Application Priority Data**

Jul. 1, 2015 (KR) 10-2015-0094345

Publication Classification

(51) **Int. Cl.**

C21D 9/46	(2006.01)
C22C 38/02	(2006.01)
C22C 38/06	(2006.01)
C22C 38/04	(2006.01)
C21D 8/02	(2006.01)
C22C 38/12	(2006.01)

(52) **U.S. Cl.**

CPC ***C21D 9/46*** (2013.01); ***C21D 8/0205*** (2013.01); ***C21D 8/0226*** (2013.01); ***C21D 8/0231*** (2013.01); ***C21D 8/0236*** (2013.01); ***C21D 8/0263*** (2013.01); ***C21D 8/0273*** (2013.01); ***C22C 38/12*** (2013.01); ***C22C 38/06*** (2013.01); ***C22C 38/04*** (2013.01); ***C22C 38/02*** (2013.01); *C21D 2211/005* (2013.01)

(57) **ABSTRACT**

A ferritic steel sheet according to an exemplary embodiment of the present invention includes C at 0.01 to 0.3 wt %, Mn at 0.5 to 8 wt %, Al at 5 to 12 wt %, and Nb at 0.015 to 0.2 wt % based on an entire composition of 100 wt %, and a remaining part of Fe and an impurity.

FIG. 1

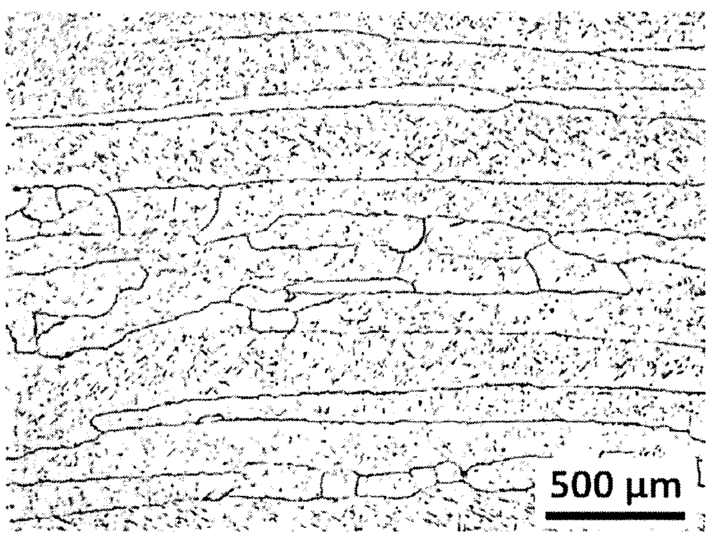


FIG. 2

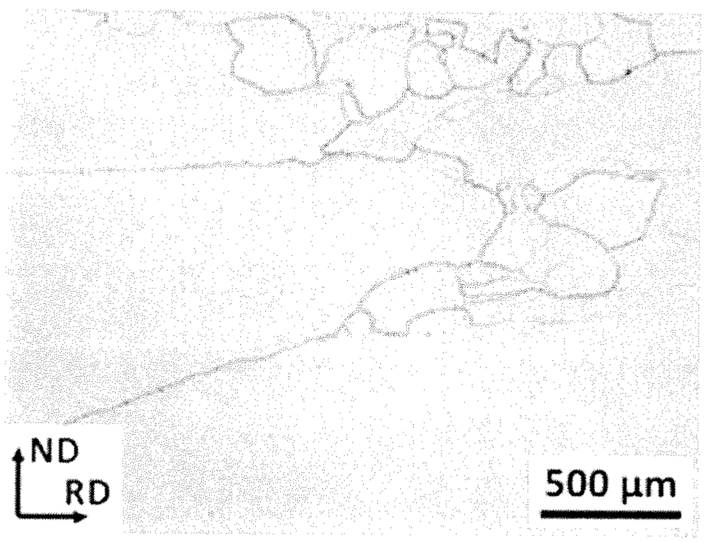


FIG. 3

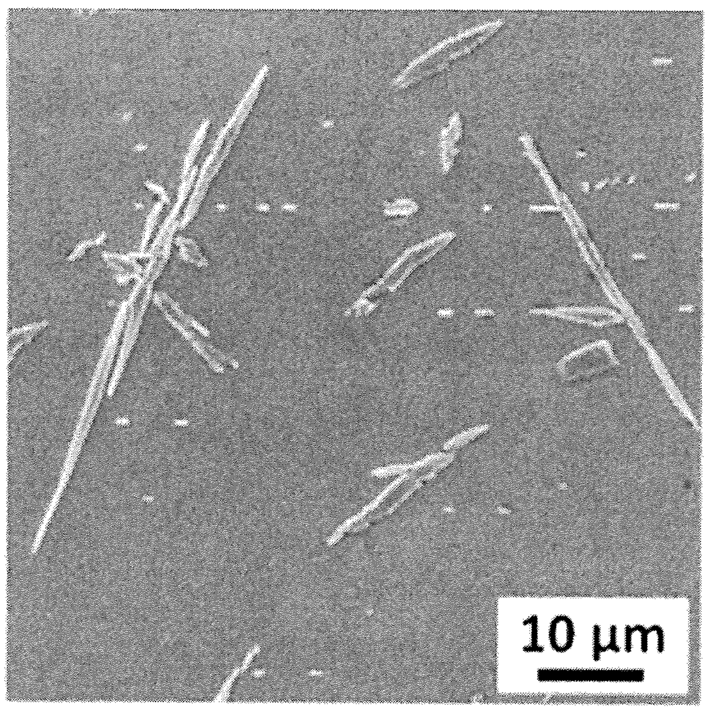


FIG. 4

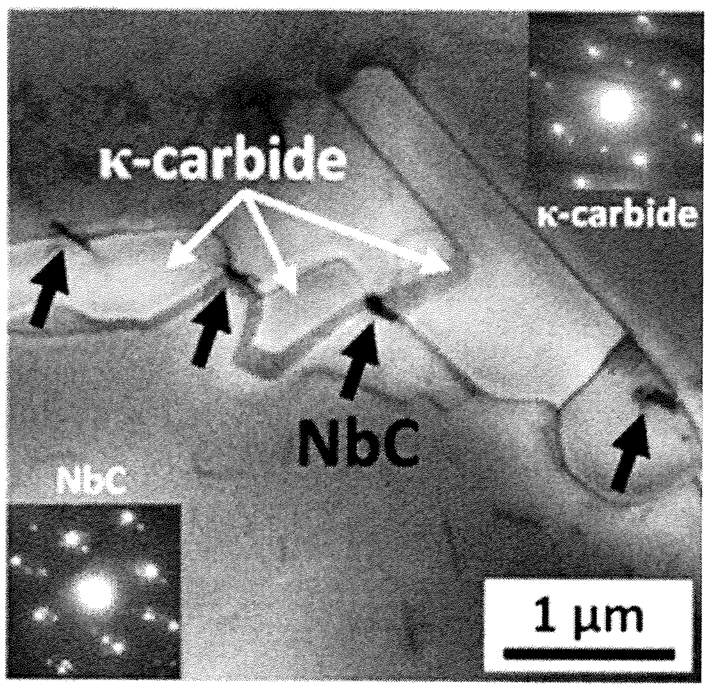


FIG. 5

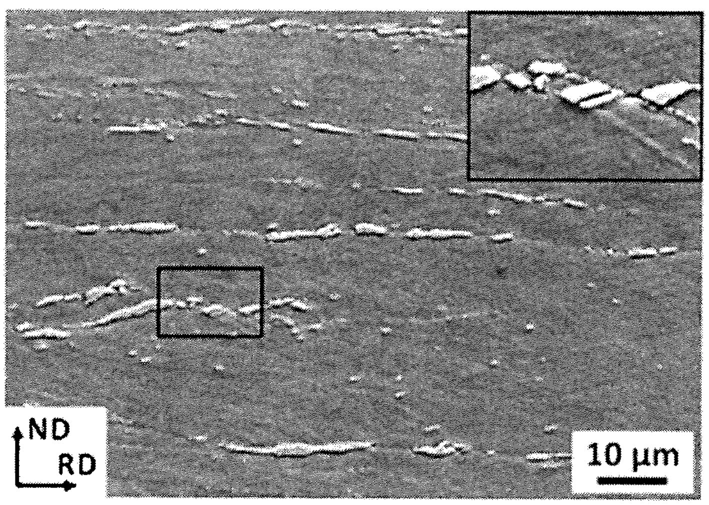


FIG. 6

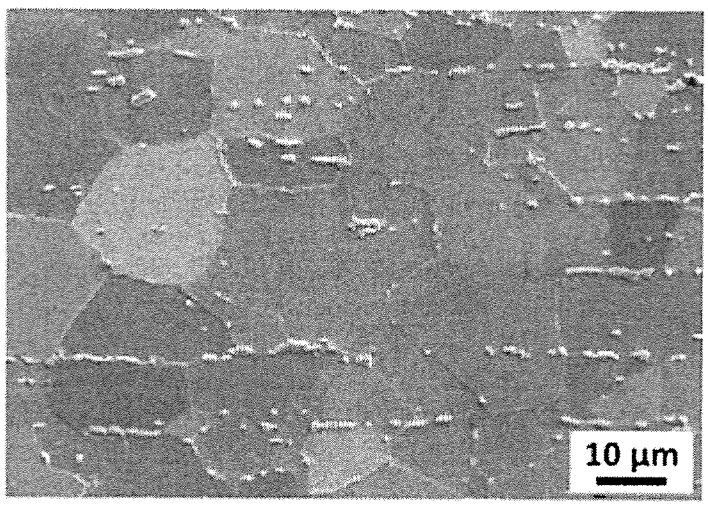


FIG. 7

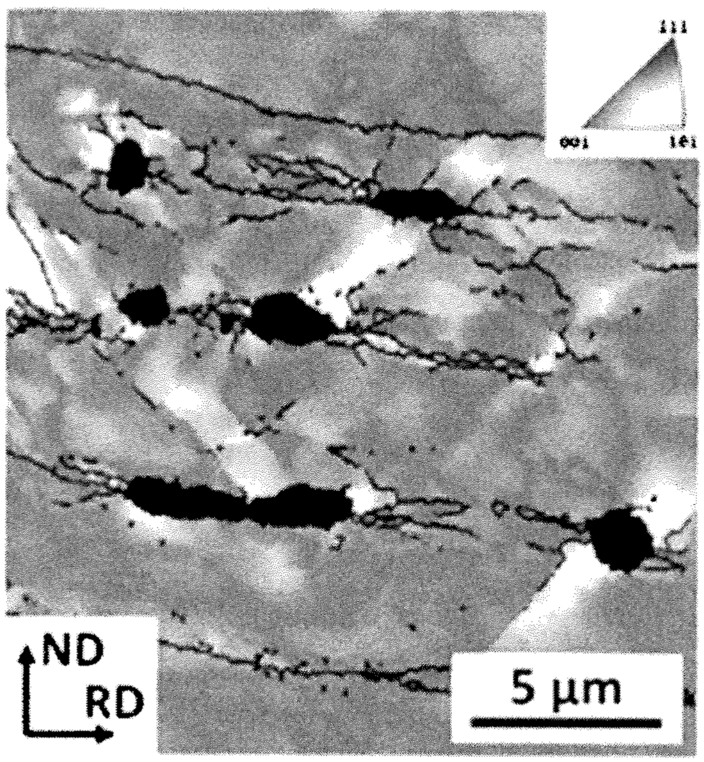


FIG. 8

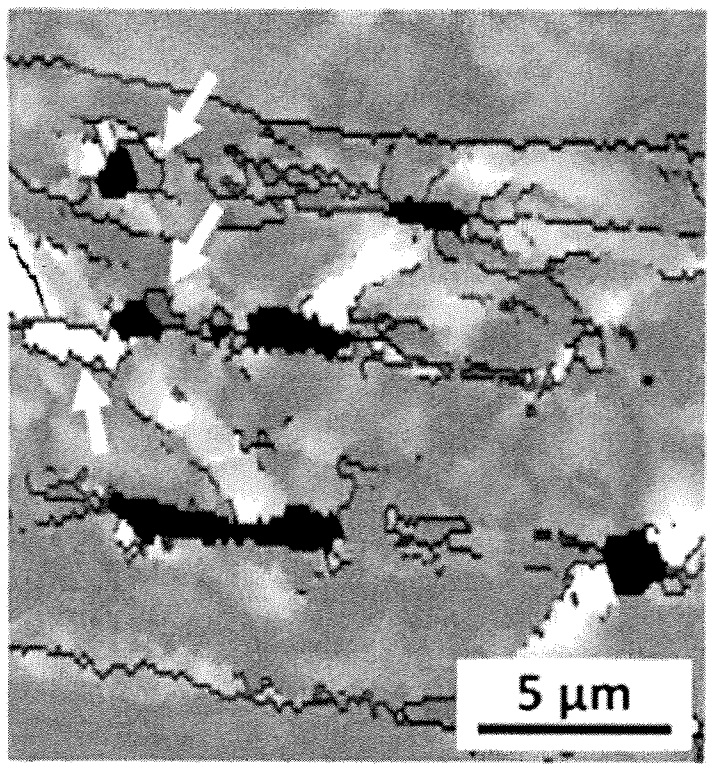


FIG. 9

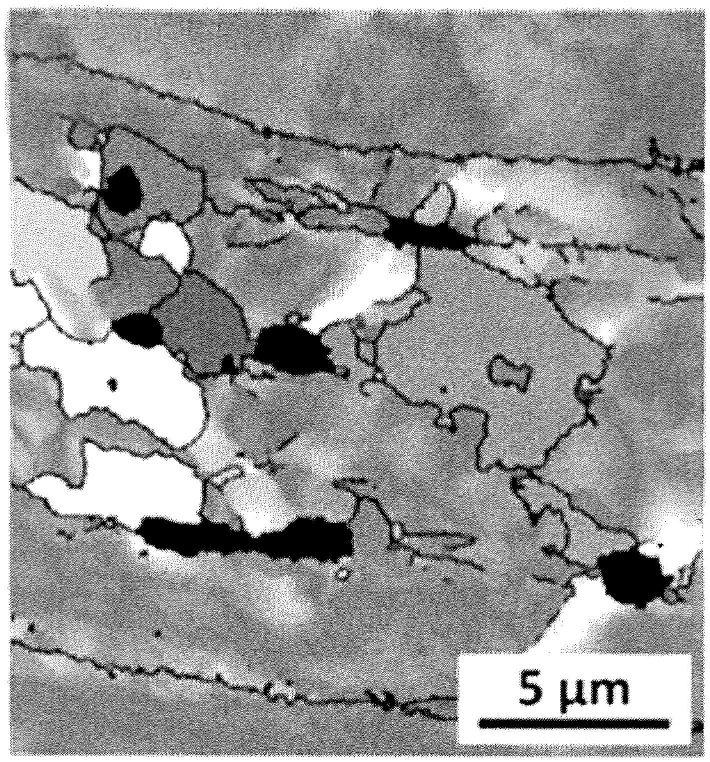


FIG. 10

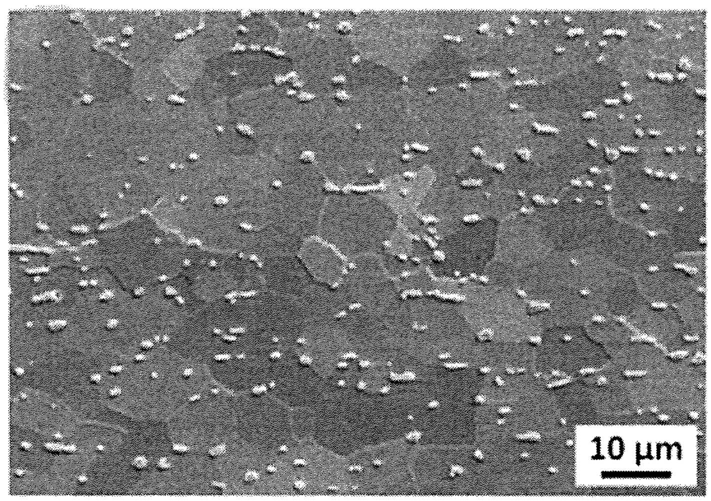
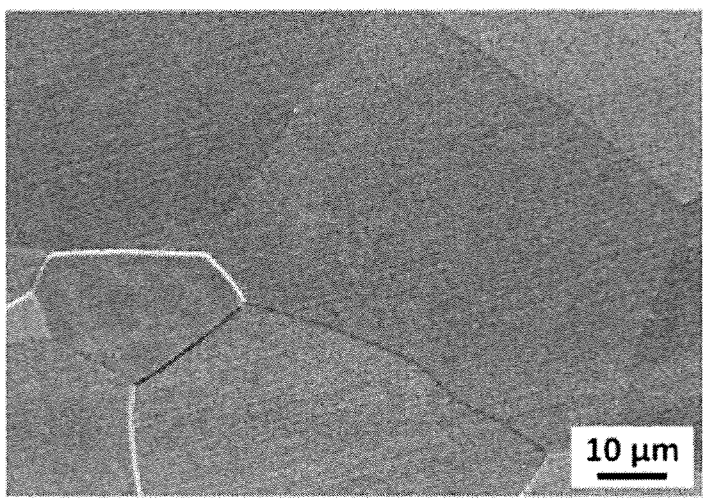


FIG. 11



FERRITIC LIGHTWEIGHT STEEL SHEET HAVING EXCELLENT STRENGTH AND DUCTILITY AND METHOD FOR MANUFACTURING THE SAME

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to and the benefit of Korean Patent Application No. 10-2015-0094345 filed in the Korean Intellectual Property Office on Jul. 1, 2015, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] (a) Field of the Invention

[0003] The present invention relates to a ferritic lightweight steel sheet having high strength and high ductility and a manufacturing method thereof.

[0004] (b) Description of the Related Art

[0005] Because lightweight steels containing large amount of Al in steels have high specific strength, the lightweight steels have been spotlighted as advanced construction materials such as for automobile parts. The lightweight steel may be divided into a ferritic lightweight steel, an austenite-based lightweight steel, and a ferrite-austenite 2-phase structure (duplex) lightweight steel.

[0006] The ferritic lightweight steel does not require addition of alloy elements for austenite stability such that the ferritic lightweight steel is economical in terms of alloy cost compared with other lightweight steels.

[0007] However, when the Al content exceeds 8 wt %, a problem that the ductility of the ferritic lightweight steel is significantly deteriorated has been reported. This is because of ordered structure formation and excessively high solid solution strengthening effect when bonding energy of Fe and Al is high such that an activity of a dislocation is significantly suppressed.

[0008] In general, C is one of the most effective alloying elements for strength improvement of the iron, however when C is added to the ferritic lightweight steel, a κ-carbide ($(Fe,Mn)_3AlC$) is formed in a grain boundary such that a brittle fracture is caused, so C is generally controlled to a very low level to suppress the formation of the κ-carbide.

[0009] It is generally widely known that the size of the grain in the structural material has a major impact on the mechanical properties, however in research of the ferritic lightweight steel, attempts to improve the physical properties by controlling the size of the grain have been shown to be insufficient. The size of the grain of most ferritic lightweight steel that has been studied is very coarse at 40 to 90 μm, and accordingly there is a drawback that the strength and the ductility are low compared with an equivalent carbon steel such that the ferritic lightweight steel is unfavorable for commercialization.

[0010] The above information disclosed in this Background section is only for enhancement of understanding of the background of the invention and therefore it may contain information that does not form the prior art that is already known in this country to a person of ordinary skill in the art.

SUMMARY OF THE INVENTION

[0011] The present invention provides a ferritic lightweight steel sheet having high strength and high ductility.

[0012] The present invention also provides a manufacturing method of the ferritic lightweight steel sheet having high strength and high ductility.

[0013] A ferritic steel sheet with high strength and high ductility according to an exemplary embodiment of the present invention includes C at 0.01 to 0.3 wt %, Mn at 0.5 to 8 wt %, Al at 5 to 12 wt %, and Nb at 0.015 to 0.2 wt % based on an entire composition of 100 wt %, and a remaining part of Fe and an impurity.

[0014] An average grain size of a ferrite crystal existing in the steel sheet may be 30 μm or less. It is preferable that the average grain size of the ferrite crystal is 15 μm or less.

[0015] The ferritic steel sheet may include Si at 0.04 to 2.0 wt %, Cr at 2.0 wt % or less (0% is not included), Mo at 1.0 wt % or less (0% is not included), Ni at 1.0 wt % or less (0% is not included), Ti at 0.1 wt % or less (0% is not included), V at 0.2 wt % or less (0% is not included), B at 0.01 wt % or less (0% is not included), Zr at 0.2 wt % or less (0% is not included), or a combination thereof based on the entire composition of 100 wt %.

[0016] The ferritic steel sheet may include a κ-carbide of a spherical shape, an oval shape, an acicular shape, or a band shape existing inside the ferritic steel sheet.

[0017] The κ-carbide at 1 to 10 vol % may be included based on the entire 100 vol % of the steel sheet.

[0018] A particle size of the κ-carbide may be in a range of 20 nm to 10 μm, and the κ-carbide may be present in a range of 5×10^3 to 1×10^6 particles per unit area (mm2).

[0019] The ferritic steel sheet may include a NbC compound existing inside the ferritic steel sheet.

[0020] The NbC compound at 0.01 to 1 vol % may be included based on the entire 100 vol % of the steel sheet.

[0021] A particle size of the NbC compound may be in the range of 10 nm to 1 μm, and the NbC compound may be present in the range of 5×10^4 to 3×10^5 particles per unit area (mm^2).

[0022] A content of Al may be in the range of 10 to 12 wt %.

[0023] A manufacturing method of a ferritic steel sheet according to an exemplary embodiment of the present invention includes: heating a slab including C at 0.01 to 0.3 wt %, Mn at 0.5 to 8 wt %, Al at 5 to 12 wt %, and Nb at 0.015 to 0.2 wt % based on an entire composition of 100 wt %, and a remaining part of Fe and an impurity; hot rough-rolling the heated slab; cold-rolling the steel sheet of which the hot rough rolling is completed; and annealing the cold-rolled steel sheet of which the cold rolling is completed.

[0024] A heating temperature may be in a range of 1000 to 1250° C. in the step of heating the slab.

[0025] A temperature may be in the range of 700 to 1250° C. in the step of hot rough rolling the slab.

[0026] Warm-rolling the slab at a temperature of 600 to 850° C. after the hot rough rolling may be further included.

[0027] Intermediate-annealing the slab at a temperature of 700 to 900° C. after the warm rolling may be further included.

[0028] Warm-rolling the slab at a temperature of 600 to 850° C. after the intermediate annealing may be further included.

[0029] Hot rolling the slab at a temperature of 1000 to 1250° C. after the hot rough rolling may be further included.

[0030] Intermediate annealing the slab at a temperature of 700 to 900° C. after the hot rolling may be further included.

[0031] In the step of the cold-rolled sheet annealing, the cold-rolled sheet annealing temperature may be in a range of 650 to 900° C.

[0032] The slab may include Si at 0.04 to 2.0 wt %, Cr at 2.0 wt % or less (0% is not included), Mo at 1.0 wt % or less (0% is not included), Ni at 1.0 wt % or less (0% is not included), Ti at 0.1 wt % or less (0% is not included), V at 0.2 wt % or less (0% is not included), B at 0.01 wt % or less (0% is not included), Zr at 0.2 wt % or less (0% is not included), or a combination thereof based on the entire composition of 100 wt %.

[0033] According to an exemplary embodiment of the present invention, the ferritic steel sheet of which specific gravity is low, tensile strength is high, and tensile elongation is large may be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] FIG. **1** is an optical microscope photograph of an inventive steel 1 of which hot rough rolling is completed.

[0035] FIG. **2** is an optical microscope photograph of a comparative steel 2 of which hot rough rolling is completed.

[0036] FIG. **3** is a scanning electron microscope (SEM) photograph of an inventive steel 1 of which hot rough rolling is completed.

[0037] FIG. **4** is a transmission electron microscope (TEM) photograph of an inventive steel 1 of which hot rough rolling is completed.

[0038] FIG. **5** is a SEM photograph of an inventive steel 1 of which warm rolling is completed.

[0039] FIG. **6** is a SEM photograph of an inventive steel 1 of which intermediate annealing is completed.

[0040] FIG. **7** is an electron backscatter diffraction (EBSD) analysis photograph of an inventive steel 1 of a cold-rolled steel sheet of which cold rolling is completed before annealing.

[0041] FIG. **8** is an EBSD analysis photograph of an inventive steel 1 of which a cold-rolled sheet is annealed at 700° C. for 5 min.

[0042] FIG. **9** is an EBSD analysis photograph of an inventive steel 1 of which a cold-rolled sheet annealed at 700° C. for 15 min.

[0043] FIG. **10** is a SEM photograph of an inventive steel 1 after cold-rolled sheet annealing is completed.

[0044] FIG. **11** is a SEM photograph of a comparative steel 2 after cold-rolled sheet annealing is completed.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0045] The advantages and features of the present invention and a method of achieving them will be made clear by referring to the exemplary embodiments described below in detail with reference to the accompanying drawings. However, the present invention is not limited to the exemplary embodiments described below and may be implemented in various ways, the exemplary embodiments are provided to complete the present invention and make the scope of the present invention clear to those skilled in the art, and the present invention is defined only by the range described in claims. Like reference numerals indicate like constituent elements throughout the specification.

[0046] Therefore, well-known technologies will not be described in detail in some exemplary embodiments in order to avoid unclear description of the present invention. Unless otherwise defined, all terms (including technical and scientific terms) used herein may be used with meanings that those skilled in the art understand. Throughout the specification, unless explicitly described to the contrary, the word “comprise” and variations such as “comprises” or “comprising” will be understood to imply the inclusion of stated elements but not the exclusion of any other elements. Further, singular terms include plural terms, unless specifically stated otherwise.

[0047] Also, throughout the drawings, RD means a rolling direction, and ND means a direction perpendicular to the surface of a steel sheet.

[0048] A ferritic steel sheet according to an exemplary embodiment of the present invention, with reference to an entire composition of 100 wt %, includes C at 0.01 to 0.3 wt %, Mn at 0.5 to 8 wt %, Al at 5 to 12 wt %, and Nb at 0.015 to 0.2 wt %, and the rest may include Fe and impurities.

[0049] The ferritic steel sheet, with reference to the entire composition of 100 wt %, may further include Si at 0.04 to 2.0 wt %, Cr at 2.0 wt % or less (0% is not included), Mo at 1.0 wt % or less (0% is not included), Ni at 1.0 wt % or less (0% is not included), Ti at 0.1 wt % or less (0% is not included), V at 0.2 wt % or less (0% is not included), B at 0.01 wt % or less (0% is not included), Zr at 0.2 wt % or less (0% is not included), or combinations thereof.

[0050] First, a reason of composition limitation will be described.

[0051] C has an important role in strength improvement for a specific gravity of the steel sheet by the solid solution reinforcement effect, and is an essential element for refining a grain of a final product by forming NbC carbide and kappa carbide (κ-carbide, $(Fe,Mn)_3AlC$). To obtain these effects in the present invention, it is preferable that an additive amount of carbon of 0.01 wt % or more is included. When the additive amount of carbon exceeds 0.3 wt %, because high temperature precipitation of κ-carbide is promoted such that hot workability and cold workability of the steel sheet are greatly deteriorated, it is preferable that the content of carbon is limited to the range of 0.01 to 0.3 wt % in the present invention. In detail, the inventive steel may include C at 0.03 wt % to 0.25 wt %.

[0052] Mn not only suppresses embrittlement by formation of an intermetallic compound by interfering with ordering of Fe and Al, but also forms MnS by being combined with S that is inevitably included in the manufacturing process of the steel, thereby having a function of suppressing grain boundary embrittlement by a solid solution S. When the additive amount of Mn is less than 0.5 wt %, it is difficult to obtain the above-described effects, and when it exceeds 8 wt %, austenite is formed such that uniform ferrite morphology may not be obtained. In detail, Mn may be included in the range of 1 wt % to 6 wt %.

[0053] Al is an element reducing the specific gravity of the steel sheet, and when an additive amount there is less than 5 wt %, the specific gravity reduction effect is insignificant, while when the additive amount is more than 12 wt %, the ordering is promoted such that the ductility of the steel sheet may be deteriorated. In detail, Al may be included in the range of 7 wt % to 12 wt %. Also, in the present invention, even if a high content of Al is added, the deterioration of the ductility may be compensated such that Al may be included in the range 10 to 12 wt % in the exemplarily embodiment of the present invention.

[0054] Nb as a carbonitride forming element improves the strength and the formability of the steel, and has a function of improving toughness of the steel by grain refinement. For the above-described effects, it is preferable that the additive amount thereof is 0.015 wt % or more. When the content exceeds 0.2 wt %, the manufacturing processability and the physical properties of the steel may be degraded by excessive carbide precipitation. In detail, Nb may be included in the range of 0.02 wt % to 0.15 wt %.

[0055] Si improves the strength of the steel sheet by solid solution strengthening and has a low specific gravity such that Si is an effective element for specific strength improvement of the steel sheet. When the additive amount thereof is less than 0.04 wt %, it may be difficult to obtain the above-described effects, and when exceeding 2.0 wt %, the hot workability is not only deteriorated, but also the forming of the intermetallic compound is promoted such that the embrittlement of the steel may result.

[0056] Cr not only improves a strength-ductility balance of the steel, but also has a function of suppressing excessive precipitation of the κ-carbide. When the additive amount is more than 2.0 wt %, the ductility and the toughness of the steel are degraded, and the hot workability and the cold workability may be largely deteriorated as the precipitation of a carbide such as cementite is promoted at a high temperature.

[0057] Mo has a function of improving the strength and the toughness of the steel. When the additive amount thereof exceeds 1.0 wt %, as the excessive hard phase or precipitation is generated, the manufacturing processability and the physical properties of the steel may be degraded.

[0058] Ni has a function of suppressing excessive precipitation of the κ-carbide and improving the strength and toughness. When the additive amount exceeds 1.0 wt %, the forming of the intermetallic compound is promoted such that physical properties of the steel are degraded.

[0059] Ti as the carbonitride forming element has effects of improving the strength and the formability of the steel and suppressing grain coarsening, however when the additive amount exceeds 0.1 wt %, the toughness may be deteriorated.

[0060] V has effects of forming minute carbonitride and suppressing the grain coarsening, and when the additive amount exceeds 0.2 wt %, the toughness may be deteriorated.

[0061] B improves the toughness by a small addition amount, but promotes the formation of hard second phase. When the additive amount thereof exceeds 0.01 wt %, the hot workability, or the ductility and the toughness may be deteriorated.

[0062] Zr is an effective element for suppressing the deterioration of the hot workability or the toughness by the segregation of S, however when the additive amount exceeds 0.2 wt %, the toughness may be deteriorated.

[0063] An average grain size of the ferritic steel sheet may be in the range of 30 μm or less. When the grain size exceeds 30 μm, the tensile strength and the ductility may be deteriorated. In detail, the average grain size may be in the range of 15 μm or less.

[0064] The ferritic steel sheet may include the κ-carbide. The κ-carbide is the compound represented by Chemical Formula $(Fe,Mn)_3AlC$ having a perovskite structure.

[0065] The κ-carbide may be in the range of 0.5 to 10 vol % with reference to an entire 100 vol % of the steel sheet. When the κ-carbide is in the range of less than 0.5 vol %, there is negligible ferrite grain refinement effect, and when exceeding 10 vol %, the workability and the ductility may be deteriorated.

[0066] The particle size of the κ-carbide is in the range of 20 nm to 10 μm, and 5×10^3 to 1×10^6 particles may exist per unit area (mm^2).

[0067] The κ-carbide may have a spherical shape, an oval shape, an acicular shape, or a band shape. In detail, the κ-carbide may have the spherical shape or the oval shape. In the case of the acicular shape or the band shape, a problem that the κ-carbide causes a brittle fracture may be generated. In this case, the spherical shape or the oval shape means that an aspect ratio is less than 4, and the κ-carbide of the acicular shape or the band shape means that the aspect ratio is 4 or more.

[0068] Also, the ferritic steel sheet may further include a NbC compound inside the steel sheet.

[0069] The NbC compound may be in the range of 0.01 to 1 vol % with reference to an entire 100 vol % of the steel sheet. When the NbC compound is present at less than 0.01 vol %, the effect of suppressing the coarsening of the ferrite grain is small, while when the NbC compound is present at more than 1 vol %, the ductility is deteriorated by excessive carbide formation.

[0070] The particle size of the NbC compound is in the ranges of 10 nm to 1 μm, and 5×10^4 to 3×10^5 particles per unit area (mm^2). In the above-described ranges, the effect of suppressing the coarsening of the ferrite grain may be improved.

[0071] The ferritic steel sheet may have tensile strength of 450 MPa or more. In detail, the tensile strength may be 650 MPa or more.

[0072] Also, the ferritic steel sheet may have a density reduction ratio of 7% or more.

[0073] Next, a manufacturing method of the ferritic steel sheet according to an exemplary embodiment of the present invention will be described.

[0074] Firstly, a slab including C at 0.01 to 0.3 wt %, Mn at 0.5 to 8 wt %, Al at 5 to 12 wt %, and Nb at 0.015 to 0.2 wt % with reference to the entire composition of 100 wt % and the rest of Fe and the impurities is heated (S**100**).

[0075] The temperature for heating the slab may be in the range of 1000 to 1250° C. If the temperature for heating the slab is less than 1000° C., the rollability may be deteriorated. Also, if the temperature for heating the slab exceeds 1250° C., a liquid metal embrittlement phenomenon may occur by partial melting of Al. In detail, the heating may be performed in the range of 1100° C. to 1200° C.

[0076] Next, the slab with the heating completed is hot rough rolled (S**200**). The hot rough rolling temperature is in the range of 700 to 1250° C. If the hot rough rolling temperature is less than 700° C., the rollability may be deteriorated, while if the hot rough rolling temperature exceeds 1250° C., grain boundary embrittlement is generated by Al having a low melting point such the rollability may be deteriorated.

[0077] After the hot rough rolling is completed, warm rolling may be performed (S**210**).

[0078] The warm rolling temperature may be in the range of 600 to 850° C. If the warm rolling temperature is less than 600° C., an overload may be applied to a rolling roller, and if the warm rolling temperature exceeds 850° C., the recrystallization occurs in the steel sheet such that it may be difficult to control the final microstructure.

[0079] After the warm rolling is completed, the steel sheet may be intermediate-annealed (S**211**). The intermediate annealing temperature may be in the range of 700 to 900° C. If the intermediate annealing temperature is less than 700° C., the annealing time is long such that the productivity may be deteriorated. If the intermediate annealing temperature exceeds 900° C., the kappa carbide is dissolved such that a ferrite recrystallization nuclei generator may not function, such that the grain refinement effect may be reduced. In detail, the intermediate annealing temperature may be in the range of 800 to 900° C.

[0080] After the intermediate annealing is completed, the warm rolling may be performed again (S**211**-**1**).

[0081] The warm rolling temperature may be in the range of 600 to 850° C. If the warm rolling temperature is less than 600° C., the overload may be applied to the rolling roller, and if the warm rolling temperature exceeds 850° C., the recrystallization occurs in the steel sheet such that it may be difficult to control the final microstructure.

[0082] After the hot rough rolling is completed, the hot rolling may be performed S**220**.

[0083] The hot rolling temperature may be in the range of 1000 to 1250° C. If the hot rolling temperature is less than 1000° C., the rollability may be deteriorated, and if the hot rolling temperature exceeds 1250° C., the grain boundary embrittlement is generated by Al having the low melting point such that the rollability may be deteriorated.

[0084] After the hot rolling is completed, the steel sheet may be intermediate-annealed (S**221**). The intermediate annealing temperature may be in the range of 700 to 900° C. If the intermediate annealing temperature is less 700° C., the annealing time is long such that the productivity may be deteriorated. If the intermediate annealing temperature exceeds 900° C., the kappa carbide is dissolved such that the ferrite recrystallization nuclei generator may not function, such that the grain refinement effect may be reduced. In detail, the intermediate annealing temperature may be in the range of 800 to 900° C.

[0085] Next, the steel sheet is cold-rolled (S**300**). A reduction ratio in the cold rolling process may be in the range of 30 to 90%. In this case, the reduction ratio is (the thickness of the steel sheet before the rolling-the thickness of the steel sheet after the rolling)/(the thickness of the steel sheet before the rolling)×100.

[0086] Next, the cold-rolled steel sheet is annealed (S**400**). The annealing temperature of the cold-rolled steel sheet (cold-rolled sheet) may be in the range of 650 to 900° C. If the cold-rolled sheet annealing temperature is less than 650° C., the recrystallization is delayed such that the productivity is deteriorated, and if the cold-rolled sheet annealing temperature exceeds 900° C., the κ-carbide is dissolved such that the austenite is formed and it is difficult to obtain the uniform microstructure, and the coarsening by the grain growth is occurred such that the physical properties may be deteriorated.

[0087] The κ-carbide of the acicular shape is present like in FIG. **3** inside the steel sheet after the completion of hot rough rolling. This type of κ-carbide causes the brittle fracture. However, in the manufacturing method of the ferritic steel sheet according to an exemplary embodiment of the present invention, the κ-carbide is segmented in the warm rolling and the cold rolling, and the κ-carbide of the acicular shape is modified into the spherical shape or the oval shape like in FIG. **6** and FIG. **10** to be finely and uniformly distributed inside the steel sheet.

[0088] When a force is applied from the outside thereof, since the stress is concentrated to the interface of the κ-carbide and the matrix, the strain is concentrated in the vicinity of the κ-carbide during the rolling. Accordingly, during the cold-rolled sheet annealing, the κ-carbide acts as the nucleation site of a new BCC crystal, and the grain size of the final microstructure may be refined.

[0089] Also, a NbC compound exists like in FIG. **4** inside the steel sheet after the completion of hot rolling. The NbC compound has a function of suppressing dynamic recrystallization during the hot rough rolling and suppressing the grain growth during the cold-rolled sheet annealing. Accordingly, the size of the grain may be refined.

[0090] Hereafter, exemplary embodiments will be described. However, the following exemplary embodiments only illustrate the present invention, and the contents of the present invention are not limited by the following exemplary embodiments.

Exemplary Embodiment 1

[Slab Heating and Hot Rough Rolling]

[0091] The slab having the composition as shown in Table 1 and the remaining part of Fe and the impurities is prepared. The thickness of the slab is 70 mm, and the width thereof is 140 mm. The specific gravities of the partial inventive steel and comparative steel are shown in Table 1. The slab is heated at 1200° C. for 1 h 30 min. Next, the slab is subjected to the hot rough rolling at 25% of the reduction ratio per a pass at 1100° C. and is finish-rolled at 1000° C. The thickness of the steel sheet of which the hot rough rolling is completed is 20 mm. FIG. **1** is an optical microscope photograph of an inventive steel 1 of which hot rough rolling is completed. FIG. **2** is an optical microscope photograph of a comparative steel 2 of which hot rough rolling is completed. Referring to FIG. **1** and FIG. **2**, it may be confirmed that the grain size of the inventive steel 1 may be finer than that of the comparative steel 2.

[0092] FIG. **3** is a scanning electron microscope (SEM) photograph of an inventive steel 1 of which a hot rough rolling is completed. Referring to FIG. **3**, it may be confirmed that the κ-carbide of the acicular shape is present in the matrix.

[0093] FIG. **4** is a transmission electron microscope (TEM) photograph of an inventive steel 1 of which hot rough rolling is completed. Referring to FIG. **4**, it may be confirmed that the κ-carbide and the NbC compound are present in the base.

TABLE 1

Steel No.	Al (wt %)	Mn (wt %)	Nb (wt %)	Si (wt %)	C (wt %)	Specific gravity (g/cc)
Inventive steel 1	8.3	4.9	0.095	—	0.094	6.96
Inventive steel 2	6.78	5.08	0.095	0.006	0.107	7.11
Inventive steel 3	7.68	5.04	0.095	—	0.107	7.02

TABLE 1-continued

Steel No.	Al (wt %)	Mn (wt %)	Nb (wt %)	Si (wt %)	C (wt %)	Specific gravity (g/cc)
Inventive steel 4	8.49	4.45	0.101	0.07	0.114	6.93
Inventive steel 5	9.53	4.18	0.08	0.05	0.104	6.84
Inventive steel 6	10.45	4.13	0.08	0.05	0.091	6.78
Inventive steel 7	11.8	4.25	0.08	0.06	0.089	6.72
Inventive steel 8	7.86	4.43	0.096	0.04	0.0045	7.00
Inventive steel 9	8.02	4.30	0.089	—	0.0227	6.99
Inventive steel 10	7.33	5.27	0.074	—	0.047	7.05
Inventive steel 11	8.30	4.66	0.032	—	0.088	6.96
Inventive steel 12	8.28	4.42	0.034	0.06	0.204	6.96
Inventive steel 13	11.00	4.51	0.040	0.007	0.210	6.75
Inventive steel 14	6.68	4.62	0.09	1.16	0.098	7.04
Inventive steel 15	8.84	4.40	0.041	0.254	0.216	6.90
Inventive steel 16	8.91	4.64	0.041	0.541	0.213	6.88
Comparative steel 1	8.06	—	—	—	0.0096	7.00
Comparative steel 2	7.89	4.42	—	—	0.0170	6.99

Exemplary Embodiment 1-1

[Hot Rolling, Intermediate Annealing, Hot Rolling, Cold Rolling, and Cold-Rolled Sheet Annealing]

[0094] In Exemplary Embodiment 1, the steel sheet of which the hot rough rolling is completed is hot-rolled at 650° C. to a thickness of 3 mm. The reduction ratio per pass is 30%, and the re-heating is performed for 5 min between passes. After the hot rolling is completed, the intermediate annealing is performed at 850° C. for 15 min, and then air-cooling is performed to room temperature.

[0095] FIG. **5** is a SEM photograph of an inventive steel 1 of which warm rolling is completed. FIG. **6** is a SEM photograph of an inventive steel 1 of which intermediate annealing is completed.

[0096] Referring to FIG. **5** and FIG. **6**, it may be confirmed that the κ-carbide of the acicular shape is segmented to be spherical or oval.

[0097] The steel sheet with a 3 mm thickness is re-heated to 650° C., and then is again warm-rolled to a 1.5 mm thickness. After performing pickling with hydrochloric acid, the warm rolling sheet is cold-rolled to a thickness of 1 mm. Next, the cold-rolled sheet is annealed at 750° C. for 1 h, and then is air-cooled.

[0098] FIG. **7** to FIG. **9** are EBSD analysis photographs of a steel sheet before cold-rolled sheet annealing, after cold-rolled sheet annealing for 5 min, and after being subjected to cold-rolled sheet annealing for 15 min, respectively. Referring to arrows of FIG. **8**, it may be confirmed that a new grain is generated in the vicinity of the κ-carbide with the spherical shape. Accordingly, the κ-carbide with the spherical shape acts as the nucleation site during recrystallization annealing.

[0099] Also, FIG. **10** is a SEM photograph of an inventive steel 1 after cold-rolled sheet annealing is completed.

[0100] Referring to FIG. **10**, the κ-carbide of the spherical shape is distributed along the grain boundary of ferrite crystals. Accordingly, it may be confirmed that the κ-carbide of the spherical shape acts as a grain growth inhibitor.

[0101] FIG. **11** is a SEM photograph of a comparative steel 2 of which cold-rolled sheet annealing is completed. Comparing FIG. **10** and FIG. **11**, it may be confirmed that the grain of the inventive steel 1 is finer compared with the comparative steel 2.

[0102] The grain size of the final material is measured, a tensile test is performed, and a result thereof is shown in Table 2.

TABLE 2

Steel No.	Yield strength (MPa)	Maximum tensile strength (MPa)	Uniform tensile elongation (%)	Entire tensile elongation (%)	Grain size (μm)
Inventive steel 1-1	583.5	673.1	15.5	30.4	9.9
Inventive steel 5-1	634.1	731.5	14.0	26.7	9.5
Inventive steel 6-1	698.6	806.1	11.8	23.6	9.8
Inventive steel 7-1	809.8	935.1	7.2	7.2	11.5
Inventive steel 8-1	529.6	637.0	14.0	30.4	20
Inventive steel 9-1	506.4	614.8	17.6	31.7	14
Inventive steel 10-1	551.7	640.4	17.1	33.6	14
Comparative steel 1-1	413.3	523.7	14.65	31.5	59
Comparative steel 2-1	483.5	595.5	14.2	32.1	36

Exemplary Embodiment 1-2

[Hot Rolling, Cold Rolling, and Cold-Rolled Sheet Annealing]

[0103] The steel sheet with a 20 mm thickness of which the hot rough rolling is completed in Exemplary Embodiment 1 is re-heated for 1 h at 1200° C., and then is air-cooled after hot-rolling the steel sheet to a thickness of 3 mm at 1100° C. The reduction ratio per pass during the hot rolling is 25%. The hot-rolled sheet is pickled with hydrochloric acid and then cold-rolled to a thickness of 1 mm. Next, the cold-rolled sheet is annealed at 750° C. for 1 h and then air-cooled.

[0104] The final grain size of the composition of the inventive steel 10 (referring to Table 1) is measured, the tensile test is performed, and the result thereof is shown in Table 3 as an inventive steel 10-2.

Exemplary Embodiment 1-2-1

[Hot Rolling, Intermediate Annealing, Cold Rolling, and Cold-Rolled Sheet Annealing]

[0105] The steel sheet of which the hot rough rolling is completed in Exemplary Embodiment 1 and has a thickness of 20 mm is re-heated at 1200° C. for 1 h, then is hot-rolled to a thickness of 3 mm at 1100° C. and then air-cooled. The reduction ratio per pass during the hot rolling is 25%. After performing the intermediate annealing for 15 min at 850° C. after completing the hot rolling, the steel sheet is air-cooled to room temperature. The intermediate annealed sheet is pickled with hydrochloric acid and then is cold-rolled to a thickness of 1 mm. Next, the cold-rolled sheet is annealed at 750° C. for 1 h and is air-cooled.

[0106] For the final material having the composition of the inventive steel 10 (referring to Table 1), the tensile test is performed and the result thereof is shown in Table 3 as an inventive steel 10-2-1.

TABLE 3

Steel No.	Yield strength (MPa)	Maximum tensile strength (MPa)	Uniform stretch ratio (%)	Entire stretch ratio (%)	Grain size (μm)
Inventive steel 10-2	529.4	616.1	15.0	28.9	19.8
Inventive steel 10-2-1	543.6	629.4	15.4	28.7	18.6

Exemplary Embodiment 1-3

[Warm Rolling, Intermediate Annealing, Cold Rolling, and Cold-Rolled Sheet Annealing]

[0107] The steel sheet of which the hot rough rolling is completed in Exemplary Embodiment 1 is warm-rolled to a thickness of 3 mm at 650° C. The reduction ratio per pass is 30%, and the re-heating is performed for 5 min between the passes. After completing the warm rolling, the steel sheet is subjected to the intermediate annealing at 850° C. for 15 min and then is air-cooled to room temperature. The intermediate annealed sheet is subjected to pickling with hydrochloric acid and then is cold-rolled to a thickness of 1 mm. Next, the cold-rolled sheet is subjected to the annealing process at 650° C. for 1 h and is air-cooled.

[0108] The grain size for the final material is measured, the tensile test is performed, and the result thereof is shown in Table 4.

Exemplary Embodiment 1-3-1

[0109] This is performed by the same manner as Exemplary Embodiment 1-3, however the cold-rolled sheet having the composition of the inventive steel 2 (referring to Table 1) is subjected to the cold rolled sheet annealing at 700° C. for 1 h and then is air-cooled. The grain size is measured for the final material, the tensile test is performed, and the result is shown in Table 4 as an inventive steel 2-3-1.

Exemplary Embodiment 1-3-2

[0110] This is performed by the same manner as Exemplary Embodiment 1-3, but the cold-rolled sheet having the composition of an inventive steel 4 (referring to Table 1) is subjected to the cold-rolled sheet annealing at 850° C. for 1 min, and then is air-cooled. For the final material, the tensile test is performed and the result thereof is shown in Table 4 as an inventive steel 4-3-2.

Exemplary Embodiment 1-4

[Warm Rolling, Cold Rolling, and Cold-Rolled Sheet Annealing]

[0111] The steel sheet of which the hot rough rolling is completed in Exemplary Embodiment 1 is warm-rolled to a thickness of 3 mm at 650° C. The reduction ratio per pass is 30%, and the re-heating is performed for 5 min between the passes. The warm rolled sheet is subjected to pickling with hydrochloric acid, and then is cold-rolled to a thickness of 1 mm. Next, the cold-rolled sheet is annealed at 650° C. for 1 h and then is air-cooled.

[0112] For the final material having the composition of the inventive steel 4 (referring to Table 1), the tensile test is performed and the result thereof is shown in Table 4 as an inventive steel 4-4.

TABLE 4

Steel No.	Yield strength (MPa)	Maximum tensile strength (MPa)	Uniform stretch ratio (%)	Entire stretch ratio (%)	Grain size (μm)
Inventive steel 1-3	599.6	694.5	16.5	30.7	9.8
Inventive steel 2-3	551.8	683.7	13.7	23.3	18
Inventive steel 3-3	530.7	660.8	16.4	31.5	8.0
Inventive steel 4-3	586.0	707.7	17.9	32.5	7.2
Inventive steel 5-3	645.2	755.6	17.2	32.1	7.6
Inventive steel 6-3	701.4	816.4	14.4	25.1	8.4
Inventive steel 7-3	822.4	946.6	9.7	9.9	8.2
Inventive steel 10-3	548.6	629.6	16.3	30.1	12.3
Inventive steel 11-3	581.1	670.9	15.9	29.7	7.2
Inventive steel 12-3	641.6	756.7	16.9	31.0	6.0
Inventive steel 13-3	728.6	843.2	13.8	22.8	7.1
Inventive steel 14-3	698.1	809.6	15.8	29.1	8.4
Inventive steel 15-3	690.7	804.2	15.4	28.8	7.3
Inventive steel 16-3	785.7	888.3	12.5	23.7	6.1
Inventive steel 2-3-1	551.8	683.7	13.7	23.3	18
Inventive steel 4-3-2	598.5	702.5	15.5	28.3	9.7
Inventive steel 4-4	618.3	729.6	13.8	24.5	9.2
Comparative steel 1-3	402.4	510.1	17.4	41.2	50
Comparative steel 2-3	484.0	592.2	16.9	35.9	32

[0113] Although exemplary embodiments of the present invention were described above, those skilled in the art would understand that the present invention may be implemented in various ways without changing the spirit or necessary features.

[0114] Therefore, the embodiments described above are only examples and should not be construed as being limitative in any respects. The scope of the present invention is determined not by the above description, but by the following claims, and all changes or modifications from the spirit, scope, and equivalents of claims should be construed as being included in the scope of the present invention.

What is claimed is:

1. A ferritic steel sheet including C at 0.01 to 0.3 wt %, Mn at 0.5 to 8 wt %, Al at 5 to 12 wt %, and Nb at 0.015 to 0.2 wt % based on an entire composition of 100 wt %, and a remaining part of Fe and an impurity,

wherein an average grain size of a ferrite crystal existing in the steel sheet is 30 μm or less.

2. The ferritic steel sheet of claim **1**, wherein:

the average grain size of the ferrite crystal is 15 μm or less.

3. The ferritic steel sheet of claim **1**, wherein:

the ferritic steel sheet includes Si at 0.04 to 2.0 wt %, Cr at 2.0 wt % or less (0% is not included), Mo at 1.0 wt % or less (0% is not included), Ni at 1.0 wt % or less (0% is not included), Ti at 0.1 wt % or less (0% is not included), V at 0.2 wt % or less (0% is not included), B at 0.01 wt % or less (0% is not included), Zr at 0.2 wt % or less (0% is not included), or a combination thereof based on the entire composition of 100 wt %.

4. The ferritic steel sheet of claim **1**, wherein:

a κ-carbide of a spherical shape, an oval shape, an acicular shape, or a band shape existing inside the ferritic steel sheet is included.

5. The ferritic steel sheet of claim **4**, wherein:

the κ-carbide at 1 to 10 vol % is included based on the entire 100 vol % of the steel sheet.

6. The ferritic steel sheet of claim **4**, wherein:

a particle size of the κ-carbide is in a range of 20 nm to 10 μm, and

the κ-carbide is present in the range of 5×10^3 to 1×10^6 particles per unit area (mm^2).

7. The ferritic steel sheet of claim **1**, wherein:

a NbC compound existing inside the ferritic steel sheet is included.

8. The ferritic steel sheet of claim **7**, wherein:

the NbC compound at 0.1 to 1 vol % is included based on the entire 100 vol % of the steel sheet.

9. The ferritic steel sheet of claim **7**, wherein:

a particle size of the NbC compound is in the range of 10 nm to 1 μm, and

the NbC compound is present in the range of 5×10^4 to 3×10^5 particles per unit area (mm^2).

10. The ferritic steel sheet of claim **1**, wherein:

a content of Al is in the range of 10 to 12 wt %.

11. A method for manufacturing a ferritic steel sheet, comprising:

heating a slab including C at 0.01 to 0.3 wt %, Mn at 0.5 to 8 wt %, Al at 5 to 12 wt %, and Nb at 0.015 to 0.2 wt % based on an entire composition 100 wt %, and a remaining part of Fe and an impurity;

hot rough-rolling the heated slab;

cold-rolling the steel sheet of which the hot rough rolling is completed; and

annealing the cold-rolled steel sheet of which the cold rolling is completed.

12. The method of claim **11**, wherein:

a heating temperature is in a range of 1000 to 1250° C. in the step of heating the slab.

13. The method of claim **11**, wherein:

a temperature is in the range of 700 to 1250° C. in the step of hot rough rolling the slab.

14. The method of claim **11**, further comprising:

warm-rolling the slab at a temperature of 600 to 850° C. after the hot rough rolling.

15. The method of claim **14**, further comprising:

intermediate-annealing the slab at a temperature of 700 to 900° C. after the warm rolling.

16. The method of claim **15**, further comprising:

warm-rolling the slab in a temperature of 600 to 850° C. after the intermediate annealing.

17. The method of claim **11**, further comprising:

hot rolling the slab in a temperature of 1000 to 1250° C. after the hot rough rolling.

18. The method of claim **17**, further comprising:

intermediate annealing the slab at a temperature of 700 to 900° C. after the hot rolling.

19. The method of claim **11**, wherein:

in the step of the cold-rolled sheet annealing, the cold-rolled sheet annealing temperature is in a range of 650 to 900° C.

20. The method of claim **11**, wherein:

the slab includes Si at 0.04 to 2.0 wt %, Cr at 2.0 wt % or less (0% is not included), Mo at 1.0 wt % or less (0% is not included), Ni at 1.0 wt % or less (0% is not included), Ti at 0.1 wt % or less (0% is not included), V at 0.2 wt % or less (0% is not included), B at 0.01 wt % or less (0% is not included), Zr at 0.2 wt % or less (0% is not included), or a combination thereof based on the entire composition of 100 wt %.

* * * * *