The present invention provides a high-strength composite steel sheet which has a tensile strength of 980 MPa class as well as excellent and excellent anti-delayed fraction property, and also has excellent spot-weldability. The high-strength composite steel sheet comprises a steel satisfying: C: 0.10 to 0.25% (% by mass in case of a chemical component, the same shall apply hereinafter), Si: 1.0 to 3.0%, Mn: 1.5 to 3.0%, P: 0.15% or less, S: 0.02% or less, Al: 0.4% or less, and comprising the remnant made from iron and unavoidable impurities; the contents of Si, Al, Mn and Cr satisfy the relationship of “(Si+Al)/Mn or (Si+Al)/(Mn+Cr)=0.74 to 1.26”; and microstructure is specified.
Fig. 1

A3=910-203°C-
15.2Ni+44.7Si+104V+31.5Mo+30Mn+11Cr-
20Cu+700P+400AL+400Ti
HIGH-STRENGTH COMPOSITE STEEL SHEET HAVING EXCELLENT MOLDABILITY AND DELAYED FRACTURE RESISTANCE

TECHNICAL FIELD

[0001] The present invention relates to a high-strength composite steel sheet which has a tensile strength of 980 MPa or higher as well as excellent formability and excellent anti-delayed fracture property, and also has excellent spot-weldability and is useful as automotive structural parts (body flame members such as pillar, member and reinforcement; bumper, door guard bar, sheet parts, suspension parts, and other reinforcing members).

BACKGROUND ART

[0002] In recent years, for the purpose of reducing fuel consumption due to saving body weight of automobiles and ensuring safety upon collision, demands for high-strength steels have increased more and more. Accordingly, steel sheets having a tensile strength of 980 MPa or higher class have been required in place of those having a tensile strength of 590 MPa class. However, in the case of high-strength steel sheets having a tensile strength of 980 MPa or higher class, deterioration of formability cannot be avoided and there is restriction on applications since it is possible to apply to parts having complicated shapes.

[0003] In the case of high-strength steel sheets having a tensile strength of 980 MPa or higher class, residual stress generated upon press forming increases and thus a risk of delayed fracture enhances. That is, delayed fracture is a phenomenon in which hydrogen in the corrosion medium or atmosphere is diffused and accumulated at dislocations, vacancies and grain boundaries in the structure of steel materials, especially high-strength steel sheets thereby causing embrittlement of the materials, leading to fracture when stress is applied. Therefore, delayed fracture exerts a severe influence on ductility and toughness of steel materials.

[0004] Thus, it is very important to improve, in addition to the strength, formability (i.e., elongation and stretch flangeability) and anti-delayed fracture property so as to respond to the above-described demand of increasing the strength.

[0005] Now various steel sheets including residual austenite in the metal structure are put into practical use as high-strength steel sheets which exhibit excellent formability.

[0006] For example, Non-Patent Document 1 discloses a steel sheet in which a bore expansion property (i.e., stretch flangeability) is enhanced while ensuring a high strength by constituting the metal structure with a composite structure which mainly contains bainitic ferrite and also contains lath-type residual austenite. However, when a tensile strength (TS) becomes a tensile strength of 980 MPa or higher class, this steel sheet shows TS×EI as an indicator of the strength (TS) and ductility (EI) of 9,000 to 10,300 at most and therefore it is hardly to say that the steel sheet is satisfactory.

[0007] It is considered that, in a mass production line of a practical operation using a continuous annealing furnace, a maximum heating temperature is about 900°C and a heating time is 5 minutes or less. However, under the production conditions disclosed in this document, it is required to cool to a temperature within the range from 350 to 400°C in a salt bath after annealing at 950°C for 1,200 seconds, and thus this method is not suited for the practical operation.

[0008] In Patent Document 1, elongation of about 20% and stretch flangeability (λ) of 55% are attained while ensuring a tensile strength of 980 MPa or higher by constituting a matrix phase with a structure composed mainly of bainitic ferrite and 3% or more of residual austenite. However, in this technique, the addition of expensive alloy elements such as Mo, Ni and Cu is indispensable and it leaves a room for improvement in cost.

[0009] Furthermore, in Patent Document 2, high-level elongation and stretch flangeability are attained by constituting a matrix structure with tempered martensite and ferrite and adjusting the occupancy ratio of residual austenite within the range from 5 to 30%. However, since a microstructure before annealing is important so as to obtain the required metal structure using this technique, it is necessary to perform continuous annealing or annealing twice or more after incorporating a proper metal structure by reeling up at low temperature during a hot rolling step. However, in the case of reeling up at low temperature during the hot rolling step, since the structure before annealing is broken and the intended metal structure is not obtained unless the subsequent cold rolling reduction is controlled to the low value, severe restriction is added to the thickness and thickness tolerance. When continuous annealing is performed twice, although there is no restriction on the thickness, the number of steps increases when compared with the case of a conventional method and thus cost-up cannot be avoided.

[0010] Furthermore, Patent Document 3 discloses the sheets having total elongation and stretch flangeability by mainly constituting a matrix structure with tempered bainite. However, since a study is mainly made on steels having a tensile strength of 900 MPa class in this steel type, delayed fracture, which is caused in steels having a tensile strength of 980 MPa or higher class, is not sufficiently studied.


DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

[0015] The present invention has been made in view of the above-mentioned prior arts, and an object thereof is to provide a high-strength composite steel sheet which has a tensile strength of 980 MPa class suited for use as automotive structural parts and has excellent formability (stretch flangeability), and also has excellent spot-weldability and excellent anti-delayed fracture property, without adding expensive alloying elements such as Mo, Ni and Cu.

Means for Solving the Problems

[0016] The high-strength composite steel sheet of the present invention, which could achieve the above object, is a high-strength composite steel sheet having excellent formability and anti-delayed fracture property, comprising a steel satisfying C: 0.10 to 0.25%, Si: 1.0 to 3.0%, Mn: 1.5 to 3.0%, P: 0.15% or less (excluding 0%), S: 0.02% or less (excluding 0%), Al: 0.4% or less (excluding 0%), and comprising a
remnant made from iron and unavoidable impurities, wherein the contents of Si, Al and Mn satisfy the relationship of the following formula (I):

\[
\frac{(Si+Al)}{Mn} = 0.34 \text{ to } 1.26
\]  

(1)

or comprising a steel satisfying C: 0.12 to 0.25%, Si: 1.0 to 3.0%, Mn: 1.5 to 3.0%, Cr: 1.0% or less (excluding 0%), P: 0.15% or less (excluding 0%), S: 0.02% or less (excluding 0%), Al: 0.4% or less, and comprising a remnant made from iron and unavoidable impurities, wherein the contents of Si, Al, Mn and Cr satisfy the relationship of the following formula (II):

\[
\frac{(Si+Al)}{(Mn+Cr)} = 0.74 \text{ to } 1.26
\]  

(II)

and a microstructure in a longitudinal section comprises, by an occupancy ratio based on the entire structure,

[0017] 1) bainitic ferrite: 50% or more,
[0018] 2) polygonal ferrite: 5 to 35%,
[0019] 3) average grain size of polygonal ferrite: 10 µm or less, and
[0020] 4) residual austenite: 5% or more.

[0021] The high-strength composite steel sheet of the present invention optionally contains, in addition to the above elements, Ti: 0.15% or less (excluding 0%) and/or Nb: 0.1% or less (excluding 0%), or optionally contains Ca: 30 ppm or less (excluding 0%) and/or REM: 30 ppm or less (excluding 0%) as other elements.

[0022] It is particularly preferred that the high-strength composite steel sheet of the present invention has a tensile strength of 980 MPa or higher so as to more effectively make use of its high strength.

EFFECT OF THE INVENTION

[0023] According to the present invention, by specifying chemical components of the steel material as described above, particularly controlling a ratio (Si+Al)/Mn or a ratio (Si+Al)/(Mn+Cr), and constituting the metal structure with a composite structure which mainly contains bainitic ferrite (BF) and also contains polygonal ferrite (PF) and residual austenite (residual γ), it is possible to provide a composite steel sheet which has good formability (elongation-stretch flangeability) and also excellent spot-weldability and anti-delayed fracture property while ensuring a tensile strength of 980 MPa or higher class at cheap price.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIG. 1 is a diagram for explaining a heat pattern of a heat treatment employed in Test Example.

BEST MODE FOR CARRYING OUT THE INVENTION

[0025] In light of the problems described above, the present inventors have focused on a TRIP steel sheet (Transformation Induced Plasticity) having a tensile strength of 980 MPa or higher class, containing bainitic ferrite as a matrix phase, and intensively studied by paying attention to the form of the second phase in the metal structure and chemical components, especially Si, Al and Mn (and/or Cr) so as to further improve formability, spot-weldability and anti-delayed fracture property. Thus, the following findings were obtained.

[0026] 1) When a predetermined amount of fine polygonal ferrite is incorporated into a structure composed mainly of bainitic ferrite, elongation is remarkably improved. More-

over, when the ferrite to be incorporated is fine ferrite, deterioration of the strength and stretch flangeability is suppressed and also the structure exhibits excellent performances in anti-delayed fracture characteristics.

[0027] 2) When (Si+Al) and Mn or (Mn+Cr) among chemical components of the steel are adjusted so as to obtain a predetermined ratio, it is possible to obtain a desired structure having a tensile strength of 980 MPa or higher class while suppressing deterioration of spot-weldability.

[0028] Based on these findings, the present inventors have intensively studied about an influence of the contents of Si, Al, Mn and Cr in steel components and the metal structure on the strength, formability, spot-weldability and anti-delayed fracture characteristics. As a result, they have confirmed that a high-strength composite steel sheet having high performances, which achieve the above object, can be obtained by controlling the occupancy ratio of bainitic ferrite in the metal structure, controlling the occupancy ratios of polygonal ferrite and residual γ and controlling an average grain size of the polygonal ferrite to a specific value or less using a steel material having specific component composition described above. Thus, the present invention has been completed.

[0029] Specific constitutions of the present invention will be made clear by way of reasons for decision of chemical components of the steel material.

[0030] First, reasons for decision of chemical components of the steel material are explained.

C: 0.10% or more and 0.25% or less

Si: 1.0% or more and 3.0% or less

Mn: 1.5% to 3.0% or less

P: 0.15% or less, S: 0.02% or less

Cr: 0.2% or less, Al: 0.4% or less, and

Rem: 30 ppm or less (excluding 0%)

[0031] C is an element which is indispensable so as to ensure a high strength and residual γ, and is an important element as to incorporate a sufficient amount of C in a γ phase thereby retaining a desired amount of the γ phase at room temperature. In order to effectively exert such an effect, the content of C must be 0.10% or more, preferably 0.12% or more, and 0.15% or more. When the content of C is too large, a severe adverse influence is exerted on spot-weldability, and thus the upper limit was 0.25% in view of security of spot-weldability. The C content is preferably 0.23% or less, and more preferably 0.20% or less.

[0032] Si is an essential element which effectively serves as a solution-hardening element and also suppresses formation of a carbide as a result of decomposition of residual γ. In order to effectively exert such an effect, the content of Si must be 1.0% or more, and preferably 1.2% or more. Since the effect is saturated at 3.0% and problems such as deterioration of spot-weldability and hot shortness arise when the content is more than the above value, the content may be suppressed to 3.0% or less, and preferably 2.5% or less.

Mn: 1.5 to 3.0%

[0033] Mn is an element required to suppress formation of excess polygonal ferrite thereby forming a structure composed mainly of bainitic ferrite. Also it is an important element required to stabilize γ thereby ensuring desired residual γ. The occupancy ratio of Mn is at least 1.5% or more, and preferably 2.0% or more.

[0034] However, since excess addition causes deterioration of spot-weldability and anti-delayed fracture property, the content is suppressed to 3.0% at most, and preferably 2.5% or less.

P: 0.15% or less, S: 0.02% or less

[0035] These elements are inevitably incorporated into the steel and cause deterioration of formability and spot-weldability when the content increases, and thus the content must be suppressed to the upper limit or less.
AI: 0.4% or less

[0036] AI is a useful element so as to suppress formation of a carbide thereby ensuring residual Y similar to Si. However, if AI is too much, polygonal ferrite is likely to be produced; therefore, the content should be suppressed to 0.4% at most, and preferably 0.2% or less.

Cr: 1.0% or less

[0037] Since Cr has the effect of suppressing formation of polygonal ferrite thereby enhancing the strength, it can be optionally added. However, when it is excessively added, an adverse influence may be exerted on formation of the target metal structure in the present invention. Therefore, the content should be suppressed to 1.0% at most.

(Si+Al)/Mn (or Mn+Cr): 0.74 to 1.26 (mass ratio)

[0038] It is necessary to suppress excess formation of polygonal ferrite (PF) thereby promoting a bainitic ferrite (BF) transformation so as to obtain the intended metal structure in the present invention. Moreover, since C (carbon) discharged from bainitic ferrite is concentrated in a lath-type residual γ, it is important to promote the bainitic ferrite transformation so as to obtain the lath-type residual γ.

[0039] In the present invention, it is necessary to disperse an appropriate amount of fine ferrite in the metal structure. It was found that controlling a ratio of the content of Si and Al as ferrite formation promoting elements to Mn (or Mn+Cr) as ferrite formation suppressing elements so as to satisfy a given relation is extremely effective. Moreover, it was confirmed that controlling the content ratio of the ferrite formation promoting element/ferrite formation suppressing element is effective so as to enhance anti-delayed fraction property.

[0040] When the ratio (Si+Al)/Mn (or Mn+Cr) is less than 0.74, not only it becomes difficult to ensure a proper degree of polygonal ferrite, but also it becomes impossible to sufficiently ensuring bainitic ferrite. Moreover, C cannot be sufficiently concentrated in the residual γ and stability of the residual γ deteriorates and elongation deteriorates, and also the amount of martensite increases and stretch flangeability deteriorates.

[0041] Furthermore, anti-delayed fraction property is improved by controlling the ratio of the elements within a proper range. Details of this reason are not sure, but are considered as follows. That is, Ms promotes delayed fracture by decreasing a grain boundary strength by grain boundary segregation and also promotes formation of voids serving as the starting point of delayed fracture upon working, whereas, Si and Al have the effect of increasing a tolerance amount of hydrogen which induces delayed fracture. Therefore, it is considered that anti-delayed fraction property varies by a ratio of both elements.

[0042] In contrast, when the ratio (Si+Al)/Mn (or Mn+Cr) exceeds 1.26, formation of polygonal ferrite is excessively promoted and the occupancy ratio becomes excessive, and also the grain size of ferrite is likely to exceed 10 μm and thus both the strength and stretch flangeability deteriorate. Further, since a ferrite grain boundary decreases when the ferrite grain size increases, anti-delayed fraction property deteriorates.

[0043] Therefore, it is important to adjust the component so as to control the ratio (Si+Al)/Mn (or Mn+Cr) within the range from 0.74 to 1.26, and more preferably 0.84 or more and 1.16 or less.

Nb: 0.1% or less, Ti: 0.15% or less

[0044] Since these elements have the effect of enhancing toughness by refinement of the metal structure, these elements can be optionally added in a small amount. However, further effect is not obtained to cause cost-up even if they are added in the amount of more than the upper limit, therefore it is wasteful.

Ca: 0.01% or less, REM: 0.01% or less

[0045] Ca and REM have the effect of enhancing stretch flangeability by adding in a small amount and therefore they may be optionally added in a small amount. Since the effect is saturated at about 0.01%, it is wasteful even if they are added in a larger amount.

Mo, Cu, Ni: each about 0.1% or less

[0046] These elements are effective for improving the strength and anti-delayed fraction property as described in the prior art. In the present invention, excellent performances are sufficiently obtained without adding these elements and it is not necessary to add because these elements are expensive and cause cost-up. There is no restriction on the content in a level of impurities and these elements may be respectively added in the amount of about 0.1% or less.

[0047] Next, reasons of limitation of the metal texture will be explained.

Bainitic Ferrite: ≥50%

[0048] Bainitic ferrite has not only the effect of easily achieving a high strength because of somewhat high dislocation density, but also the effect of decreasing a difference in hardness between bainitic ferrite and the second phase thereby enhancing stretch flangeability. Bainitic ferrite is a structure which is useful for enhancing anti-delayed fraction property. This reason is considered that bainitic ferrite does not contain or contains little cementite serving as the starting point of delayed structure, and has a high hydrogen absorbing effect because of a lot of dislocations. In order to effectively exert these effects, it is necessary that the content of bainitic ferrite exist at 50% or more. The content is more preferably 60% or more.

[0049] The bainitic ferrite is different from a bainite structure in that the structure does not include carbides, and is also different from a polygonal ferrite structure having a lower bainite structure which does not contain or contains little dislocation, or a quasi-polygonal ferrite structure having a lower bainite structure such as fine subgran. These differences can be easily identified by TEM (Transmission Electron Microscope) observation.

Polygonal Ferrite (PF): 5 to 35%

[0050] When a steel sheet having a tensile strength of 980 MPa or higher class, comprising bainite ferrite (BF) as a matrix phase contains a predetermined amount of polygonal ferrite having an average grain size described below, elongation is further improved. The content of polygonal ferrite must be contained at 5% or more so as to exert such an effect. However, since it becomes difficult to ensure the tensile strength and stretch flangeability when the content of polygonal ferrite is too large, the content should be suppressed to 35% at most. Preferred occupancy ratio of polygonal ferrite is 10% or more and 30% or less.

Average Grain Size of Polygonal Ferrite: 10 μm or less

[0051] The average grain size of polygonal ferrite must be 10 μm or less by the following reason. That is, refinement of ferrite enables uniform dispersion of the second phase, and thus both stretch flangeability and strength are enhanced and also anti-delayed fraction property is improved. This reason...
is considered that refinement of ferrite enables trap of hydrogen at the ferrite grain boundary and suppression of concentration of hydrogen at a dangerous site. The average grain size of polygonal ferrite as used herein means an average of an equivalent circle diameter (diameter of a circle having the same area) of polygonal ferrite.

Residual \( \gamma \leq 5\% \)

Residual \( \gamma \) has the effect of promoting hardening of the deformed part by transforming into martensite when the material is deformed by application of strain, and thus preventing strain concentration (TRIP effect). It is necessary that the content of the residual \( \gamma \) is 5% or more so as to effectively exert such the effect. There is no restriction on the upper limit of the amount of the residual \( \gamma \). Since a large amount of C is required so as to form excessive residual \( \gamma \), it becomes difficult to reconcile with spot-weldability and workability, especially stretch flangeability. Therefore, the content is preferably suppressed to about 30% or less.

In the composite steel sheet of the present invention, martensite, bainite and pearlite can exist as the other balance structure. The contents of these other structures are preferably suppressed to 5% or less so as not to exert an adverse influence on the above operations and effects.

There is no noticeable restriction on the production conditions required to obtain the above metal structure defined in the present invention. In usual production procedures of a steel sheet, for example, continuous casting, hot rolling, pickling, cold rolling and continuous annealing, a heating temperature, a heating rate, a holding temperature, a cooling initiation temperature and a cooling rate may be properly controlled. In the case of a galvanized steel sheet and a galvannealed steel sheet, proper temperature control including a continuous galvanizing line may be performed. Since heat treatment conditions in a continuous annealing line are most important so as to obtain the metal structure, preferred heat treatment conditions in the continuous annealing line will be mainly explained.

Heating Temperature upon Annealing: \( \text{Ac}_{1} + 10^\circ \text{C} \) or higher

In order to obtain the bainitic ferrite-riced metal structure, the heating temperature upon annealing may be adjusted to \( \text{Ac}_{1} + 10^\circ \text{C} \) or higher so as to suppress formation of polygonal ferrite. By the way, when continuous annealing is performed at an \( \text{Ac}_{1} \) point or lower, polygonal ferrite is likely to be formed in the subsequent cooling step since the residual ferrite serves as a nucleus, and thus it becomes difficult to obtain the intended metal structure in the present invention. Therefore, more preferred heating temperature is \( \text{Ac}_{1} + 30^\circ \text{C} \) or higher.

Cooling Rate after Annealing

The larger the cooling rate after annealing, the better since formation of polygonal ferrite is suppressed. Considering equipment restriction and difficulty in temperature control, the cooling rate is preferably 25°C/sec or higher, and more preferably 30°C/sec or higher, so as to suppress the amount of polygonal ferrite to a certain amount of less according to each component system.

Quenching Termination Temperature after Annealing

The temperature at which quenching after annealing is terminated should be controlled to the temperature at which fine polygonal ferrite is formed or lower, and is preferably 650°C or lower, and more preferably 600°C or lower. When the quenching termination temperature becomes higher, coarse polygonal ferrite is formed and it becomes impossible to achieve the object of the present invention. However, since it becomes impossible to obtain a sufficient amount of polygonal ferrite when the quenching termination temperature becomes too low, the quenching termination temperature should be about 360°C or higher, and more preferably up to 400°C.

Holding Temperature after Cooling

The holding temperature after cooling is determined by the bainitic transformation temperature range. After cooling, since bainitic transformation proceeds by holding at a given temperature and also concentration of C to austenite proceeds to form residual \( \gamma \), it is important to properly control the holding temperature after cooling. The holding temperature is preferably within the range from 360°C to 440°C, so as to obtain the metal structure of the present invention. The retention time is preferably one minute or more. It is necessary that the holding temperature is lower than the quenching termination temperature. After passing through the temperature range where fine ferrite is likely to be formed, the material is transferred to a bainitic ferrite transformation temperature range.

In the high-strength composite steel sheet of the present invention, a composite steel sheet having a high strength of 980 MPa or higher, good spot-weldability and anti-delayed fraction property can be provided at cheap price by using a steel material having specified chemical components as described above and employing proper heat treatment conditions including cooling conditions and holding conditions thereby ensuring a predetermined metal structure.

EXAMPLES

The present invention is further illustrated by the following examples. It is to be understood that the present invention is not limited to the examples, and various design variations made in accordance with the purports described hereinbefore and hereinafter are also included in the technical scope of the present invention.

Test Example

Steel materials with compositions shown in Table 1 were prepared, subjected to continuous casting, subjected to hot rolling and cold rolling under the conditions described below and then subjected to a heat treatment (annealing) under the conditions shown in Table 2 (also refer to FIG. 1) to obtain cold rolled steel sheets.

[Hot Rolling]

Heating temperature: 1,200°C for 60 minutes
Finish temperature: 880°C.
Cooling: Cooling to 720°C at 40°C/sec, cooling for 10 seconds, cooling to 500°C at 40°C/sec and holding at 500°C for 60 minutes, followed by furnace cooling.
Finish thickness: 3.2 mm

[Pickling, Cold Rolling]

After pickling, cold rolling was performed to obtain a cold sheet having a thickness of 1.2 mm.

[Heat Treatment (Annealing)]

As shown in Table 2, each cold rolled sheet was heated to a predetermined annealing temperature, held at the same temperature for 180 seconds, cooled to a predetermined
cooling termination temperature at a predetermined cooling rate, held at a predetermined temperature for 6 minutes and then furnace-cooled.

The metal structure of the resultant cold rolled steel sheet was confirmed by the following method and each test steel sheet was subjected to a tension test, a bore expansion test, a spot-welding test and an anti-delayed fracture test. The results collectively shown in Table 3 were obtained.

[0065] The metal structure of the resultant cold rolled steel sheet was confirmed by the following method and each test steel sheet was subjected to a tension test, a bore expansion test, a spot-welding test and an anti-delayed fracture test. The results collectively shown in Table 3 were obtained.

[0066] A: Optical microscope observation (magnification: ×1,000) by repeller corrosion, 1 visual field
B: SEM observation (magnification: ×4,000), 4 visual fields

Polygonal Ferrite (PF)

[0067] Polygonal ferrite is identified by a micrograph taken by A described above. Since etched residual γ and etched martensite show a white color, whereas, etched PF shows a gray color, PF can be identified. After tracing the periphery of polygonal ferrite in the SEM micrograph taken by B described above, an equivalent circle diameter was calculated from the resultant trace image by image analysis. An average of the resultant equivalent circle diameter was taken as an average grain size of the polygonal ferrite.

Retained γ, Martensite (M) and Bainite (B)

[0068] After residual γ, M and B were confirmed by a transition electron microscope (TEM: magnification of ×15,000), the occupancy ratio was calculated from the micrograph taken by B described above.

Bainitic Ferrite (BF)

[0069] After confirming that the structure is not a structure of bainite or pseudo-ferrite by a transition electron microscope (TEM: magnification of ×15,000), the occupancy ratio was calculated by subtracting an amount of polygonal ferrite, an amount of residual γ, and balance of martensite (M) and bainite (B) from 100%.

[Performance Evaluation Test]

[0070] Tension test: The measurement was performed using JIS No. 5 tension test specimens.
Bore expansion test: The test was performed in accordance with the Japan Iron and Steel Federation Standard (JIST) 1001.

Spot-Weldability:

[0071] Spot-welding was performed under the following conditions. The case where a ductility ratio at a nugget diameter of 5r is 0.25 or more was rated Good (○).

<Welding Conditions>

[0072] Thickness of test material: 1.2 mm
Electrode: Dome radius type (tip diameter: 6 mm)
[0073] Pressure: 375 kg
Upslope: 1 cycle, electrification time: 12 cycles, hold: 1 cycle (60 Hz)
Adjustment of nugget: adjusted by welding current
Ductility ratio: Cross tensile strength/Shear tensile strength

[Anti-Delayed Fraction Property]

[0074] After performing V-shaped bending using a 60° V-block of R=3 mm, stress of 1,500 MPa was applied to the bent portion, followed by immersion in an aqueous 5% hydrochloric acid solution. Then, the time until cracking occurs was measured. The case where cracking did not occur after 48 hours was rated good anti-delayed fraction property (○).

TABLE 1

<table>
<thead>
<tr>
<th>Steel type</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Al</th>
<th>Cr</th>
<th>Nb</th>
<th>Ti</th>
<th>Others (Si + Al)/(Mn + Cr)</th>
<th>A3 point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.17</td>
<td>1.7</td>
<td>2.3</td>
<td>0.010</td>
<td>0.002</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.76</td>
</tr>
<tr>
<td>B</td>
<td>0.23</td>
<td>1.8</td>
<td>2.3</td>
<td>0.005</td>
<td>0.002</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
<td>Ca; 0.002</td>
<td>0.80</td>
</tr>
<tr>
<td>C</td>
<td>0.17</td>
<td>2.3</td>
<td>2</td>
<td>0.005</td>
<td>0.002</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.17</td>
</tr>
<tr>
<td>D</td>
<td>0.17</td>
<td>2.3</td>
<td>2.6</td>
<td>0.005</td>
<td>0.002</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.90</td>
</tr>
<tr>
<td>E</td>
<td>0.14</td>
<td>2.0</td>
<td>2.5</td>
<td>0.005</td>
<td>0.002</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.82</td>
</tr>
<tr>
<td>F</td>
<td>0.20</td>
<td>1.6</td>
<td>2.04</td>
<td>0.005</td>
<td>0.002</td>
<td>0.045</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td>G</td>
<td>0.17</td>
<td>1.8</td>
<td>2.1</td>
<td>0.005</td>
<td>0.002</td>
<td>0.045</td>
<td>0.2</td>
<td></td>
<td></td>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td>H</td>
<td>0.17</td>
<td>1.8</td>
<td>2.2</td>
<td>0.001</td>
<td>0.002</td>
<td>0.045</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td>0.84</td>
</tr>
<tr>
<td>I</td>
<td>0.17</td>
<td>1.8</td>
<td>2.3</td>
<td>0.001</td>
<td>0.002</td>
<td>0.045</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td>0.80</td>
</tr>
<tr>
<td>J</td>
<td>0.16</td>
<td>1.8</td>
<td>2.4</td>
<td>0.010</td>
<td>0.001</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.81</td>
</tr>
<tr>
<td>K</td>
<td>0.08</td>
<td>1.6</td>
<td>1.6</td>
<td>0.010</td>
<td>0.003</td>
<td>0.040</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.03</td>
</tr>
<tr>
<td>L</td>
<td>0.22</td>
<td>0.5</td>
<td>2.8</td>
<td>0.010</td>
<td>0.003</td>
<td>0.040</td>
<td>0.5</td>
<td></td>
<td></td>
<td></td>
<td>0.19</td>
</tr>
<tr>
<td>M</td>
<td>0.17</td>
<td>1.8</td>
<td>1.2</td>
<td>0.010</td>
<td>0.003</td>
<td>0.040</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.53</td>
</tr>
<tr>
<td>N</td>
<td>0.23</td>
<td>2.3</td>
<td>1.5</td>
<td>0.010</td>
<td>0.003</td>
<td>0.040</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.56</td>
</tr>
<tr>
<td>O</td>
<td>0.18</td>
<td>1.5</td>
<td>2.1</td>
<td>0.010</td>
<td>0.002</td>
<td>0.040</td>
<td>0.2</td>
<td>0.05</td>
<td></td>
<td>Ca; 0.002</td>
<td>0.73</td>
</tr>
</tbody>
</table>
TABLE 2

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Steel type</th>
<th>Annealing temperature (°C)</th>
<th>Cooling rate 1 (°C/min)</th>
<th>T1 (Temperature at which cooling rate varies: °C)</th>
<th>T2 (Holding temperature: °C)</th>
<th>T3 (Holding termination temperature: °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>900</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>880</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>930</td>
<td>100</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>910</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>900</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>890</td>
<td>100</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>7</td>
<td>G</td>
<td>900</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>8</td>
<td>H</td>
<td>900</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>9</td>
<td>I</td>
<td>900</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>10</td>
<td>J</td>
<td>900</td>
<td>50</td>
<td>580</td>
<td>420</td>
<td>380</td>
</tr>
<tr>
<td>11</td>
<td>K</td>
<td>920</td>
<td>50</td>
<td>—</td>
<td>440</td>
<td>340</td>
</tr>
<tr>
<td>12</td>
<td>L</td>
<td>820</td>
<td>50</td>
<td>—</td>
<td>380</td>
<td>380</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>800</td>
<td>50</td>
<td>—</td>
<td>380</td>
<td>380</td>
</tr>
<tr>
<td>14</td>
<td>N</td>
<td>920</td>
<td>50</td>
<td>—</td>
<td>400</td>
<td>380</td>
</tr>
<tr>
<td>15</td>
<td>O</td>
<td>820</td>
<td>30</td>
<td>600</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>16</td>
<td>O</td>
<td>880</td>
<td>30</td>
<td>550</td>
<td>420</td>
<td>400</td>
</tr>
</tbody>
</table>

TABLE 3

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Steel type</th>
<th>Metal structure</th>
<th>Physical properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ferrite grain size (μm)</td>
<td>YP (MPa)</td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>5.5</td>
<td>650</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>3.7</td>
<td>735</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>8.7</td>
<td>647</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>6.1</td>
<td>778</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>7.4</td>
<td>744</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>8.6</td>
<td>643</td>
</tr>
<tr>
<td>7</td>
<td>G</td>
<td>6.1</td>
<td>651</td>
</tr>
<tr>
<td>8</td>
<td>H</td>
<td>5.9</td>
<td>728</td>
</tr>
<tr>
<td>9</td>
<td>I</td>
<td>5.6</td>
<td>738</td>
</tr>
<tr>
<td>10</td>
<td>J</td>
<td>8.4</td>
<td>746</td>
</tr>
<tr>
<td>11</td>
<td>K</td>
<td>9.7</td>
<td>518</td>
</tr>
<tr>
<td>12</td>
<td>L</td>
<td>4.1</td>
<td>783</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>15.7</td>
<td>553</td>
</tr>
<tr>
<td>14</td>
<td>N</td>
<td>1.5</td>
<td>676</td>
</tr>
<tr>
<td>15</td>
<td>O</td>
<td>3.5</td>
<td>688</td>
</tr>
</tbody>
</table>

**Note:**
PF: Polygonal ferrite,  
BF: Bainitic ferrite,  
Remnant (M Martensite, B Bainite)  

[0075] The following facts become apparent from the results shown in Tables 1 to 3.

[0076] Tests Nos. 1 to 10 and 16 are Examples which satisfy all defined features of the present invention. All steel materials have a tensile strength of 980 MPa or higher class and have good formability evaluated by strength elongation characteristics and strength-stretch flangeability characteristics, and also have good spot-weldability and anti-delayed fraction property.

[0077] In contrast, in Test No. 11, since the steel material has a low C content and also has a low bainitic ferrite content in the metal structure, it has poor tensile strength and also has poor formability evaluated by strength elongation characteristics and strength-stretch flangeability characteristics. In Test No. 12, since the steel material has low Si content and also has a ratio (Si+Al)/(Mn+Cr) which is not within a defined range, no residual γ exist in the metal structure and also has very poor formability evaluated by strength elongation characteristics and strength-stretch flangeability characteristics, and poor anti-delayed fraction property.

[0078] In Test No. 13, since the Mn content is not within a defined range and the ratio (Si+Al)/Mn exceeds a defined range, polygonal ferrite excessively increases and the amount of bainitic ferrite drastically decreases, and thus the steel material has low strength and very poor workability. In Test No. 14, although each content satisfies defined constituents, the ratio (Si+Al)/Mn exceeds a defined range and polygonal ferrite is coarse and an average grain size exceeds a defined
value, and thus the steel material has low strength, poor workability and poor spot-weldability.

In Test No. 15, although the steel components satisfy defined constituents, since the heat treatment conditions are not proper, the amount of polygonal ferrite in the structure excessively increases and the bainitic amount is low, and thus the steel material has very poor formability evaluated by strength elongation characteristics and strength-stretch flangeability characteristics, and also has poor anti-delayed fraction property.

1. A high-strength composite steel sheet having excellent formability and anti-delayed fraction property, comprising a steel satisfying:
   - C: 0.10 to 0.25% (% by mass in case of a chemical component, the same shall apply hereinafter),
   - Si: 1.0 to 3.0%,
   - Mn: 1.5 to 3.0%,
   - P: 0.15% or less,
   - S: 0.02% or less,
   - Al: 0.4% or less, and comprising the remnant made from iron and unavoidable impurities, wherein the contents of Si, Al and Mn satisfy the relationship of the following formula (I):
     \[
     \frac{(Si+Al)}{Mn} = 0.34 \text{ to } 1.26
     \]
   and a microstructure in a longitudinal section comprises, by an occupancy ratio based on the entire structure,
   - 1) bainitic ferrite: 50% or more,
   - 2) polygonal ferrite: 25 to 35%,
   - 3) average grain size of polygonal ferrite: 10 \( \mu m \) or less,
   - 4) residual austenite: 5% or more.

2. A high-strength composite steel sheet having excellent formability and anti-delayed fraction property, comprising a steel satisfying:
   - C: 0.12 to 0.25%,
   - Si: 1.0 to 3.0%,
   - Mn: 1.5 to 3.0%,
   - Cr: 1.0% or less,
   - P: 0.15% or less,
   - S: 0.02% or less,
   - Al: 0.4% or less, and comprising the remnant made from iron and unavoidable impurities, wherein the contents of Si, Al, Mn and Cr satisfy the relationship of the following formula (II):
     \[
     \frac{(Si+Al)}{(Mn+Cr)} = 0.74 \text{ to } 1.26
     \]
   and a microstructure in a longitudinal section comprises, by an occupancy ratio based on the entire structure,
   - 1) bainitic ferrite: 50% or more,
   - 2) polygonal ferrite: 25 to 35%,
   - 3) average grain size of polygonal ferrite: 10 \( \mu m \) or less,
   - 4) residual austenite: 5% or more.

3. The high-strength composite steel sheet according to claim 1 or 2, wherein the steel further contains, as other elements,
   - 1) Ti: 0.15% or less and/or Nb: 0.1% or less.

4. The high-strength composite steel sheet according to claim 1 or 2, wherein the steel further contains,
   - Ca: 30 ppm or less and/or REM: 30 ppm or less as other elements.

5. The high-strength composite steel sheet according to claim 1 or 2, which has a tensile strength of 980 MPa or higher.

* * * * *