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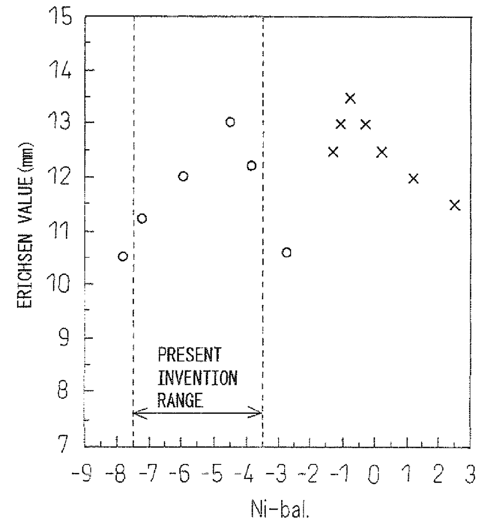
(54) **DUPLEX STAINLESS STEEL PLATE HAVING EXCELLENT PRESS MOLDABILITY**

(57) The present invention provides a duplex stainless steel sheet with excellent press-formability which defines the ingredients of the steel, Ni balance, and austenite phase rate to obtain a 0.2% proof stress and Erichsen value equal to that of SUS304 or another austenitic stainless steel, that is, a duplex stainless steel sheet which contains, by mass%, C: 0.05% or less, Si: 0.5 to 3%, Mn: 1 to 5%, Cr: 16 to 21%, Ni: 1 to 6%, Cu: 0.5 to 3%, and N: 0.07% or less, has an Ni-bai. value given by the following formula <1> of -7.5 to -3.5, has a balance of Fe and unavoidable impurities, has an austenite phase rate of 50% to 95%, and has a balance of ferrite phases:

Ni-bal.=30(C+N)+Ni+0.5Mn+0.3Cu-1.1(Cr+1.5Si)+8.2 <1>

FIG. 2



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Description

Technical Field

[0001] The present invention relates to duplex stainless steel sheet with excellent press-formability such as stretchability.

Background Art

[0002] Austenitic stainless steel such as SUS304 is excellent in balance of corrosion resistance and workability, so is being used for a broad range of applications such as for kitchen appliances, household electric appliances, and electronic equipment. In general, austenitic stainless steel is much higher in elongation at break compared with ferritic stainless steel or duplex stainless steel, is excellent in stretchability, and is often preferred for press-formability of steel sheet. However, austenitic stainless steel contains large amounts of the rare and expensive Ni, so has problems in general applicability and economy in the future.

[0003] In the past, as an alternative to austenitic stainless steel, duplex stainless steel which conserves on the amount of Ni has been known. PLTs 1 to 3 disclose high strength duplex stainless steels for automotive use which contain Ni: 1 to 7%, Si: over 1 to 5%, N: 0.04 to 2%, and Cr: 17 to 22% and which have Mn, Cu, etc. added to adjust the Ni balance value and raise the Young's modulus. These duplex stainless steels are characterized by high Si and low Ni and are provided with a high strength of a 0.2% proof stress of over 500 MPa and a high elongation.

[0004] In recent years, austenitic-ferritic stainless steel which further conserves on the content of Ni and has a relatively large amount of N added to give a high ductility has been reported. PLT 4 and PLT 5 disclose austenitic-ferritic stainless steels with excellent formability which restrict the amount of Ni to 3% or less and adjust the C+N and ingredient balance in the austenite phases to obtain a high ductility. As art related to this, PLT 6 discloses austenitic-ferritic stainless steel with excellent stretchability and crevice corrosion resistance which restricts the amount of Ni to 1% or less and the amount of Mn to 2% or less and adds an amount of N in 0.05 to 0.6% in range. In the examples of the above publication, the amount of Ni is reduced by adding an amount of N in at least 0.08% or more.

[0005] Recently, PLT 7 has disclosed ferritic-austenitic stainless steels with excellent corrosion resistance and workability which make the upper limit of the amount of N 0.15% and thereby lower the amount of Ni. These stainless steels set Cr+3Mo+10N-Mn≥18% from the viewpoint of the corrosion resistance and define the size, aspect ratio, and intergranular distance of austenite grains from the viewpoint of the workability. The steels disclosed in the above publication have less than 50% of austenite phases and are mainly comprised of ferrite phases.

[0006] The steels disclosed in the above PLTs use quite a bit of N to conserve Ni and raise the strength. Much research is being performed on the effects of N on the mechanical properties of stainless steel and other ferrous metal materials. Addition of N has a large effect on the rise of the 0.2% proof stress. For example, in NPLT 1, if adding over 0.1% of N to the Fe-Cr-Ni-Mn alloy, at ordinary temperature, the 0.2% proof stress greatly exceeds 400 MPa. In actuality, the steels disclosed in PLTs 1 to 3 have 0.2% proof stresses of over 500 MPa. PLTs 4 to 7 do not describe a 0.2% proof stress, but from NPLT 1, it is easy to deduce that the value is over 400 MPa.

[0007] As explained above, when the 0.2% proof stress exceeds 400 MPa, generally the value becomes one over 100 MPa higher if compared with SUS304 and other austenitic stainless steel. For this reason, in the press-formability of the steel sheet, with current press machines, the power is insufficient, so forming becomes difficult and the problem of wear and damage to the dies becomes feared. In other words, at the present time, how to obtain press-formable steel sheet no different from SUS304 and other austenitic stainless steel sheet in duplex stainless steel conserving Ni has not yet been clarified.

Citation List

Patent Literature

[0008]

PLT 1: Japanese Patent Publication (A) No. 62-47461
PLT 2: Japanese Patent Publication (A) No. 62-47462
PLT 3: Japanese Patent Publication (A) No. 62-47463
PLT 4: Japanese Patent Publication (A) No. 2006-169622
PLT 5: Japanese Patent Publication (A) No. 2006-183129
PLT 6: Japanese Patent Publication (A) No. 2006-200035
PLT 7 WO2009/017258

Non-Patent Literature

[0009]

NPLT 1: 1.90th Nishiyama Commemorative Technical Course, November 2006, the Iron and Steel Institute of Japan, p. 60
NPLT 2: Nippon Stainless Steel Technical Reports, No. 21 (1986), p. 3 to 5

Summary of Invention

Technical Problem

[0010] The present invention has as its object to provide duplex stainless steel sheet with excellent press-formabillty provided with a 0.2% proof stress and Erichsen value equivalent to those of SUS304 and other austenitic stainless steel by controlling the steel ingredients, the Ni balance, and the austenite phase rate.

Solution to Problem

[0011] The inventors engaged in intensive research on the effects of ingredients, the Ni balance, and the austenite phase rate on the 0.2% proof stress and Erichsen value of duplex stainless steel conserving Ni so as to solve the above problem and thereby completed the present invention:
[0012] The gist of the present invention is as follows:

(1) A duplex stainless steel sheet with excellent press-formability characterized by containing, by mass%,
C: 0.05% or less,
Si: 0.5 to 3%,
Mn: 1 to 5%,
Cr: 16 to 21%,
Ni: 1 to 6%,
Cu: 0.5 to 3%, and
N: 0.07% or less
having an Ni-bal value given by the following formula <1> of -7.5 to -3.5, having a balance of Fe and unavoidable impurities, having an austenite phase rate of 50% to 95%, and having a balance of ferrite phases:

Ni-bal.=30(C+N)+Ni+0.5Mn+C.3Cu-1.1(Cr+1.5Si)+8.2... formula <1>

(2) A duplex stainless steel sheet with excellent press-formability as set forth in (1) **characterized in that** said steel further contains, by mass%, one or more of:

Mo: 1% or less,
Nb: 0.5% or less,
V: 0.5% or less,
Ti: 0.5% or less,
Sn: 1% or less,
Sb: 1% or less,
W: 1% or less, and
Al: 0.1% or less.

(3) A duplex stainless steel sheet with excellent press-formability as set forth in (1) or (2) **characterized in that** said steel further contains, by mass%, one or more of
B: 0.01% or less,
Ca: 0.01% or less,
Mg: 0.01% or less,
La: 0.3% or less,
Ce: 0.3% or less,
Zr: 0.3% or less, and
Y: 0.3% or less.
(4) A duplex stainless steel sheet with excellent press-formability as set forth in (1) or (2) **characterized in that** a

0.2% proof stress in a tensile test is less than 400 MPa and an elongation at break is 35% or more.
(5) A duplex stainless steel sheet with excellent press-formability as set forth in (3) **characterized in that** a 0.2% proof stress in a tensile test is less than 400 MPa and an elongation at break is 35% or more.
(6) A duplex stainless steel sheet with excellent press-formability as set forth in (1) or (2) **characterized in that** a formed height found by an Erichsen test (Erichsen value) is 11 mm or more.
(7) A duplex stainless steel sheet with excellent press-formability as set forth in (3) **characterized in that** a formed height found by an Erichsen test Erichsen value) is 11 mm or more.
(8) A duplex stainless steel sheet with excellent press-formability as set forth in (4) **characterized in that** a formed height found by an Erichsen test (Erichsen value) is 11 mm or more.
(9) A duplex stainless steel sheet with excellent press-formability as set forth in (5) **characterized in that** a formed height found by an Erichsen test (Erichsen value) is 11 mm or more.

[0013] In the following explanation, the inventions according to the steels of the above (1) to (9) will be called "present inventions". Further, the inventions of (1) to (9) combined will sometimes be called "the present invention".

Advantageous Effects of Invention

[0014] According to the present invention, it is possible to provide a duplex stainless steel sheet with excellent press-forrtability which defines the ingredients of the steel, Ni balance, and austenite phase rate to obtain a 0.2% proof stress and Erichsen value equal to that of SUS304 or another austenitic stainless steel. The remarkable effect is exhibited that the duplex stainless steel sheet of the present invention can be pressed-formed no different from SUS304 or other austenitic stainless steel sheet and Ni can be conserved.

Brief Description of Drawings

[0015]

FIG. 1 is a view showing the relationship between the Erichsen value and ingredients.
FIG. 2 is a view showing the relationship between the Erichsen value and Ni balance.

Description of Embodiments

[0016] The inventors engaged in intensive research on the effects of ingredients, the Ni balance, and the austenite phase rate on the 0.2% proof stress and Erichsen value of duplex stainless steel conserving Ni so as to solve the above problem and thereby completed the present invention. Below, representative experiment findings will be explained.
[0017] Table 1 shows representative ingredients of the test steel. Duplex stainless steels of these ingredients were vacuum melted and used to produce 5 mm thick hot rolled sheets. The hot rolled sheets were annealed at 1050°C and then pickled to produce 0.6 mm thick cold rolled sheets. The cold rolled sheets were annealed at 1053°C. The cold rolled annealed sheets were measured for austenite (γ) phase rate and were used for a JIS No. 13B tensile test and Erichsen test.

Table 1

	Chemical ingredients (mass%)							Ni-bal
	C	Si	Mn	Cr	Ni	Cu	N	
A	0.015	1.9	4.0	17.1	4.9	1.9	0.025	-5.1
B	0.028	0.1	3.4	21.3	1.6	0.5	0.086	-8.5
C	0.030	0.3	4.6	20.5	3.7	0.5	0.150	-3.3
Ni-bal = 30(C+N)+0.5Mn+0.3Cu+Ni-1.1(Cr+1.5Si)+8.2								

[0018] The γ-phase rate was found by measurement of a phase map identifying the fcc and bcc crystal structures by the EBSP method at the sheet cross-sections. The JIS No. 13B tensile test obtains a tensile test piece from the rolling direction, sets the tensile speed at 10 mm/min (range prescribed in JIS Z 2241), and measures the 0.2% proof stress (0.2% PS), tensile strength (TS), and elongation at break (EL). The Erichsen test obtains a 90 mm square test piece, performs the Method B based on JIS Z 2247 (wrinkle pressure of 1 ton), and measures the deformed height when a crack runs through the sheet thickness (Erichsen value).

[0019] Table 2 shows the mechanical properties, Erichsen value (Er), and γ-phase rate (γ) obtained from sheets of typical test sheet ingredients compared with ferrite (α) and γ single phase SUS430LX and SUS304 steels. As will be understood from Table 2, the steel A has an Erichsen value no different from SUS304. On the other hand, the steels B and C to which N has been added have high elongations, but have much higher 0.2% proof stresses compared with SUS304 and have Erichsen values equal to or lower than that of α-based SUS430LX.

Table 2

	0.2%PS N/mm^2	TS N/mm^2	EL %	Fr mm	γ vol%
A	320	700	47	12.5	75
B	427	730	46	9.5	30
C	535	790	47	10.0	70
S430LX	270	400	34	10.0	0
S304	300	700	51	12.8	100
Er: Erichsen test value					

[0020] Normally, it is known that the Erichsen value rises proportionally with the elongation at break of a material. However, as explained above, high strength duplex stainless steel to which N is added does not necessarily have an Erichsen value commensurate with high elongation. That is, the steels B and C to which N is added sometimes cannot give a high workability in a mode of deformation envisioning press-formation different from a tensile test. To clarify the reasons for this, the inventors examined parts of the steels A, B, and C after the tensile test and Erichsen Lest near the fractured parts for detailed microstructure by an optical microscope and scan electron microscope (SEM). As a result, they obtained the following discoveries explaining the experimental findings described in Table 2.

[a] The fractured parts after the tensile test all had necking along with the reduction of sheet thickness. On the other hand, after the Erichsen test, the steels B and C low in Erichsen value fractured without almost any necking.
[b] Near the fractured parts of the steels B and C after the Erichsen test, large number of fine voids were formed from near the boundaries of different phases of γ/α. The state where these fine voids formed starting points for progression of cracks through the α-phases or γ/α-phases boundaries was observed.
[c] N concentrates at the γ-phases and raises the strength and work hardening. Therefore, if adding N, it can be easily predicted that the difference in strength between the γ-phases and the α-phases would increase along with the working degree. The results of observation of [b] are believed to be due to the difference in strength between the α-phases and the γ-phases.
[d] The steel A with a high Erichsen value is greatly suppressed in formation of fine voids from the α/γ boundary. It was confirmed that the α-phases follow the large deformation ability γ-phases and thereby are greatly necked and fracture in the same way as a tensile test.
[e] The ingredients of the steel A feature low addition of N and Si. By reducing N, the strength and work hardening of the γ-phases fall. Si selectively forms a solid solution in the α-phases and raises the strength and work hardening of the α-phases. In this way, it is believed that by reducing the difference in strength of the α-phases and α-phases and making the high deformation ability α-phases the main phases, a good Erichsen value is obtained.
[f] Based on the thinking of the above [e], the inventors took note of the amount of N and the amount of Si and investigated in detail the range of ingredients giving a high Erichsen value. Cr, Ni, Mn, and Cu were adjusted to a range of -9 to -2 by the Ni balance. FIG. 1 shows the results. In the figure, an Erichsen value of 11 mm or more is indicated by "O" while a value of less than 11 mm is indicated by "×". An Erichsen value of 11 mm is difficult tc reach with α-based stainless steel and was made a threshold value close to γ-based stainless steel. As will be understood from FIG. 1, it was learned that a high Erichsen value of 11 mm or more is obtained when the N is made 0.07% or less and adding Si in 0.5 to 3% in range.
[g] The inventors arranged the Erichsen values of FIG. 1 by the Ni-bal. The results are shown in FIG. 2.

Here, the Ni-bal is defined as 30(C+N)+Ni+0.5Mn+0.3Cu-1.1(Cr+1.5Si)+8.2. The Ni-bal is often used as a parameter relating to the production of the γ-phases and α-phases. FIG. 2 also shows the Erichsen values of the γ-basec stainless steel by the same parameter. In γ-based stainless steel, there is a range of ingredients giving a good Erichsen value. The reason is the rise in the elongation due to work induced martensite transformation of the γ-phases (transformation induced plasticity: TRIP). From this study, the inventors discovered a balance of ingredients in which both the elongation and the Erichsen value effectively rise due to the TRIP phenomenon similar to that of γ-based stainless steel in the range of ingredients described in [e] and [f] (range of Ni-bal). That is, the inventors obtained the new discovery that a high Erichsen value is obtained in an Ni-bal of -7.5 to - 3.5 in range, more preferably -6 to -4 in range.

[0021] The present inventions of (1) to (4) were completed based on the discoveries of [a] to [g].

[0022] Below, the different requirements of the present invention will be explained in detail. Note that the indications of "%" in the contents of the ingredients mean "mass%".

(A) The reasons for limitation of the ingredients will be explained below.

[0023] C raises the γ-phase rate and concentrates in the γ-phases to raise the stability of the γ-phases. Therefore, it effectively acts to adjust the Ni-bal to express the press-formability targeted by the present invention. To obtain the above effect, 0.001% or more is preferably contained. However, if over 0.05%, the strength of the γ-phases rises and facilitates increased sensitization due to grain boundary precipitation of the carbides leading to a drop in corrosion resistance. For this reason, the upper limit is made 0.05%, preferably 0.03% or less.

[0024] Si selectively forms a solid solution at the α-phases, raises the strength and work hardening of the α-phases, and reduces the difference in strengths of the α-phases and the γ-phases to express the press-formability targeted by the present invention. It is an essentially added element for this. Further, it has the action of raising the stability of the α-phases and suppressing the martensite transformation in the cooling process after annealing. If undergoing martensite transformation, the α-phases become hard phases and the workability is remarkably impaired. To obtain the effect on the workability targeted by the present invention, as shown also in FIG. 1, 0.5% or more is added. However, over 3% addition invites an increase in the hardening of the α-phases and a drop in the workability. For this reason, the upper limit is made 3%. The preferable range is 1.5 to 2.5%.

[0025] Mn raises the γ-phase rate and concentrates at the γ-phases to raise the stability of the γ-phases. Therefore, it effectively acts to adjust the Ni-bal to express the press-formability targeted by the present invention. To obtain the above effect, 1% or more is added. However, if over 5%, in addition to a drop in the corrosion resistance, the strength of the γ-phases rises and a drop in the press-formability is invited. For this reason, the upper limit is made 5%. From the viewpoints of the workability and the corrosion resistance, the preferable range is 2 to 4.5%, more preferably 3 to 4%.

[0026] Cr is an element forming α-phases and also has the action of securing the corrosion resistance and adjusting the stability of the γ-phases to express the press-formability targeted by the present invention. Further, Cr, like Si, suppresses the martensite transformation of the α-phases in the cooling process after annealing. Therefore, to secure the stability of the α-phases and the action on the corrosion resistance etc., the content is made 16% or more. However, if over 21%, making the γ-phases the main phases becomes difficult. This invites a drop in the workability targeted by the present invention. For this reason, the upper limit is made 21% or less. From the viewpoints of the workability and corrosion resistance, the preferable range is 16.5 to 18.5%.

[0027] Ni is an effective element forming γ-phases and effectively acts to adjust the Ni-bal to express the press-formability targeted by the present invention. To obtain this effect, 1% or more is added. However, if over 6%, it cannot be said that the Ni is conserved and a rise in the material costs is incurred. For this reason, the upper limit is made 6%. From the viewpoints of the workability and costs, the preferable range is 2 to 5%, more preferably 2.5 to 4.5%.

[0028] Cu is an effective element forming γ-phases in the same way as Ni and Mn and effectively acts to adjust the Ni-bal to express the press-formability targeted by the present invention. To obtain this effect, 1% or more is added. Further, it is also an element effective for improvement of the corrosion resistance by composite addition with Ni. To obtain this effect, 0.5% or more is added. However, if over 3%, a drop in the manufacturability and a rise in the material costs are incurred. For this reason, the upper limit is made 3%. From the viewpoints of the performance and manufacturability, the preferable range is 1.5 to 2.5%.

[0029] N, like C and Ni, is an effective element for forming γ-phases. It effectively acts to adjust the Ni-bal and expresses press-formability targeted by the present invention. For this reason, 0.001% or more is preferably contained. On the other hand, it has the action of raising the strength of the γ-phases and the work hardening and enlarging the difference of strength of the γ-phases and α-phases. For this reason, when actively utilizing the N in this way, this leads to a drop in the press-formability targeted by the present invention. Therefore, as shown in FIG. 1 as well, the upper limit is made 0.07%. From the viewpoint of the workability targeted by the present invention, the preferable range is 0.02 to 0.06%.

[0030] Next, the optional ingredients of the present invention will be explained.

[0031] Mo may be suitably added for improving the corrosion resistance. To obtain the effect of improvement of the corrosion resistance, 0.1% or more is preferably added. However, if over 1%, the economy is liable to be impaired. For this reason, when added, the content is made 1% or less. From the viewpoints of the corrosion resistance and economy, the preferable range when added is respectively 0.2 to 0.8%.

[0032] Nb, V, and Ti improve the corrosion resistance and express effects similar to Si. That is, by solution strengthening of the α-phases, the strength difference of the α-phases and the γ-phases is reduced to improve the press-formability and suppress the martensite transformation of the α-phases in the cooling process after annealing. These may be suitably added to obtain the above effects. When added, the contents are preferably respectively 0.05% or more. However, if over 0.5%, the economy is liable to be impaired. For this reason, when added, the contents are respectively made 0.5% or less. From the viewpoints of the above effects and economy, the preferable ranges when added are respectively 0.1 to 0.3%.

[0033] Sn, Sb, and W may be suitably added for improving the corrosion resistance. To obtain the effect of improvement of the corrosion resistance, it is preferable to respectively add 0.01% or more. However, if over 1%, the hot workability and other aspects of the manufacturability are sometimes impaired. For this reason, when added, the contents are respectively made 1% or less. From the viewpoints of the corrosion resistance and manufacturability, the preferable ranges when added are respectively 0.1 to 0.6%.

[0034] Al is a powerful deoxidizing agent and may be suitably added. To obtain the above effect, 0.001% or more is preferably added. However, if over 0.1%, nitrides are formed and surface flaws or a drop in corrosion resistance is liable to be incurred. For this reason, when added, the content is made 0.1% or less. From the viewpoints of the above effects and manufacturability, the preferable range when added is 0.005 to 0.05%.

[0035] B, Ca, and Mg may be suitably added for improving the hot workability. To obtain the above effect, preferably 0.0002% or more are respectively added. However, if over 0.01%, the corrosion resistance sometimes remarkably falls. For this reason, when added, the contents are respectively made 0.01% or less. From the viewpoints of the above effects and manufacturability, the preferable ranges when added are 0.0005 to 0.01%.

[0036] La, Ce, Zr, Y, and other rare earth metals (REM) also have actions of improving the hot workability in the same way as B, Ca, and Mg. Therefore, they may be suitably added. To obtain these effects, 0.001% or more are preferably respectively added. However, if over 0.3%, sometimes the economy is impaired. For this reason, when added, the contents are made 0.3% or less. From the viewpoints of the above effects and economy, the preferable ranges when added are 0.002 to 0.1%.

[0037] Further, in addition to the above ingredients, P, S, and O (oxygen) may also be included as unavoidable impurities. P, S, and O are elements harmful to the hot workability and corrosion resistance. P is preferably made 0.1% or less, more preferably 0.05% or less. S is preferably made 0.01% or less, more preferably 0.005% or less, still more preferably less than 0.002%. O is preferably made 0.01% or less, more preferably 0.005% or less, still more preferably less than 0.002%.

[0038] In addition to the above ranges of ingredients, a parameter relating to the production of the γ-phases and α-phases defined by the Ni-bal of the following formula <1> from the amounts of C, N, Ni, Mn, Cu, Cr, and Si is prescribed in range to obtain the press-formability targeted by the present invention. The Erichsen value made the parameter of the press-formability, from the results of FIG. 2, reaches the target value of the Erichsen value of 11 mm of the present invention in the range of an Ni-bal of -7.5 to -3.5. For this, the contents of the elements are adjusted so as to give an Ni-bal of -7.5 to -3.5 in range. Preferably, from the results of the study of FIG. 2, the value is made -6 to - 4 in range so that the Erichsen value becomes a maximal value.

$$\text{Ni-bal.}=30(C+N)+Ni+0.5Mn+0.3Cu-1.1(Cr+1.5Si)+8.2 \qquad \langle 1 \rangle$$

(B) The metal microstructure will be explained below:

[0039] The duplex stainless steel sheet of the present invention has the ingredients and Ni-bal explained in section (A) and defines the γ-phase rate for improving the press-formability. The γ-phase rate has a general correlation with the Ni-bal. That is, the γ-phase rate tends to increase along with the rise of the Ni-bal. However, the γ-production ability in the final annealing temperature region explained later does not necessarily correspond straight with the coefficients of the elements in the Ni-bal. For this reason, to obtain a press-formability targeted by the present invention, it is necessary to define both the Ni-bal and the γ-phase rate.

[0040] The γ-phase rate, as explained above, can be found by the EBSP method. The EBSP method, for example, as described in Microscope; Seiichi Suzuki, vol. 39, no. 2, 121 to 124, designates crystal data of the γ-phases (fcc) and α-phases (bcc) and displays a phase distribution map color coding the individual phases. Due to this, it becomes possible to find the γ-phase rate. Further, it is possible to obtain a grasp of the state of dispersion of the γ-phases and the α-phases. For example, the samples are examined from the cross-sections in the sheet thickness directions under a measurement ratio of 500.

[0041] The lower limit of the γ-phase rate is made 50% for securing the press-formability targeted by the present invention. To reduce the 0.2% proof stress and effectively express the press-formability, the rate is preferably 60% or more. On the other hand, if the γ-phase rate exceeds 95%, large amounts of Ni, Mn, and Cu have to be added. This is a problem from the viewpoints of conserving Ni and economy. Furthermore, differentiation from γ-based stainless steel is also not easy. For this reason, the upper limit is made 95%. From the viewpoint of conserving Ni and economy, the preferable range is 60 to 80%.

[0042] NPLT 2 reports the metal microstructure of duplex stainless steel characterized by a high Si and low Ni in relation to development of PLTs 1 to 3. These steels aim at a rise of the 0.2% proof stress to secure strength for automotive use as explained in the Background Art. In general, the 0.2% proof stress of the γ-phases is smaller than that of the α-phases. For this reason, to raise the 0.2% proof stress, it is preferable to provide a duplex microstructure wherein the α-phases are the main phases. The metal microstructure shown in NPLT 2 is a duplex stainless steel with an amount of Cr over 17% where the α-phases constitute the main phases (53.3 to 75.0%α). Therefore, the metal microstructure of the present invention targeted by the press-formability of the steel sheet differs from the metal microstructure of the steel disclosed in PLTs 1 to 3.

[0043] As explained above, the duplex stainless steel sheet of the present invention is mainly comprised of γ-phases, and has a balance of α-phases. If the amount of Cr or the amount of Si is low, the α-phases sometimes undergo martensite transformation in the cooling process after annealing. Martensite phases may also be unavoidably included to an extent not obstructing the press-formability targeted by the present invention.

[0044] The form of dispersion of the α-phases when making γ the main phases is not particularly limited. From the viewpoint of the press-formability, the α-phases are preferably finely dispersed. Specifically, the less than 50 μm α-phases are preferably dispersed in fibrous shapes or grain shapes in the sheet thickness direction. (C) The mechanical properties and Erichsen value will be explained below.

[0045] The duplex stainless steel sheet of the present invention has the ingredients and Ni-bal explained in section (A) and defines the γ-phase rate explained in section (B) so as to improve the press-formability. The mechanical properties and Erichsen value of the steel sheets satisfying these provisions are preferably the following values so as to enable a press-formability no different from that of SUS304 or other austenitic stainless steel sheet.

[0046] The 0.2% proof stress is preferably made less than 400 MPa to make it an extent no different from SUS304 or other austenitic stainless steel. When 400 MPa or more, if envisioning an actual press, there is a fear of insufficient power of the press or wear and damage to the die. More preferably, the value is made 350 MPa or less. The lower limit is not particularly defined, but if considering amount of C+N or amount of alloy added, the more preferable range is 250 to 350 MPa.

[0047] The elongation at break is preferably 35% or more to obtain a high Erichsen value as explained in the explanation of the test steels A, B, and C in Table 2 and [g]. The value is more preferably 40% or more, still more preferably 45% or more.

[0048] The Erichsen value is important as a parameter of the press-formability such as the stretchability. As explained in the test method and [f], to obtain an extent of press-formability no different from austenitic stainless steel targeted by the present invention, the value is preferably 11 mm or more, more preferably 12 mm or more. The upper limit is not particularly provided, but making it over 15 mm is difficult under conditions prescribed in Method B of JIS Z 2241 (wrinkle pressure of 1 tons). (D) The method of production will be explained below.

[0049] So long as satisfying the ingredients and Ni-bal explained in section (A) and the γ-phase rate explained in section (B), the method of production is not particularly limited.

[0050] The final cold rolling and final annealing conditions have an effect on the γ-phase rate and the dispersed state of the microstructure. The reduction rate of the cold rolling is preferably 40% or more from the viewpoint of fine dispersion of the α-phases as the second phase. The final annealing is preferably heated to 950 to 1150°C in range in order to main the γ-phases the main phases. If over 1150°C, the amount of production of the α-phases increases and the microstructure is liable to coarsen. If less than 950°C, the recrystallization and softening of the γ-phases are liable to become insufficient. The cooling after annealing is preferably a cooling rate of air cooling or more (about 3°C/sec or more) for suppressing martensite transformation of the α-phases in the case of a small amount of Cr, amount of Si, etc.

Examples

[0051] Below, examples of the present invention will be explained.

[0052] Duplex stainless steels having the ingredients shown in Table 3 were smelted and hot rolled to produce 4.0 to 5.0 mm thick hot rolled sheets. Steel No. 1 to Steel No. 22 have ingredients and Ni-bal's prescribed by the present invention. Steel Nows. 23 and 24 have the ingredients prescribed by the present invention, but have Ni-bal's outside the present invention. Steel Nos. 25 to 27 have Ni-bal's prescribed by the present invention, but have ranges of ingredients outside of the present invention. These hot rolled sheets were annealed and pickled, then cold rolled to 0.7 mm thickness and final annealed at 1050°C.

Table 3

Steel No.	C	Si	Mn	Cr	Ni	Cu	N	Ni-bal	Others	Remarks
1	0.015	1.9	4.0	17.1	5.2	1.9	0.005	-5.4		Inv. ex.
2	0.015	1.9	4.0	17.1	5.2	1.9	0.005	-5.4 B:	10 ppm, Ca: ppm	5 Inv. ex.
3	0.03	1.9	3.7	17.1	3.9	1.8	0.028	-6.6		Inv. ex.

(continued)

Steel No.	C	Si	Mn	Cr	Ni	Cu	N	Ni-bal	Others	Remarks
4	0.019	1.9	1.3	17.2	4.8	1.8	0.028	-6.5		Inv. ex.
5	0.020	2.3	4.2	17.0	1.5	2.7	0.068	-7.2		Inv. ex.
6	0.021	1.5	3.0	16.2	2.5	1.0	0.051	-5.6		Inv. ex.
7	0.021	2.8	3.8	16.3	3.0	1.8	0.060	-6.5		Inv. ex.
8	0.025	1.7	4.2	16.8	1.2	1.8	0.045	-7.2		Inv. ex.
9	0.046	2.0	3.5	16.8	2.0	0.6	0.040	-7.1		Inv. ex.
10	0.025	1.7	3.8	16.8	4.7	2.3	0.045	-3.7		Inv. ex.
11	0.025	1.7	3.8	16.8	4.7	2.3	0.045	3.7	Mo: 0.3, Ce: 0.01, Zr: 0.01, Y: 0.01	Inv. ex.
12	0.05	0.6	3.0	18.2	3.0	2.0	0.025	-6.5		Inv. ex.
13	0.015	0.6	3.0	18.2	3.0	2.0	0.025	-6.5	Nb: 0.1, V: 0.1	Inv. ex.
14	0.015	2.1	4.8	18.0	3.8	1.9	0,030	-6.9		Inv. ex.
15	0.015	1.9	3.0	18.0	5.7	1.5	0.015	-6.2		Inv. ex.
16	0.015	1.1	3.9	19.2	4.8	2.0	0.025	-6.2		Inv. ex.
17	0.015	0.7	3.8	20.5	5.2	2.0	0.020	-6.8	Al: 0.05	Inv. ex.
18	0.015	0.7	3.8	20.5	5.2	2.0	0.020	-6.8		Inv. ex.
19	0.05	1.9	3.0	18.0	5.7	1.5	0.015	-6.2		Inv. ex.
20	0.010	1.8	3.7	17.6	4.8		2.1 0.025	-5.8	Sb: 0.1	Inv. ex.
21	0.010	1.8	3.7	17.6	4.8	2.1	C.025	-5.8	W: 0.1, La: 0.05	Inv. ex.
22	0.010	1.8	3.7	17.6	4.8	2.1	0.025	-5.8	Ti: 0.1, Sn: 0.1, Mg: 5ppm	Inv. ex.
23	0.020	0.8	4.2	16.9	4.2	1.9	0.040	*-3		Comp. ex.
24	0.020	1.9	4.2	19.5	4.0	1.9	C.040	*-7.9		Comp. ex.
25	0.030	0.6	3.5	20.5	1.7	0.5	*0.14	-6.6		Comp. ex.
26	0.030	0.8	3.5	*15.5	1.7	0.5	0.020	-5.1		Comp. ex.
27	0.030	0.7	4.7	*21.5	3.5	2.5	0.060	-7.3		Comp, ex.

Ni-bal.= 30(C+N)+0.5Mn+0.3Cu+Ni-1.1(Gr+1.5Si)+8.2
*: means outside target of the present invention

[0053] From the obtained cold rolled annealed sheets, various test pieces were taken and measured for γ-phase rate or used for JIS No. 13B tensile tests and Erichsen tests. The measurement and test methods were as follows. The 0.2% proof stress, tensile strength, elongation, Erichsen value, and γ-phase rate were evaluated. The results of evaluation are shown in Table 4.

Table 4

Steel No Steel No	0.2%PS N/mm^2	TS N/mm^2	EL %	Er mm	γ vol%	Remarks
1	280	650	49	12.3	70	Inv. ex.
2	275	650	50	12.8	70	Inv. ex.
3	310	690	44	11.9	55	Inv. ex.
4	320	690	46	12.1	55	Inv. ex.
5	380	740	43	11.3	50	Inv. ex.

(continued)

Steel No Steel No	0.2%PS N/mm^2	TS N/mm^2	EL %	Er mm	γ vol%	Remarks
6	330	700	52	13.2	65	Inv. ex.
7	340	720	43	11.4	55	Inv. ex.
8	320	700	44	11.5	50	Inv. ex.
9	350	700	43	11.4	50	Inv. ex.
10	340	730	53	13.5	80	Inv. ex.
11	350	720	49	12.8	75	Inv. ex.
12	300	680	46	12.2	55	Inv. ex.
13	320	700	49	12.6	55	Inv. ex.
14	290	670	44	11.6	50	Inv. ex.
15	310	71.0	47	12.2	60	Inv. ex.
16	290	690	45	11.8	55	Inv. ex.
17	360	650	39	11.1	50	Inv. ex.
18	360	650	42	11.3	50	Inv. ex.
19	330	680	44	11.7	55	Inv. ex.
20	290	670	50	12.9	68	Inv. ex.
21	290	670	51	13.1	72	Inv. ex.
22	310	670	48	12.9	68	Inv. ex.
23	330	600	34*	10.5*	80	Comp. ex.
24	320	650	38	10.5*	45*	Comp. ex.
25	450*	720	48	10*	40*	Comp. ex.
26	500*	650	25*	9*	60	Comp. ex.
27	370	680	38	9.5*	35*	Comp. ex.
S430LX	270	400	34	10.0	0	-
S304	300	700	51	12.8	100	-
Target 0.2%PS: less than 400 MPa, EL: 35% or more, Erichsen value: 11 mm or more *: means outside target of the present invention						

[0054] Steel Nos. 1 to 22 have 0.2% proof stresses of less than 400 MPa, elongations of 35% or more, and Erichsen values higher than the 11 mm targeted by the present invention. Further, the γ-phase rates are 50% or more. These are mainly γ-phase duplex stainless steel sheets. Due to this, it is learned that by satisfying both the ingredients and Ni-bal range prescribed in the present invention, the Erichsen values become higher than SUS430LX and become no different from or more than SUS304 and other γ-based stainless steels.

[0055] Nos. 23 and 24 have an elongation of less than 35% or a γ-phase rate of less than 50% and failed to reach Erichsen values of 11 mm or more targeted by the present invention. Due to this, it is learned that even if satisfying the ingredients prescribed in the present invention, when outside the Ni-bal range, the Erichsen value targeted by present invention is not reached.

[0056] Nos. 25 to 27 have 0.2% proof stresses of over 400 MPa or γ-phrase rates of less than 50% and failed to reach Erichsen values of 11 mm or more targeted by the present invention. Due to this, iL is learned that even if satisfying the Ni-bal range prescribed in the present invention, when outside the ranges of ingredients, the Erichsen value targeted by present invention is not reached.

Claims

1. A duplex stainless steel sheet with excellent press-formability **characterized by** containing, by mass%,
C: 0.05% or less,
Si: 0.5 to 3%,
Mn: 1 to 5%,
Cr: 16 to 21%,
Ni: 1 to 6%,
Cu: 0.5 to 3%, and
N: 0.07% or less
having an Ni-bal value given by the following formula <1> of -7.5 to -3.5, having a balance of Fe and unavoidable impurities, having an austenite phase rate of 50% to 95%, and having a balance of ferrite phases:

$$\text{Ni-bal}=30(C+N)+Ni+0.5Mn+0.3Cu-1.1(Cr+1.5Si)+8.2 \qquad \text{formula <1>}$$

2. A duplex stainless steel sheet with excellent press-furmability as set forth in claim 1 **characterized in that** said steel further contains, by mass%, one or more of:

   Mo: 1% or less,
   Nb: 0.5% or less,
   V: 0.5% or less,
   Ti: 0.5% or less,
   Sn: 1% or less,
   Sb: 1% or less,
   W: 1% or less, and
   Al: 0.1% or less.

3. A duplex stainless steel sheet with excellent press-formability as set forth in claim 1 or 2 **characterized in that** said steel further contains, by mass%, one or more of
B: 0.01% or less,
Ca: 0.01% or less,
Mg: 0.01% or less,
La: 0.3% or less,
Ce: 0.3% or less,
Zr: 0.3% or less, and
Y: 0.3% or less.

4. A duplex stainless steel sheet with excellent press-formability as set forth in claim 1 or 2 **characterized in that** a 0.2% proof stress in a tensile test is less than 400 MPa and an elongation at break is 35% or more.

5. A duplex stainless steel sheet with excellent press-formability as set forth in claim 3 **characterized in that** a 0.2% proof stress in a tensile test is less than 400 MPa and an elongation at break is 35% or more.

6. A duplex stainless steel sheet with excellent press-formability as set forth in claim 1 or 2 **characterized in that** a formed height found by an Erichsen test (Erichsen value) is 11 mm or more.

7. A duplex stainless steel sheet with excellent press-formability as set forth in claim 3 **characterized in that** a formed height found by an Erichsen test (Erichsen value) is 11 mm or more.

8. A duplex stainless steel sheet with excellent press-formability as set forth in claim 4 **characterized in that** a formed height found by an Erichsen test (Erichsen value) is 11 mm or more.

9. A duplex stainless steel sheet with excellent press-formability as set forth in claim 5 **characterized in that** a formed height found by an Erichsen test (Erichsen value) is 11 mm or more.

FIG.1

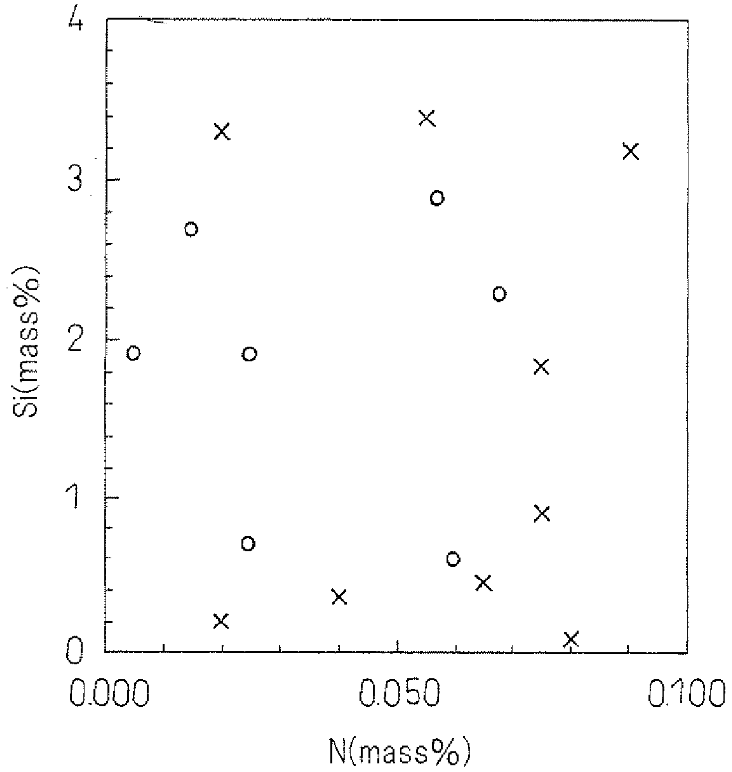
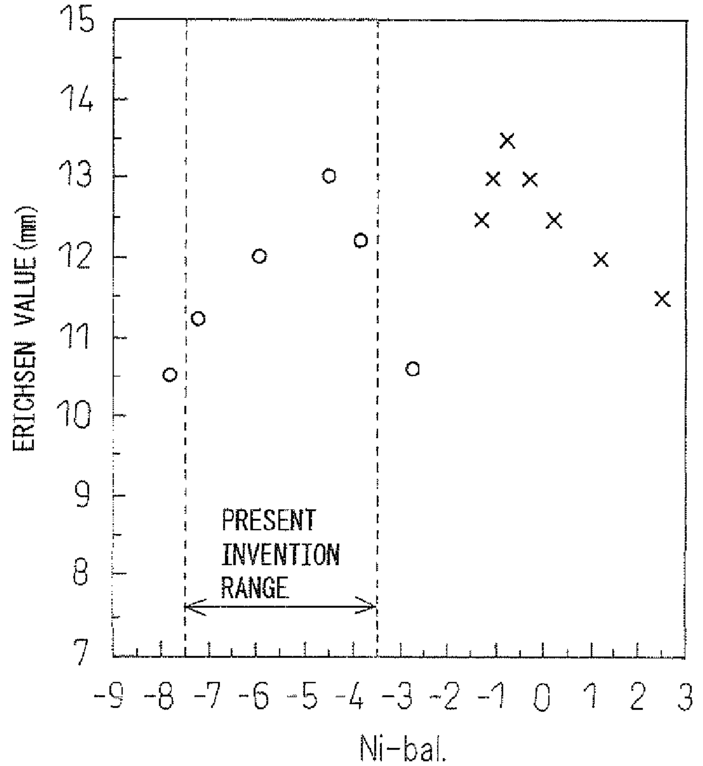

4
3
2
1
0
Si(mass%)
0.000
0.050
0.100
N(mass%)

FIG.2


15
14
13
12
11
10
9
8
7
ERICHSEN VALUE (mm)
PRESENT
INVENTION
RANGE
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3
Ni-bal.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2010/055147

A. CLASSIFICATION OF SUBJECT MATTER
C22C38/00(2006.01)i, *C22C38/58*(2006.01)i, *C22C38/60*(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C22C1/00-61/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho	1922-1996	Jitsuyo Shinan Toroku Koho	1996-2010
Kokai Jitsuyo Shinan Koho	1971-2010	Toroku Jitsuyo Shinan Koho	1994-2010

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 1-225754 A (Armco Advanced Materials Corp.), 08 September 1989 (08.09.1989), & US 4828630 A & EP 327053 A1	1-9
A	JP 2006-265662 A (Nisshin Steel Co., Ltd.), 05 October 2006 (05.10.2006), (Family: none)	1-9
A	JP 2007-63632 A (Nippon Metal Industry Co., Ltd.), 15 March 2007 (15.03.2007), (Family: none)	1-9

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"&" document member of the same patent family

Date of the actual completion of the international search 02 June, 2010 (02.06.10)	Date of mailing of the international search report 15 June, 2010 (15.06.10)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

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

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- *Nippon Stainless Steel Technical Reports,* 1986, 3-5 **[0009]**
- **Seiichi Suzuki.** *Microscope,* vol. 39 (2), 121-124 **[0040]**