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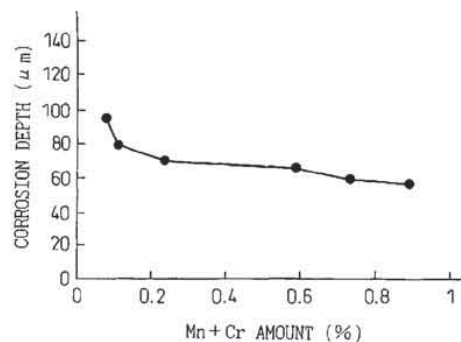
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(54) Title: HIGH-STRENGTH ALLOYED ALUMINUM-SYSTEM PLATED STEEL SHEET AND HIGH-STRENGTH AUTOMOTIVE PART EXCELLENT IN HEAT RESISTANCE AND AFTER-PAINTING CORROSION RESISTANCE



(57) Abstract: The present invention provides a hot press method used for producing a high-strength member for an automobile and, in particular, a part which requires high-strength, such as an undercarriage component of an automobile. More specifically, the present invention provides an aluminum plated steel sheet or an aluminum-zinc plated steel sheet suitable for high temperature forming (hot forming) wherein high strength is obtained after high temperature forming, and a method of producing the same. Also, the present invention provides a hot dip aluminum plated steel sheet which suppresses the alloying reaction of a plated layer during press forming and has beautiful appearance, and an aluminum-system plated steel sheet for hot press having excellent after-painting corrosion resistance. Concretely, the present invention is a high-strength aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance, characterized by having an Fe-Al-system coating containing, in mass, Mn and Cr of more than 0.1% in total on the surface of the steel containing, in mass, C: 0.05 to 0.7%, Si: 0.05 to 1%, Mn: 0.5 to 3%, P: not more than 0.1%, S: not more than 0.1% and Al: not more than 0.2%, and, in addition, one or more element(s) selected from among Ti: 0.01 to 0.8%, Cr: not more than 3% and Mo: not more than 1%, so as to satisfy the following expression (1):  $Ti + 0.5xMn + Cr + 0.5xMo > 0.4 \dots 1$

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## DESCRIPTION

5      HIGH-STRENGTH ALLOYED ALUMINUM-SYSTEM PLATED STEEL SHEET  
         AND HIGH-STRENGTH AUTOMOTIVE PART EXCELLENT IN HEAT  
         RESISTANCE AND AFTER-PAINTING CORROSION RESISTANCE

## Technical Field

10      The present invention relates to an alloyed  
aluminum-system plated steel sheet suitable for a member,  
which is produced by a high-temperature press and  
requires strength, as represented by a structural member  
for an automotive part, and a method of producing the  
same and, in particular, to a member which requires high  
15      strength such as an undercarriage component of an  
automobile or the like, and a steel material used for  
producing the same.

## Background Art

20      For pursuing the weight reduction of an automobile,  
originating from global environmental problems, a steel  
sheet used for an automobile is required to have the  
highest possible strength. However, in general, when the  
strengthening of a steel sheet is enhanced, elongation  
25      and an r-value are lowered and thus formability is  
deteriorated. Therefore, a steel sheet is desired to  
have high-strength, high formability and shape fixability  
simultaneously.

30      One solution to the problem is a TRIP  
(Transformation Induced Plasticity) steel produced by  
using the martensite transformation of retained austenite  
and the application of a TRIP steel is increasing  
recently. However, though it is possible to produce a  
1,000 MPa class high-strength steel sheet excellent in  
35      formability using a TRIP steel, it is difficult to secure  
good formability in a higher-strength steel sheet, for  
example, an ultra-high-strength steel sheet having a

strength of not lower than 1,500 MPa. Moreover, it is difficult to solve the problem of the shape fixability by that technology.

5 To cope with the problems, there is a warm press technology which is a technology attracting attention recently as another means which reconciles high-strength and high formability. A technology of increasing strength by forming a steel sheet while warm and making use of the heat generated during the forming is disclosed  
10 in Japanese Unexamined Patent Publication No. 2000-234153. This technology aims at increasing strength by controlling components in a steel appropriately, heating the steel sheet in the temperature range of ferrite and making use of the precipitation strengthening in the  
15 temperature range.

In Japanese Unexamined Patent Publication No. 2000-87183, proposed is a high-strength steel sheet wherein the yield strength at a temperature during forming is decreased far lower than the yield strength at the room  
20 temperature, aiming at improving the accuracy of press forming. However, there may be a limitation in the strength obtained by this technology.

As a technology which overcomes this drawback, a technology of heating a steel sheet to the temperature  
25 range where austenite single phase is formed and then cooling it during press forming is disclosed in the literature (SAE, 2001-01-0078).

This is a technology of obtaining desired material properties by forming a steel sheet in the state of  
30 heating it to a high temperature of not lower than 800°C, by so doing, solving the forming problem of a high-strength steel sheet, and then quenching it in the cooling after forming. However, as the technology involves heating in the atmosphere, oxides are generated  
35 on the surface of a steel sheet and it is required to remove the oxides in a downstream process. A technology of applying aluminum plating for suppressing the

oxidation during heating is also disclosed in the  
aforementioned literature (SAE, 2001-01-0078).

As another means, a means of obtaining high strength  
by, after forming a steel sheet at the room temperature,  
5 heating rapidly and cooling rapidly a part of the steel  
sheet and thus quenching it can be adopted. In this  
case, by heating the steel sheet locally, it is possible  
to enhance the strength of only the portion where high  
strength is required. Japanese Unexamined Patent  
10 Publication No. 2000-83640 discloses such a technology  
and a steel sheet containing carbon at 0.15 to 0.5% is  
used therefor.

A hot forming technology and a technology of  
applying an aluminum plated steel sheet in the hot  
15 forming are disclosed in the aforementioned prior arts.  
However, in the prior arts, when a steel sheet is heated  
to a high temperature of not lower than 800°C, Fe  
diffuses up to the surface for a short period of time and  
an aluminum plated layer changes to an intermetallic  
20 compound, hereinafter called "alloyed aluminum-system  
plated layer". Since the alloyed aluminum-system plated  
layer is very hard and brittle, sometimes it generates  
cracks and peels off in the state of powder, and  
therefore the deterioration of corrosion resistance after  
25 painting has been a concern. Even when cracks are not  
generated, there have been cases where an aluminum plated  
steel sheet is inferior to another surface treated steel  
sheet, for example, a hot-dip galvanized steel sheet or a  
hot-dip galvanized steel sheet, in after-painting  
30 corrosion resistance. More specifically, after-painting  
corrosion resistance is evaluated after a forming at a  
high temperature and, when scratches, such as cutting in  
a cross shape, are provided, the corrosion of the base  
steel has been apt to propagate from the portion in the  
35 direction of the depth and to advance more than the case  
of a hot-dip galvanized or hot-dip galvanized steel  
sheet of a sacrificial corrosion prevention type.

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Further, there also is the possibility that the exfoliated plated layer piles up on dies and causes flaws during pressing. This is because, though the plated layer can withstand the working of a hot forming, it is practically difficult to work the whole part while it is hot and there is the problem of the plated layer being apt to peel off at the portion where the working has been delayed and the temperature has dropped. Another problem here is that, when the temperature drops, the base steel constitutes a hard structure mainly composed of martensite as a result of quenching, and therefore the stress is apt to escalate.

#### Disclosure of the Invention

The present inventors conducted a basic study for solving the aforementioned problems, and found that a plated steel sheet excellent in after-painting corrosion resistance could be produced by applying an Fe-Al-system coating containing Mn and Cr of more than 0.1% in total on the surface of a steel sheet after a high temperature forming. An aluminum-system plated layer after being subjected to a hot forming and being rapidly heated locally is transformed into an alloyed aluminum-system plated layer up to its surface, and the compound is very brittle and thus tends to generate cracks during working. The aluminum-system plated steel sheet defined in the present invention means a plated steel sheet having a plated layer composed of Al and Fe content of at least 70%. Further, since the layer has a nobler electric potential than the base steel sheet, the corrosion of the base steel is initiated starting from the cracks and after-painting corrosion resistance is apt to deteriorate. For avoiding the deterioration of the after-painting corrosion resistance, Mn addition to the alloyed aluminum-system plated layer is very effective. Though the function of Mn is not clarified yet, it is said that Mn plays the roll of bringing the electric

potential of an Fe-Al-system plated layer close to that of the steel sheet by controlling the electric potential of the alloy layer, and, in addition to the function, there is also the possibility that Mn controls also the shape of phosphate crystals in a phosphating treatment which is a pre-painting treatment.

Extremely excellent heat resistance, in particular, heat resistance after working, can be obtained by specifying the amounts of C, Si, Mn, P, S and Al as base steel components and by adding Ti, Cr and Mo, which addition was effective, so as to satisfy the following equation 1:

$$\text{Ti} + 0.5 \times \text{Mn} + \text{Cr} + 0.5 \times \text{Mo} > 0.4 \dots 1$$

It is estimated that those elements accelerate the diffusion between Al and Fe, and, by so doing, even when cracks are generated in a plated layer, the reaction between Fe and Al proceeds from the circumference of the cracks and therefore the base steel is hardly exposed.

Further, the present inventors also obtained the knowledge that, by adding N, Nb, V, Ni, Cu, B, Sn and Sb as steel components, further excellent after-painting corrosion resistance could be obtained.

In the meantime, it is advantageous for a plated layer after alloying treatment to contain Si further, and furthermore, better corrosion resistance is obtained by adding Zn, Mg, etc. It is important that Al content in an alloy layer is not more than 35% in view of suppressing cracks in the alloy layer. Further, it is desirable that the thickness of an Fe-Al-system alloy layer is 3 to 35  $\mu\text{m}$  from the viewpoint of after-painting corrosion resistance.

Further, for overcoming the above-mentioned problems, the present inventors studied in detail the factors influencing the workability of an aluminum-system plated steel sheet after alloying treatment, and obtained

the following knowledge. That is, since both an alloyed aluminum-system plated layer and a base steel are hard, the internal stress increases, but, since a soft layer exists between the alloyed aluminum-system plated layer and the base steel, the stress is mitigated and therefore exfoliation resistance is improved markedly. The soft layer is composed of a ferrite phase, and it is estimated that the fact that the thickness of the soft layer is not less than 1  $\mu\text{m}$  prevents the cracks in the alloyed layer propagating up to the base steel.

In addition, for overcoming the above-mentioned problems, the present inventors studied in detail the factors influencing the workability of an aluminum-system plated steel sheet after alloying treatment, and obtained the following knowledge. That is, it is possible to prevent the exfoliation of a plated layer by optimizing the heating conditions. The reason is not clear but it is estimated that a plated layer is alloyed according to heating conditions, the phase structure changes complicatedly, and there is an appropriate phase structure for securing workability. The gist of the present invention is as follows:

(1) A high-strength alloyed aluminum-system plated steel sheet excellent in after-painting corrosion resistance, characterized by having an Fe-Al-system coating containing Mn and Cr of more than 0.1% in total on the surface of the steel sheet.

(2) A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance, characterized by having an Fe-Al-system coating containing, in mass, Mn and Cr of more than 0.1% in total on the surface of the steel containing, in mass, C: 0.05 to 0.7%, Si: 0.05 to 1%, Mn: 0.5 to 3%, P: not more than 0.1%, S: not more than 0.1% and Al: not more than 0.2%, and, in addition, one or more element(s) selected from among Ti: 0.01 to 0.8%, Cr: not

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more than 3% and Mo: not more than 1%, so as to satisfy the following equation 1:

$$\text{Ti} + 0.5 \times \text{Mn} + \text{Cr} + 0.5 \times \text{Mo} > 0.4 \dots 1$$

- 5 (3) A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to the item (2), characterized in that the steel further contains, in mass, one or more element(s) selected from among N: not  
10 more than 0.1%, Nb: not more than 0.1%, V: not more than 0.1%, Ni: not more than 1%, Cu: not more than 1%, B: 0.0003 to 0.03%, Sn: not more than 0.1% and Sb: not more than 0.1%.
- 15 (4) A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to the item (1), characterized in that the steel contains, in mass, C:  
0.15 to 0.55%, Si: not more than 0.5%, Mn: 0.2 to 3%, P:  
20 not more than 0.1%, S: not more than 0.04%, Al: 0.01 to 0.1% and N: not more than 0.01%, and also one or more element(s) selected from among B: 0.0002 to 0.0050%, Ti:  
0.01 to 0.8%, Cr: not more than 2%, Mo: not more than 1%, Ni: not more than 1%, Cu: not more than 0.5% and Sn: not  
25 more than 0.2%.
- (5) A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to any one of the  
30 items (1) to (4), characterized in that the Fe-Al-system coating further contains Si of 1 to 20%.
- (6) An alloyed aluminum-system plated steel sheet for high-strength automotive members according to any one  
35 of the items (1) to (5), characterized in that Al concentration in the Fe-Al-system coating layer is not more than 35% in weight.

(7) A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to any one of the items (1) to (6), characterized in that the Fe-Al-system coating further contains either one or both of Zn: 1 to 50% and Mg: 0.1 to 10%.

(8) An alloyed high-strength aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to any one of the items (1) to (7), characterized in that the thickness of the Fe-Al-system coating layer is 3 to 35  $\mu\text{m}$ .

(9) An alloyed aluminum-system plated steel sheet for high-strength automotive members, characterized by having: a coating layer mainly composed of Fe-Al on the surface of the steel sheet; a ferrite layer having a thickness from not less than 2  $\mu\text{m}$  to not more than one tenth of the steel sheet thickness at the underside of the coating layer; and the base steel mainly composed of martensite at the underside of the ferrite layer.

(10) An alloyed aluminum-system plated steel sheet for high-strength automotive members according to the item (9), characterized in that the alloyed aluminum-system plated layer on the surface of the steel sheet and the ferrite layer at the underside of the intermetallic compound layer contain Si.

(11) An alloyed aluminum-system plated steel sheet for high-strength automotive members according to the item (9) or (10), characterized in that the hardness of the ferrite phase is not higher than 200.

(12) A high-strength automotive part formed by press

forming, at least a portion of which is composed of a steel according to any one of the items (1) to (11).

(13) A high-strength automotive part according to the item (12), characterized by having a coated film 1 to 200  $\mu\text{m}$  in thickness on at least a part of the surface.

(14) A hot forming method for a high-strength automotive member, wherein, when the automotive member is produced by a hot forming using a steel sheet produced by plating a steel containing C of not less than 0.05% in weight as a steel component with a metal mainly composed of Al, the member is formed by press forming after heated on the heating condition of the longer time period side than the following regions, A, B, C and D, and at least a part of the member is cooled at a cooling rate of not lower than  $10^{\circ}\text{C}/\text{sec.}$ :

A ( $800^{\circ}\text{C}$ , 13 min.), B ( $900^{\circ}\text{C}$ , 6 min.), C ( $1,050^{\circ}\text{C}$ , 1.5 min.), D ( $1,200^{\circ}\text{C}$ , 0.3 min.).

#### Brief Description of the Drawings

Fig. 1 is a graph showing the influence of the total amount of Mn and Cr in an alloyed aluminum-system plated layer on after-painting corrosion resistance.

Fig. 2 is a graph showing the relation between the addition amount of Ni, Cu and Sn and bare corrosion resistance.

Fig. 3 is a graph showing the relation between the addition amount of Ni, Cu and Sn and after-painting corrosion resistance.

Fig. 4 is a graph showing the relation between the addition amount of Cr and Mo and bare corrosion resistance.

Fig. 5 is a graph showing the relation between the addition amount of Cr and Mo and after-painting corrosion resistance.

Fig. 6 is the Fe-Al-Si-system ternary phase diagram

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at the temperature of 950°C.

Fig. 7 is a photograph (back scattered election image) showing an example of structures according to the present invention, taken by an optical microscope.

5 Fig. 8 is a graph showing the relation between the thickness of an outer layer and the workability of a plated layer.

10 Fig. 9 is a photograph (back scattered electron image) showing an example of metallic structures according to the present invention, taken by a microscope.

Fig. 10 is a view showing a shape obtained by forming a steel sheet according to the present invention.

15 Fig. 11 is a graph showing the relation between a heating time and a heating temperature according to the present invention.

#### Best Mode for Carrying out the Invention

##### Embodiment 1

20 Chemical compositions of steel sheets used in the present invention will be explained hereunder.

C: A steel sheet according to the present invention has a high-strength of not lower than 1,000 MPa after forming and is obtained by rapidly cooling it after a high temperature press and thus transforming the structure thereof into a structure mainly composed of martensite. In that sense, a C content of not less than 0.05% is desirable, and, for obtaining a high-strength stably, the content of not less than 0.1% is more desirable. On the other hand, even though C content is increased to not less than 0.7%, the strength is saturated and also weld cracking tends to be generated, and therefore the upper limit is set at 0.7%.

35 Si: Since too low an Si content causes fatigue property to deteriorate, the addition amount of not less than 0.05% is desirable. However, Si is also an element which forms a stable oxide film on the surface of a steel

sheet during recrystallizing annealing and hinders aluminum plating properties. For that reason, the upper limit of Si is set at 1%.

5 Mn: Mn is well known as an element which enhances the hardenability of a steel sheet. Also, Mn is an element which is necessary for preventing hot embrittlement caused by S which is an unavoidable impurity. For that reason, the addition amount of not less than 0.5% is preferable. Further, Mn also enhances  
10 heat resistance after aluminum plating. However, since Mn addition amount exceeding 3% causes the impact property after quenching to deteriorate, the value is determined to be the upper limit.

15 Ti: Ti affects the heat resistance of an aluminum plated layer most. In the case where a steel sheet is used in such a temperature range as exceeding 900°C, as is the case of the present invention, Ti addition is preferable from the viewpoint of heat resistance, and an addition amount of not less than 0.01% is desirable for  
20 achieving the effect. However, since Ti forms TiC with C and decreases the amount of C which contributes to strength, it is necessary to increase C amount corresponding to the Ti addition amount. Further, the effect of Ti is saturated in the amount of about 0.8%,  
25 and therefore this value is determined to be the upper limit.

Cr: Cr, like Mn and Ti, contribute to the improvement of the heat resistance after aluminum plating. However, Mn deteriorates aluminum plating  
30 properties by forming a stable oxide film on the surface of a steel sheet, in the same way as Si. Further, Cr is a relatively expensive element, and therefore the upper limit is set at 3% when it is added.

35 Mo: Mo, like Mn, Ti and Cr, also contributes to the improvement of the heat resistance after aluminum plating and its addition is desirable. However, since Mo is a relatively expensive element and the effect is saturated,

the upper limit is set at 1%.

In the present invention, it is preferable to add the elements which improve the heat resistance after aluminum plating, such as Ti, Mn, Cr and Mo, in a manner of satisfying the following expression:

$$\text{Ti} + 0.5 \times \text{Mn} + \text{Cr} + 0.5 \times \text{Mo} > 0.4.$$

In particular, Ti and Cr have an effect against the exfoliation of a plated layer during heating. Further, Mn may be added relatively abundantly and greatly contributes to heat resistance.

The present invention prescribes that P, S and Al are further added in a steel. However, since P and Al deteriorate the ductility and fatigue strength of a steel and S deteriorates toughness thereof, an upper limit is determined for each of them. In addition, one or more of Ni, Nb, V, N, Cu, B, Sn and Sb can be contained in a steel as occasion demands. Ni and Cu contribute to the corrosion resistance of a steel and B improves hardenability.

On many occasions, a steel sheet is used after an aluminum plated layer is alloyed and then it is painted. On those occasions, after-painting corrosion resistance is affected by the amounts of Mn and Cr in an alloyed aluminum-system plated layer. When the amount of these elements is not less than 0.1%, good after-painting corrosion resistance is obtained. As the methods of adding Mn and Cr, there are a method of diffusing steel components and a method of adding them in a plating bath, and either of the methods can achieve the effect as long as the addition amount is not less than 0.1%. It is known that one to five phases can coexist in an alloyed aluminum-system plated layer depending on the deposit amount of plating, the steel composition, the heating conditions and the like. Since the influence of phases in the vicinity of a surface is particularly large, when analyzing them, it is preferable to judge by measuring them at about 5 portions on a cross-section in the region

within 5  $\mu\text{m}$  in depth from the surface using a means such as the EPMA quantitative analysis or the like, and by calculating the average thereof. As is stated later, in case of hot dip aluminum plating, it is common to add Si and, at that time, Si is further contained in the alloyed aluminum-system plated layer. The amount is about 1 to 20% and the Si amount in the alloyed aluminum-system plated layer of one to five phases may vary considerably. Though an Fe-Al-system coating of one to five phases can have various compositions, such as an Fe-Al-Si-system alloyed aluminum-system plated layer,  $\text{Fe}_2\text{Al}_5$ ,  $\text{FeAl}_3$ ,  $\text{Fe}_3\text{Al}$ ,  $\text{FeAl}$ , Al dissolved ferrite, or the like, in any of the compositions, stable after-painting corrosion resistance can be obtained as long as the total amount of Mn and Cr is not less than 0.1%. With regard to which phase should be analyzed when a plurality of phases exist, since the knowledge that Mn and Cr contribute to the improvement of after-painting corrosion resistance was obtained and the corrosion phenomenon is a macroscopic phenomenon, the present inventors think that; general information can be obtained by analyzing them at about 5 portions at random, even when a plurality of phases exist, and calculating the average thereof and, by so doing, the judgement can be made. Further, it is prescribed that a cross-section is etched with nitral of 2 to 3% for observing the cross-section of a structure after heating. This is because the interface between a base metal and Al dissolved ferrite, which is formed particularly when the heating time is longer, cannot be observed without etching.

The deposit amount of aluminum plating affects corrosion resistance, weldability, workability and the like. If the deposit amount is too small, after-painting corrosion resistance is insufficient, and if it is too large, weldability and workability deteriorate. With regard to workability, it is because a brittle alloyed aluminum-system plated layer tends to peel off during the

press after heating.

A method of aluminum plating is not specifically restricted, and the hot dip plating method, the electroplating method, the vacuum deposition method, the clad method or the like can be employed. The method most widely employed industrially at present is the hot dip plating method, and usually Al-10%Si is frequently used in a plating bath and Fe is contained therein as an unavoidable impurity. It was already described before that, in addition to those, the addition of Cr and Mn improves after-painting corrosion resistance. As other additional elements, Mg, Ti, Zn, Sb, Sn, Cu, Ni, Co, In, Bi, misch metal, etc. are nominated, and those elements may be applied as long as the plated layer is mainly composed of Al.

The present invention does not specifically define a pre-treatment and a post-treatment of aluminum plating. As a plating pre-treatment, a pre-plating of Ni, Cu, Cr, or Fe, or the like is nominated, and any of those can be adopted. As a plating post-treatment, a chromate treatment, a resin coating treatment or the like is nominated aiming at primary rust prevention and lubricity, but an organic resin is not preferable because it disappears when heated. With regard to a chromate treatment, considering the recent regulation against hexavalent chrome, a treatment film containing trivalent chrome, such as electrolytic chromate or the like, is preferable. Another post-treatment other than an inorganic-system chromate treatment can be applied. It is also possible to apply a treatment of alumina, silica, MoS<sub>2</sub> or the like, beforehand, aiming at lubricity.

#### Embodiment 2

The reason why the steel components are regulated in Embodiment 2 according to the present invention will be described hereunder.

N is an element unavoidably included and is not

specifically prescribed when B is not added, but, when B is added and the amount is excessively large, the addition amount of Ti must be increased. As a result, there is a problem that the amount of resultantly generated TiN increases and hot cracking occurs, and that costs increase also. Therefore, the upper limit is set at 0.1%.

B is added for enhancing hardenability at cooling during or after press forming, and, for achieving the effect, the addition of not less than 0.0002% is necessary. However, when the addition amount is excessive, there is a problem of hot cracking and the effect is saturated. Therefore, the upper limit is set at 0.03%.

Ni, Cu and Sn have the effect of changing the state of surface cracking during press forming after high temperature heating by changing the state of alloying an aluminum plated layer during the high temperature heating, and are important since they lead to an improvement of after-painting corrosion resistance of a formed product. With regard to those elements, from the results shown in Figs. 2 and 3 which were obtained by measuring the addition amounts of Ni, Cu and Sn, and bare corrosion resistance and after-painting corrosion resistance of the samples after high temperature forming in a laboratory test, the present inventors found that, for obtaining above-mentioned effects, Ni, Cu and Sn had to be added so that they might satisfy the equation 3. Here, the bare corrosion resistance and the after-painting corrosion resistance were evaluated by the method examined under the conditions shown in Example, using samples taken from the portions to which working was applied after high temperature forming.

$$(Ni+0.5 \times Cu+3 \times Sn) \geq 0.012 \dots 3$$

With regard to each of Ni, Cu and Sn, an excessive addition of Ni makes the effects saturated and causes a

cost increase, Cu and Sn have the problem of generating surface cracking and, therefore, the upper limit of each element is set at 1.0%, 1% and 0.2%, respectively.

5 The production conditions of a steel sheet according to the present invention is not specifically prescribed, but preferable production conditions will be explained hereunder.

10 A steel having components as described above was cast, and the obtained hot slab, directly or after heated, or the slab once cooled and reheated, was hot-rolled. Here, the difference in the properties of the steel between the direct rolling of the hot slab and the rolling after reheating is scarcely recognized. Further, the reheating temperature is not specified, but it is  
15 preferable to regulate it in the range from 1,000 to 1,300°C, taking productivity into consideration.

With regard to hot-rolling, either a regular hot-rolling process or a continuous hot-rolling process wherein slabs are connected with each other and rolled at  
20 the finish rolling can be adopted. It is preferable to control the finishing temperature at the hot-rolling to not lower than Ar3 transformation temperature taking the productivity and the accuracy of the sheet thickness into consideration.

25 The cooling after hot-rolling is carried out by a usual method. In that case, it is preferable to control the coiling temperature to not lower than 550°C from the viewpoint of productivity. On the other hand, if the coiling temperature is too high, pickling capability  
30 deteriorates, and therefore it is preferable to control the coiling temperature to not higher than 750°C.

For a pickling process or a cold-rolling process, a usual method may be employed, and, for a subsequent aluminum plating process or a subsequent aluminum-zinc  
35 plating process, a usual method may be employed too. That is, in case of an aluminum plating process, Si concentration of 5 to 12% in a plating bath is

appropriate, and, in case of an aluminum-zinc plating process, Zn concentration of 40 to 50% in a plating bath is appropriate.

Here, with regard to the atmosphere in a plating process, plating can be carried out using either a  
5 continuous plating equipment having a non-oxidizing furnace or a continuous plating equipment not having a non-oxidizing furnace as long as usual conditions are preserved. Therefore, no specific control is required in  
10 the production of a product according to the present invention and thus the productivity is not hindered.

In the above production conditions, metal pre-plating is not applied to the surface of a steel sheet before plating, but no specific problem arises even when  
15 Ni pre-plating, Fe pre-plating, or another metal pre-plating which improves plating properties is employed.

Further, even when Mg and Zn are included in an aluminum plated layer or Mg is included in an aluminum-zinc plated layer, no specific problem occurs and a steel  
20 sheet having similar properties can be produced.

### Embodiment 3

Firstly, the reason why the steel components are regulated in Embodiment 3 according to the present  
25 invention will be described hereunder.

C is an element which is added for making a structure after cooling composed of martensite and securing material quality, and the addition amount of not less than 0.15% is required for securing a strength of  
30 not lower than 1,200 MPa. On the other hand, if the addition amount is excessive, the strength against impact deformation is hardly secured and, therefore, the upper limit is set at 0.55%.

Si is a solute strengthening element and can  
35 increase the strength of a steel sheet at a relatively low cost. However, if it is added excessively, plating properties are deteriorated, and therefore the upper

limit is set at 0.5%.

Mn is added for making it possible to secure the strength after cooling in a wide range of cooling rates.

When the C amount is large but the addition amount of Mn is small, a martensite structure cannot be obtained in a usual range of cooling rate, which range can be obtained during press forming, and therefore the strength is hardly secured. The range of cooling rates cited here is not higher than 500°C/sec. in the case of the sheet thickness of 1.4 mm. To demonstrate such function, the addition amount of not less than 0.2% is required. On the other hand, if the Mn amount is too large, not only the cost increases but also the effect is saturated. Therefore, the upper limit is set at 3%.

S is an element which is included unavoidably and causes the deterioration of workability. Therefore, it is necessary to decrease the amount as much as possible. By decreasing the amount to not more than 0.04%, the problem of the workability is eliminated and therefore the range is determined to be not more than 0.04%.

P is a solute strengthening element and can increase the strength of a steel sheet at a relatively low cost. However, if the addition amount increases too much, cracks are generated during hot-rolling or cold-rolling caused by the embrittlement, and therefore the upper limit is set at 0.1%.

Al is used as a deoxidizing agent and, for demonstrating the effect, an Al content of not less than 0.005% in a steel is required. On the other hand, the addition amount exceeding 0.1% causes the increase of oxide-system inclusions and a problem of the deterioration of surface quality, and therefore the upper limit is set at 0.10%.

Cr and Mo have the effect of changing the state of surface cracking during press forming after a high temperature heating by changing the state of alloying an aluminum plated layer during the high temperature

heating, and are important since they lead to the improvement of after-painting corrosion resistance of a formed product. With regard to those elements, from the results shown in Figs. 2 and 3, which were obtained by measuring the addition amounts of Cr and Mo, and bare corrosion resistance and after-painting corrosion resistance of the samples after high temperature forming in a laboratory test, the present inventors found that Cr and Mo had to be added. Here, the bare corrosion resistance and the after-painting corrosion resistance were evaluated by the method examined under the conditions shown in Example, using samples taken from the portions to which working was applied after high temperature forming.

With regard to each of Cr and Mo, an excessive addition of Cr causes problems in plating properties and cost increase and Mo makes the effects saturated and causes cost increase. Therefore, the upper limit of each element is set at 2.0% and 1.0%, respectively.

Other components are not specifically prescribed. Ni is included unavoidably, and, if the amount is within the usual range, no problem arises.

The production conditions of a steel sheet according to the present invention are not specifically prescribed, but preferable production conditions will be explained hereunder.

A steel having components as described above was cast, and the obtained hot slab, directly or after being heated, or the slab once cooled and reheated, was hot-rolled. Here, the difference in the properties of the steel between the direct rolling of the hot slab and the rolling after reheating is scarcely recognized. Further, the reheating temperature is not specified, but it is preferable to regulate it in the range from 1,000 to 1,300°C taking the productivity into consideration.

With regard to hot-rolling, either a regular hot-rolling process or a continuous hot-rolling process

wherein slabs are connected with each other and rolled at the finish rolling can be adopted. It is preferable to control the finishing temperature at the hot-rolling to not lower than Ar3 transformation temperature taking the productivity and the accuracy of the sheet thickness into consideration.

The cooling after hot-rolling is carried out by a usual method. In that case, it is preferable to control the coiling temperature to not lower than 550°C from the viewpoint of productivity. On the other hand, if the coiling temperature is too high, pickling capability deteriorates, and therefore it is preferable to control the coiling temperature to not higher than 750°C.

For a pickling process or a cold-rolling process, a usual method may be employed, and, for a subsequent aluminum plating process or a subsequent aluminum-zinc plating process, a usual method may be employed too. That is, in case of an aluminum plating process, Si concentration of 5 to 12% in a plating bath is appropriate and, in case of an aluminum-zinc plating process, Zn concentration of 40 to 50% in a plating bath is appropriate.

Here, with regard to the atmosphere in a plating process, plating can be carried out using either a continuous plating equipment having a non-oxidizing furnace or a continuous plating equipment not having a non-oxidizing furnace as long as usual conditions are preserved. Therefore, no specific control is required in the production of a product according to the present invention and thus the productivity is not hindered.

In the above production conditions, metal pre-plating is not applied to the surface of a steel sheet before plating, but no specific problem arises even when Ni pre-plating, Fe pre-plating, or another metal pre-plating which improves plating properties is employed. Further, even when Mg and Zn are included in an aluminum plated layer or Mg is included in an aluminum-zinc plated

layer, no specific problem occurs and a steel sheet having similar properties can be produced.

#### Embodiment 4

5 By heating an aluminum plated layer and thus converting it into an alloy layer, namely an Fe-Al-system coating layer, and also by controlling the Al amount to not more than 35% and thus converting the Fe-Al-system  
10 coating layer into Fe+Fe<sub>3</sub>Al wherein Al and Si are dissolved, obtained are far more excellent workability and corrosion resistance at a portion which is subjected to working than those of a plated layer which contains other phases than Fe+Fe<sub>3</sub>Al.

15 C: A steel sheet according to the present invention has a high-strength of not lower than 1,000 MPa after forming and is obtained by rapidly cooling it after a hot press and thus transforming the structure thereof into a structure mainly composed of martensite. To do so, a C content of not less than 0.05% is necessary. On the  
20 other hand, even though the C content is increased to not less than 0.7%, the strength is saturated and also weld cracking tends to be generated, and therefore the upper limit is set at 0.7%.

Steel components except C are not specifically  
25 prescribed, but elements such as Si, Mn, P, Al, N, Cr, Mo, Ti, Nb, B, Ni, Cu, V, Sn, Sb, etc., are nominated as addition elements or unavoidable impurity elements. Those elements may be added as occasion demands. Examples are: Mn and B are effective in hardenability;  
30 Cr, Ti and Mo are effective in the heat resistance of an aluminum plated layer; and Ni and Cu improve corrosion resistance. The desirable ranges of their addition are Mn: 0.5 to 3%, Si: not more than 1%, P: not more than 0.1%, S: not more than 0.1%, Al: not more than 0.1%, N:  
35 not more than 0.01%, Cr: not more than 2%, Mo: not more than 0.5%, Ti: not more than 0.5%, Nb: not more than 0.1%, B: not more than 0.05%, Ni: not more than 1%, Cu:

not more than 1%, V: not more than 0.1%, Sn: not more than 0.1% and Sb: not more than 0.1%.

As stated above, the smaller the deposit amount of aluminum plating is, the more easily an Fe+Fe<sub>3</sub>Al region is formed. In that sense, it is desirable that the  
5 deposit amount is not more than 120 g/m<sup>2</sup> per both sides.

A method of aluminum plating is not specifically restricted, and the hot dip plating method, the electroplating method, the vacuum deposition method, the  
10 clad method or the like can be employed. The method most widely employed industrially at present is the hot dip plating method, and usually Al-10%Si is frequently used in a plating bath and Fe is contained therein as an unavoidable impurity. In this case, Si enters into an  
15 alloy layer after heating and the Si amount may vary depending on the phase structure. However, the Si amount in the Fe+Fe<sub>3</sub>Al region is not more than 15% and therefore the value is determined to be the upper limit of Si. As other additional elements, Mn, Cr, Mg, Ti, Zn, Sb, Sn,  
20 Cu, Ni, Co, In, Bi, misch metal, etc. are nominated, and those elements may be applied as long as the plated layer is mainly composed of Al. The addition of Zn and Mg is effective in making red rust hardly generated. However, the excessive addition of those elements, whose vapor  
25 pressures are high, causes the generation of fumes containing Zn and Mg, the generation of powdery substances on the surface caused by Zn and Mg, and the like. Therefore, a Zn addition of not less than 60% and a Mg addition of not less than 10% are not desirable.

30 The present invention does not specifically define a pre-treatment and a post-treatment of aluminum plating. As a plating pre-treatment, a pre-plating of Ni, Cu, Cr, or Fe, or the like is nominated, and any of these can be adopted. As a plating post-treatment, a chromate  
35 treatment, a resin coating treatment or the like is nominated aiming at primary rust prevention and lubricity, but an organic resin is not preferable because

it disappears when heated. With regard to a chromate treatment, considering the recent regulation against hexavalent chrome, a treatment film containing trivalent chrome, such as electrolytic chromate or the like, is preferable. Another post-treatment other than an inorganic-system chromate treatment can be applied. It is also possible to apply a treatment of alumina, silica, MoS<sub>2</sub> or the like beforehand aiming at lubricity.

10 Embodiment 5

In Embodiment 5, the restriction of the composition of an aluminum-system plated layer will be explained. The aluminum-system plated layer cited here means a plated layer which is not heated yet and thus not alloyed yet.

Si: Si is effective in decreasing the thickness of an alloy layer (a layer composed of an intermetallic compound formed at an interface between a plated layer and a steel sheet) of aluminum-system plating. Further, Si forms Mg<sub>2</sub>Si by adding Mg complexly and is effective in improving corrosion resistance. To enjoy the effects, the addition of not less than 1% is effective. An excessive addition of Si causes the rise of a melting point and, when Si single phase crystallizes at the plated layer, it causes the deterioration of corrosion resistance. Therefore, the upper limit is set at 15%.

Mg: It is known that Mg is effective in improving corrosion resistance particularly under a salt damage environment. By forming Mg<sub>2</sub>Si particularly, a emission efficiency into an environment is increased and corrosion resistance is improved. For securing corrosion resistance, a Mg amount of not less than 0.5% is added. Since an excessive addition causes fierce oxidation at the surface of a plating bath and a rise in the melting point of the plating bath, the addition amount is determined to be not more than 10%. For suppressing the oxidation of the surface of a plating bath, the addition

of a small amount of Ca (not more than 0.5%) is effective, and about this amount of Ca may be added.

5 Zn: Zn has an electric potential more basic than that of Al or steel and a function of suppressing the corrosion of a base steel. The effects begin to appear when Zn addition amount is not less than 1% and the best properties are obtained when Zn amount is 20 to 60%. However, with the addition amount exceeding 60%, corrosion resistance is rather deteriorated. Therefore,  
10 the lower limit and the upper limit of Zn amount are set at 1% and 60%, respectively.

When a part is practically produced using an aluminum-system plated steel sheet according to the present invention, quenching is carried out by rapidly  
15 cooling the part with the dies after press, and thus the structure is mainly composed of martensite. For securing a sufficient strength as a member, the percentage of martensite is determined to be not less than 60% in volume. Here, the percentage of martensite is calculated  
20 by polishing and etching a specimen and, after that, observing it with an optical microscope and using image analysis.

#### Embodiment 6

25 The reason why the components of a steel sheet and the like are regulated in Embodiment 6 will be described hereunder.

A steel sheet according to the present invention has a soft ferrite layer having a thickness from not less  
30 than 2  $\mu\text{m}$  to not more than one tenth of a steel sheet thickness at the interface between an intermetallic compound layer formed by alloying an aluminum plated layer and a base steel mainly composed of martensite. Usually, Al of about 1 to 10% exists in the ferrite  
35 layer. The ferrite phase can also contain Si, in addition to Al. The thickness is limited to not less

than 1  $\mu\text{m}$ . The reason is that, if the thickness of the soft ferrite layer is not more than the above thickness, the exfoliation resistance of the plated layer is not sufficiently obtained. On the other hand, this layer is soft and, if it is too thick, the strength of the whole steel sheet is deteriorated. For that reason, the upper limit is determined to be not more than one tenth of the steel sheet thickness. Usually, an aluminum plated steel sheet is often produced by the hot dip plating method, and, in this case, an alloyed aluminum-system plated layer (called "alloy layer") at the interface between the steel sheet and the plated layer tends to grow. If the layer grows excessively, the workability of the steel sheet is deteriorated and, therefore, the aluminum plated steel sheet is produced in a plating bath wherein Si of about 10% is added. In the present invention, as an aluminum plated steel sheet is worked in the hot after the whole plated layer is alloyed by heating, Si is not necessarily required to be added in the plating bath, but there is no specific problem even when Si is added.

In the present invention, it is desirable that the hardness of a ferrite layer is not higher than 200 in terms of Vickers hardness. As stated above, the layer plays a role of preventing a hard alloy layer from peeling off during working. For that reason, it is preferable that the layer is soft. However, as the layer contains solute strengthening elements such as Al, Si, etc., it is harder than a usual ferrite layer.

Next, other components related to the present invention will be described hereunder. Firstly, with regard to steel components, as the present invention aims at a high-strength region which cannot be obtained with a regular TRIP steel or the like and the enhancement of strength by quenching, it is desirable that C amount is not less than 0.05%, preferably not less than 0.1%. With regard to other elements in a steel, the elements of Si, Mn, Ti, B, Cr, Mo, Al, P, S, N, etc. are used usually.

Si is effective in fatigue property, and Mn and B contribute to the improvement of hardenability. Ti, Si, Cr, Mo and Al are elements which improve heat resistance after aluminum plating.

5           With regard to the construction of an aluminum plated layer, an aluminum plated layer is mainly composed of Al and may contain Si as stated above. As other addition elements, Cr, Mg, Ti, Sb, Sn, Zn, etc. are nominated, and those are applicable as long as the plated  
10          layer is mainly composed of Al. However, Zn has a low boiling point and, when added excessively, Zn generates zinc powder on the surface during heating and that causes galling during pressing. Therefore, the addition amount of not less than 60% is not desirable.

15            $\text{FeAl}_3$ ,  $\text{Fe}_2\text{Al}_5$ ,  $\text{Fe}_3\text{Al}$ ,  $\text{Fe}_2\text{Al}_6\text{Si}$ , etc. are generated as an element of the alloyed aluminum-system plated layer. Those phases tend to form a multi-layered structure in a laminar manner, but the structures of the phases are not specifically regulated. When the composition is mainly  
20          composed of Al and Fe, and Si is added in an aluminum plating bath, Si of about 5 to 10% is contained. Those elements account for not less than 90% of the composition in total. Further, a small amount of not-alloyed Al may remain, but it does not affect the properties of an  
25          aluminum plated steel sheet as long as the amount is small.

          The thickness of a ferrite layer is measured with an optical microscope. The thickness of a ferrite layer is clearly observed by polishing a cross-section and, after  
30          that, etching it with nital at about 2%. However, there is a case where the boundary with an intermetallic compound layer is hardly observed, and, in that case, EPMA analysis is additionally adopted. By so doing, a ferrite layer can easily be identified from the  
35          difference between the radiation strength of Fe and that of Al. It is determined that the measurement of the thickness of a ferrite layer is carried out by measuring

the thickness at about 5 portions at random and calculating the average value. Further, a base steel consists of a structure mainly composed of martensite, and the structure can be observed, for example, by

5 etching it with picral and using an optical microscope.

Fig. 7 shows an example of structures according to the present invention. Two layers are recognized at the interface, and, as a result of quantitative analysis with an EPMA, the lower layer is a ferrite layer about 5  $\mu\text{m}$  in

10 thickness. Here, in Fig. 7, the reference numeral 1 shows the layer composed of Al: 26.85%, Si: 9.83%, Fe: 59.92%; the reference numeral 2 the layer composed of Al: 49.54%, Si: 3.11%, Fe: 44.89%; the reference numeral 3 the layer composed of Al: 30.75%, Si: 8.88%, Fe: 56.91%;

15 and the reference numeral 4 the layer composed of Al: 9.59%, Si: 2.92%, Fe: 84.02%.

Finally, with regard to the heating and cooling conditions of a plated steel sheet, a method of heating and cooling is not specifically defined. For obtaining a

20 hardened structure, a cooling rate affects it largely as a matter of course, and a cooling rate of not lower than about 30°C/sec. is desirable. This depends on steel components, and, in case of a steel having good hardenability, a desired structure mainly composed of

25 martensite can be obtained even at a cooling rate of about 10°C/sec., or, in another case, a cooling rate of not lower than 100°C/sec. is required depending on a steel grade. For obtaining a desired thickness of a ferrite layer, the optimization of heating conditions is

30 required.

#### Embodiment 7

The reason why the components of a steel sheet and the like are regulated in Embodiment 7 will be described

35 hereunder.

The present invention is a high-strength steel sheet having a high-strength of not lower than about 1,000 MPa

after forming, and is the steel sheet obtained by rapidly cooling it after it is subjected to hot press or partial rapid heating, thus quenching it and, by so doing, transforming it into a structure mainly composed of martensite. Therefore, the hardness of a base steel is determined to be not lower than 250. The hardness is measured in terms of Vickers hardness. For obtaining the hardness, a C amount of 0.05% is desirable. With regard to other elements in a steel, no specific restriction is determined, but the elements of Si, Mn, Ti, B, Cr, Mo, Al, P, S, N, etc. are used usually. Si is effective in fatigue property, and Mn and B contribute to the improvement of hardenability. Ti, Si, Cr, Mo and Al are elements which improve heat resistance after aluminum plating.

Further, in the present invention, a steel sheet has an alloyed aluminum-system plated layer mainly composed of Al and Fe on the surface of the base steel and the thickness of the alloyed aluminum-system plated layer is limited to 3 to 35  $\mu\text{m}$ , preferably 3 to 18  $\mu\text{m}$ . The restriction is determined considering the balance among weldability, after-painting corrosion resistance and heat resistance, as described above. That is, when the thickness of a layer is less than 3  $\mu\text{m}$ , sufficient after-painting corrosion resistance and heat resistance cannot be obtained. In case of not adding Si to an aluminum plated layer in particular, the deterioration of heat resistance is remarkable. The upper limit of the thickness is determined by spot weldability. A spot weldability (electrode life) identical with a galvanized steel sheet can be obtained when the plating thickness is not more than 35  $\mu\text{m}$ , and a spot weldability identical with a hot dip alloyed zinc-coated steel sheet can be obtained when the plating thickness is not more than 18  $\mu\text{m}$ .  $\text{FeAl}_3$ ,  $\text{Fe}_2\text{Al}_5$ ,  $\text{Fe}_3\text{Al}$ ,  $\text{Fe}_2\text{Al}_6\text{Si}$ , etc. can be formed as alloyed layers. Further, the formation of a ferrite

layer containing Al is recognized very often at the interface between the alloyed layer and the base steel.

Usually, in an aluminum plated steel sheet, an Fe-Al-system alloy layer tends to grow and deteriorate workability. Therefore, it often happens that Si is added for suppressing the growth of the alloy layer and improving workability. In case of hot press, since a steel sheet is worked in the hot after the aluminum plated layer is heated and alloyed up to the surface, Si is not particularly required to be added. However, Si may be added as a matter of course. In case of rapidly heating a part of a steel sheet, since working is applied at the room temperature, Si addition is indispensable. Cr, Mg, Ti, Sb, Sn, Zn, etc. are nominated as other addition elements in an aluminum plated layer, and those elements are applicable as long as the plated layer is mainly composed of Al. However, Zn has a low boiling point and, when added excessively, Zn generates zinc powder on the surface during heating and that causes galling during press. Therefore, the addition amount of not less than 60% is not desirable.

The present invention does not specifically define a pre-treatment and a post-treatment of plating, a heating method of a steel sheet during pressing and a cooling method thereof. As a plating post-treatment, a chromate treatment, a resin coating treatment or the like is nominated aiming at primary rust prevention and lubricity. However, with regard to a chromate treatment, considering the recent regulation against hexavalent chrome, a treatment film containing trivalent chrome, such as electrolytic chromate or the like, is preferable. A resin coating treatment is effective in improving formability in general and it is particularly effective when a part of a steel sheet is rapidly heated after forming. When a steel sheet is heated and then formed, a resin film is decomposed and therefore has no effect.

A method of producing an aluminum plated steel sheet

is not prescribed either. Regular steelmaking conditions and hot-rolling conditions may be applied. An aluminum plating is carried out by the hot dip plating method usually, but a method is not limited to it and an electroplating in nonaqueous solvent, a vapor deposition treatment or the like can be used. As a pre-treatment before plating, Ni pre-plating or the like is nominated, and it can be adopted.

A method of heating or cooling a steel sheet is not particularly prescribed either. A heating means such as electric heating, heating in a furnace, high-frequency heating or the like may be adopted. Among those means, high-frequency heating is appropriate for rapidly heating a part of a steel sheet.

#### Embodiment 8

The reason why the components of a steel sheet and the like are regulated in Embodiment 8 will be described hereunder.

As stated above, the present invention is a technology which secures a desired strength by forming an aluminum plated steel sheet while hot after heating it, cooling it immediately after that, and thus quenching it, and the components of the steel sheet are required to grant excellent hardenability to the steel sheet. To meet the requirement, a C amount of not less than 0.05%, preferably not less than 0.1%, is required. With regard to other elements in a steel, the elements of Si, Mn, Ti, B, Cr, Mo, Al, P, S, N, etc. are used as usual. Si is effective in fatigue property, and Mn and B contribute to the improvement of hardenability. Ti, Si, Cr, Mo and Al are elements which improve heat resistance after aluminum plating.

An element of an alloyed aluminum-system plated layer, such as  $\text{FeAl}_3$ ,  $\text{Fe}_2\text{Al}_5$ ,  $\text{Fe}_3\text{Al}$ ,  $\text{Fe}_2\text{Al}_3\text{Si}$ , etc. can be generated on a surface after heating. Those phases tend to form a multi-layered structure in a laminar manner,

but the structures of the phases are not specifically regulated. When the composition is mainly composed of Al and Fe and, Si is added in an aluminum plating bath, Si of about 5 to 10% is contained. Those elements account  
5 for not less than 90% of the composition in total. Further, it is determined that an aluminum plated steel sheet is subjected to press working after the plated layer is transformed into an alloyed aluminum-system plated layer up to the surface by heating. This is  
10 because, when Al remains abundantly on the surface, weldability and after-painting corrosion resistance are deteriorated.

With regard to the heating and cooling conditions in the present invention, a method of heating and that of  
15 cooling are not particularly restricted. Any one of heating in an atmospheric furnace, induction heating, electric heating or the like may be used. A heating rate at this time is not restricted either. The heating rate largely depends on the thickness and shape of a steel  
20 sheet as a matter of course. New knowledge was obtained that, the longer the retention time in a furnace was, the better the plating adhesiveness during subsequent forming was. The heating temperature is in the range roughly from 800 to 1,200°C, preferably 900 to 1,000°C, and it is  
25 important to retain a steel sheet within this temperature range for about several minutes. However, the retention time depends on temperature, and it is determined that the retention time must be longer than the four points of A (800°C, 13 min.), B (900°C, 6 min.), C (1,050°C, 1.5  
30 min.) and D (1,200°C, 0.3 min.).

However, a longer retention time causes the deterioration of the productivity in press forming. A practically sufficient plating adhesiveness can be obtained by a heating at 950°C for 5 to 8 min., which  
35 condition is determined as a point of compromise. A hardened structure is largely affected by a cooling rate as a matter of course, and, to obtain the hardened

structure, a cooling rate of not lower than 10°C/sec. is required. This depends on steel components, and, in case of a steel sheet having good hardenability, a desired structure mainly composed of martensite can be obtained even at a cooling rate of about 10°C/sec., or, in another case, a cooling rate of about 30°C/sec. is required depending on the steel grade.

Next, the present invention will hereunder be explained in detail based on Examples.

#### Example 1

Hot dip aluminum plating was applied to pickled steel sheets (1.8 mm in thickness) and cold-rolled steel sheets (1.2 mm in thickness) as the materials, having steel compositions shown in Table 1 and being produced through regular hot-rolling and cold-rolling processes. Nos. 1, 3, 5, 7 and 9 in Table 1 are cold-rolled steel sheets, and the rests are hot-rolled steel sheets. In the hot dip aluminum plating, a line of non-oxidizing furnace-reducing furnace type was used, a deposit amount of plating was adjusted to 40 g/m<sup>2</sup> per one side by the gas wiping method after plating, and, after that, the steel sheets were cooled and subjected to a zero-spangle treatment. The plating bath composition at the time was Al-10%Si-2%Fe. Fe in the bath is a component unavoidably supplied by the plating apparatus and the steel sheets in the bath. The plating appearance was good without having non-plating defects or the like. The hardenability and heat resistance of the hot dip aluminum plated steel sheets thus produced were evaluated. The evaluation methods are shown below.

As substantial alloying process, an aluminum plated steel sheet was heated at 950°C for 30 minutes and thereafter cooled while inserted between dies made of steel under a nitrogen atmosphere. The cooling rate was 100°C/sec. The exfoliation of a plated later of a steel sheet was evaluated visually. Further, Vickers hardness

at the cross-section of a steel sheet was measured  
imposing a load of 100 g. Thereafter, a steel sheet was  
subjected to a chemical treatment which was commonly used  
for aluminum plating, a steel sheet and zinc plating,  
5 coated with a cationic electrodeposition paint (Nippon  
Paint Co., Ltd.; powernix 110) in the thickness of 20  $\mu\text{m}$ ,  
baked, and subjected to a salt spray test (JIS-Z2371) for  
20 days after being cut in a cross shape, and the  
corrosion depth from the portion cut in a cross shape was  
10 measured. Here, the depth of the cut in a cross shape  
was about 50  $\mu\text{m}$ . Therefore, a value obtained by  
subtracting 50  $\mu\text{m}$  from a recorded value is a true  
corrosion depth. Further, for obtaining the  
concentrations of Mn and Cr in an Fe-Al intermetallic  
15 compound, the amounts of Mn and Cr were measured by  
quantitatively analyzing a specimen after quenched at 5  
portions in a cross-section after polished in the region  
from the surface to the depth of 5  $\mu\text{m}$ , using an EPMA.  
The evaluation results are shown in Table 2.

20 Evaluation criteria of heat resistance

O: No exfoliation

$\Delta$ : Partial exfoliation from edges

X: Exfoliation generated

25 Evaluation criteria of after-painting corrosion  
resistance

O: Corrosion depth not more than 80  $\mu\text{m}$

X: Corrosion depth more than 80  $\mu\text{m}$

(Each value includes the depth of a cut in a  
cross shape.)

30

[Tables 1 and 2]

Table 1

| No. | Chemical composition (mass%) |      |      |      |       |      |       |      |      |      |        | Ti*  |
|-----|------------------------------|------|------|------|-------|------|-------|------|------|------|--------|------|
|     | C                            | Si   | Mn   | P    | S     | Al   | N     | Ti   | Cr   | Mo   | B      |      |
| 1   | 0.23                         | 0.12 | 1.21 | 0.02 | 0.009 | 0.03 | 0.004 | 0.02 | 0.13 | -    | 0.002  | 0.76 |
| 2   | 0.21                         | 0.20 | 0.81 | 0.02 | 0.007 | 0.05 | 0.004 | 0.22 | 0.20 | -    | -      | 0.83 |
| 3   | 0.17                         | 0.15 | 1.24 | 0.01 | 0.008 | 0.03 | 0.003 | 0.01 | 1.10 | -    | 0.0008 | 1.73 |
| 4   | 0.42                         | 0.7  | 2.41 | 0.01 | 0.009 | 0.01 | 0.003 | 0.66 | 0.21 | -    | 0.001  | 2.08 |
| 5   | 0.23                         | 0.31 | 1.54 | 0.02 | 0.007 | 0.05 | 0.003 | 0.02 | 0.44 | -    | 0.002  | 1.23 |
| 6   | 0.25                         | 0.18 | 1.22 | 0.01 | 0.01  | 0.04 | 0.003 | 0.02 | 0.66 | 0.20 | 0.005  | 1.29 |
| 7   | 0.24                         | 0.2  | 0.41 | 0.01 | 0.02  | 0.05 | 0.004 | 0.09 | 0.10 | 0.15 | 0.01   | 0.47 |
| 8   | 0.2                          | 0.2  | 2.43 | 0.01 | 0.01  | 0.04 | 0.003 | 0.09 | 0.21 | -    | 0.0008 | 1.52 |
| 9   | 0.03                         | 0.1  | 1.4  | 0.02 | 0.01  | 0.03 | 0.004 | 0.25 | 0.15 | -    | 0.0003 | 1.1  |
| 10  | 0.23                         | 0.12 | 0.3  | 0.01 | 0.008 | 0.05 | 0.003 | 0.03 | 0.23 | -    | -      | 0.41 |
| 11  | 0.24                         | 0.10 | 0.51 | 0.01 | 0.008 | 0.03 | 0.004 | 0.05 | 0.03 | -    | 0.0022 | 0.34 |

Note 1) Ti\*: Ti + 0.5Mn + Cr + 0.5Mo

Table 2

| No. | Mn + Cr amount | Heat resistance | Vickers hardness | After-painting corrosion resistance |
|-----|----------------|-----------------|------------------|-------------------------------------|
| 1   | 0.4            | ○               | 515              | ○                                   |
| 2   | 0.22           | ○               | 480              | ○                                   |
| 3   | 0.96           | ○               | 405              | ○                                   |
| 4   | 0.85           | ○               | 766              | ○                                   |
| 5   | 0.30           | ○               | 511              | ○                                   |
| 6   | 0.30           | ○               | 548              | ○                                   |
| 7   | 0.15           | ○               | 539              | ○                                   |
| 8   | 0.78           | ○               | 466              | ○                                   |
| 9   | 0.44           | ○               | 200              | ○                                   |
| 10  | 0.19           | ○               | 311              | ○                                   |
| 11  | 0.21           | △               | 522              | ○                                   |

5

When the C amount is excessively low as in the No. 9 steel sheet, the strength lowers. In general, a value close to material strength (MPa) is obtained by multiply a Vickers hardness by 3, and, in this case, a strength of only 600 MPa class at the most is obtained. When the addition amounts of the elements effective in quenching, such as Mn, B, etc., are small like No. 10 steel sheet, quenching effect is not obtained even though the C amount is large and the strength tends to decrease to some

10

extent. Further, in the case where the value of  $Ti^*$ :  $Ti + 0.5 \times Mn + Cr + 0.5 \times Mo$  is low like No. 11 steel sheet, the plated layer peels off after heating and the heat resistance tends to deteriorate to some extent. In case  
5 of Nos. 1 to 8 steel sheets wherein the addition amounts of the elements in the steels are properly controlled, all of strength, heat resistance and after-painting corrosion resistance show good results.

Next, No. 7 steel sheet of this Example in Table 1  
10 was plated in a plating bath which mainly contained Al-10%Si-2%Fe and in which Mn and Cr were added. The deposit amount of the plating was 60 g/m<sup>2</sup> per one side, and good plating appearance was obtained. The steel sheet was quenched with dies after heated at 900°C for 2  
15 minutes. The cooling rate was about 100°C/sec. The amounts of Mn and Cr in the bath at this time and the evaluation results are shown in Table 3. When the amounts of Mn and Cr in the intermetallic compound are small like No 1 steel sheet, after-painting corrosion  
20 resistance is inferior, but the corrosion resistance improves with the increase of the addition amounts of Mn and Cr in the plating bath. The relation between the amounts of Mn and Cr in the intermetallic compound and the after-painting corrosion resistance at this time are  
25 shown in Fig. 3. It is understood that the after-painting corrosion resistance improves with the increase of the amounts of Mn and Cr.

[Table 3]

Table 3

| No. | Amount of element<br>in bath (%) |      | Amount of element in<br>intermetallic compound (%) |      | After-<br>painting<br>corrosion<br>resistance |
|-----|----------------------------------|------|----------------------------------------------------|------|-----------------------------------------------|
|     | Mn                               | Cr   | Mn                                                 | Cr   |                                               |
| 1   | 0                                | 0    | 0.08                                               | 0    | ×                                             |
| 2   | 0.1                              | 0    | 0.11                                               | 0    | ○                                             |
| 3   | 0.2                              | 0    | 0.24                                               | 0    | ○                                             |
| 4   | 0.4                              | 0.05 | 0.51                                               | 0.08 | ○                                             |
| 5   | 0.6                              | 0    | 0.73                                               | 0    | ○                                             |
| 6   | 0.8                              | 0.1  | 0.75                                               | 0.14 | ○                                             |

## Example 2

The steels having various chemical compositions as  
 shown in Table 4 were cast, heated again to a temperature  
 of 1,050 to 1,250°C, thereafter hot-rolled, pickled,  
 cold-rolled, annealed, subjected to a plating treatment  
 (aluminum plating or aluminum-zinc plating: "Galvalium®"  
 plating), and thereafter subjected to temper rolling at  
 the reduction rate of 0.8%. Further, as alloying  
 process, these steel sheets were heated to a temperature  
 of 900 to 1,000°C, retained for 5 minutes at the  
 temperature, thereafter subjected to press forming with  
 dies of the room temperature, and then subjected to the  
 investigation on the properties. The investigation on  
 material properties was carried out by cutting out the  
 specimens from the portions which were rapidly cooled at  
 the press and applying a tensile test thereto. The test  
 was carried out by cutting the specimens into No. 5 test  
 pieces according to JIS-Z2201 and following the test  
 method described in JIS-Z2241. The evaluation results  
 are shown in Table 5.

[Tables 4 and 5]

Table 4

| Steel No. | C    | Si   | Mn   | S     | P     | Al    | Ti    | N      | Ni   | Cu   | B      | Sn   | Ti-3.42*N |
|-----------|------|------|------|-------|-------|-------|-------|--------|------|------|--------|------|-----------|
| 1         | 0.22 | 0.20 | 1.05 | 0.020 | 0.020 | 0.025 | 0.020 | 0.0024 | 0.02 | 0.02 | 0.0030 | -    | 0.012     |
| 2         | 0.21 | 0.15 | 0.94 | 0.018 | 0.023 | 0.024 | 0.022 | 0.0035 | 0.25 | 0.10 | 0.0027 | -    | 0.010     |
| 3         | 0.22 | 0.15 | 0.94 | 0.018 | 0.023 | 0.024 | 0.022 | 0.0025 | 0.01 | 0.01 | 0.0027 | 0.01 | 0.013     |
| 4         | 0.16 | 0.48 | 1.70 | 0.009 | 0.015 | 0.021 | 0.017 | 0.0025 | 0.80 | 0.02 | 0.0002 | -    | 0.008     |
| 5         | 0.35 | 0.05 | 1.00 | 0.015 | 0.012 | 0.030 | 0.020 | 0.0028 | 0.01 | 0.01 | 0.0020 | -    | 0.010     |
| 6         | 0.53 | 0.10 | 1.10 | 0.010 | 0.020 | 0.026 | 0.200 | 0.0021 | 0.02 | 0.01 | 0.0010 | 0.05 | 0.193     |
| 7         | 0.53 | 0.10 | 0.30 | 0.010 | 0.020 | 0.030 | 0.020 | 0.0020 | 0.90 | 0.02 | 0.0047 | -    | 0.013     |
| 8         | 0.22 | 0.20 | 1.00 | 0.002 | 0.015 | 0.035 | 0.005 | 0.0034 | 0.02 | 0.02 | 0.0005 | -    | -0.007    |
| 9         | 0.21 | 0.20 | 1.10 | 0.022 | 0.021 | 0.028 | 0.020 | 0.0026 | 0.00 | 0.02 | 0.0020 | -    | 0.011     |
| 10        | 0.22 | 0.20 | 2.00 | 0.010 | 0.010 | 0.030 | 0.020 | 0.0033 | 0.01 | 0.01 | -      | -    | 0.009     |
| 11        | 0.35 | 0.15 | 2.10 | 0.012 | 0.013 | 0.023 | 0.018 | 0.0028 | 0.05 | 0.01 | -      | 0.01 | 0.008     |
| 12        | 0.24 | 0.20 | 2.50 | 0.008 | 0.009 | 0.035 | 0.026 | 0.0035 | 0.02 | 0.01 | -      | -    | 0.014     |

Table 5

| Steel No. | Coiling temperature (°C) | Annealing temperature (°C) | Kind of plating   | TS before forming (Mpa) | Heating temperature before forming (°C) | YP (MPa) | TS (MPa) | Bare corrosion resistance | After-painting corrosion resistance |
|-----------|--------------------------|----------------------------|-------------------|-------------------------|-----------------------------------------|----------|----------|---------------------------|-------------------------------------|
| 1         | 630                      | 780                        | Aluminum plating  | 560                     | 950                                     | 1250     | 1580     | ○                         | ○                                   |
|           | 610                      | 775                        | Galvalium plating | 550                     | 950                                     | 1255     | 1600     | ○                         | ○                                   |
| 2         | 680                      | 760                        | Aluminum plating  | 550                     | 950                                     | 1220     | 1610     | ○                         | ○                                   |
|           | 650                      | 780                        | Galvalium plating | 558                     | 950                                     | 1210     | 1590     | ○                         | ○                                   |
| 3         | 620                      | 730                        | Aluminum plating  | 570                     | 950                                     | 1280     | 1550     | ○                         | ○                                   |
|           | 630                      | 730                        | Galvalium plating | 564                     | 950                                     | 1270     | 1540     | ○                         | ○                                   |
| 4         | 650                      | 830                        | Aluminum plating  | 500                     | 980                                     | 1110     | 1310     | ○                         | ○                                   |
|           | 660                      | 840                        | Galvalium plating | 508                     | 980                                     | 1100     | 1320     | ○                         | ○                                   |
| 5         | 630                      | 770                        | Aluminum plating  | 603                     | 950                                     | 1480     | 1830     | ○                         | ○                                   |
|           | 640                      | 770                        | Galvalium plating | 605                     | 950                                     | 1490     | 1820     | ○                         | ○                                   |
| 6         | 650                      | 775                        | Aluminum plating  | 654                     | 940                                     | 1610     | 1990     | ○                         | ○                                   |
|           | 660                      | 780                        | Galvalium plating | 660                     | 940                                     | 1620     | 1980     | ○                         | ○                                   |
| 7         | 650                      | 760                        | Aluminum plating  | 780                     | 910                                     | 1850     | 2100     | ○                         | ○                                   |
|           | 650                      | 760                        | Galvalium plating | 774                     | 910                                     | 1820     | 2120     | ○                         | ○                                   |
| 8         | 650                      | 790                        | Aluminum plating  | 553                     | 950                                     | 750      | 980      | ○                         | ○                                   |
| 9         | 630                      | 800                        | Aluminum plating  | 558                     | 950                                     | 1210     | 1540     | ×                         | ○                                   |
| 10        | 640                      | 780                        | Aluminum plating  | 554                     | 950                                     | 1240     | 1580     | ○                         | ○                                   |
|           | 630                      | 775                        | Galvalium plating | 550                     | 950                                     | 1230     | 1575     | ○                         | ○                                   |
| 11        | 650                      | 760                        | Aluminum plating  | 572                     | 950                                     | 1200     | 1510     | ○                         | ○                                   |
|           | 650                      | 760                        | Galvalium plating | 563                     | 950                                     | 1205     | 1520     | ○                         | ○                                   |
| 12        | 620                      | 730                        | Aluminum plating  | 595                     | 950                                     | 1270     | 1560     | ○                         | ○                                   |
|           | 630                      | 730                        | Galvalium plating | 598                     | 950                                     | 1275     | 1570     | ○                         | ○                                   |

Specimens were cut out from the portions which underwent working during press forming and bare corrosion resistance and after-painting corrosion resistance were evaluated as the surface properties after high temperature forming. The bare corrosion resistance was evaluated by subjecting the specimens to a moisture tank test (relative humidity: 95%, temperature: 40°C) for 3 days, and the after-painting corrosion resistance was evaluated by subjecting the specimens to a salt spray test (JIS-Z2134) for 30 days after the specimens were cut in a cross shape. A cationic electrodeposition paint was adopted as the painting in this case and the painting thickness was 15  $\mu\text{m}$ . The bare corrosion resistance was judged from the appearance using a mark O or X, and the evaluation criteria were: X for the occurrence of red rust and O for no red rust. Likewise, the after-painting corrosion resistance was judged from the appearance using a mark O,  $\Delta$  or X, and the evaluation criteria were: O for blistering of not more than 2 mm,  $\Delta$  for blistering from more than 2 mm to not more than 4 mm, and X for blistering of more than 4 mm. Nos. 1 to 7 steels are the steels having the components within the range specified in the present invention, and all steel sheets produced on the conditions within the range specified in the present invention can secure high strength after high temperature forming and, moreover, have no problem with respect to both the bare corrosion resistance and the after-painting corrosion resistance. Here, in case of No. 7 steel, the results of the steel sheet produced on the conditions where the annealing temperature deviates from the range specified in the present invention is also shown, and, in this case, as the strength of the steel sheet is too high, the evaluation of the properties is not carried out thereafter. In case of Nos. 8 and 9 steels, the steel

compositions deviate from the range specified in the present invention. As a result, in case of No. 8 steel, the strength after high temperature forming, which is one of the targets of the present invention, is low, and, in  
5 the case of No. 9 steel, the bare corrosion resistance and the after-painting corrosion resistance are not secured.

### Example 3

10 The steels having various chemical compositions as shown in Table 6 were cast, heated again to a temperature of 1,050 to 1,250°C, thereafter hot-rolled, pickled, cold-rolled, annealed, subjected to a plating treatment (aluminum plating or aluminum-zinc plating), and  
15 thereafter subjected to temper rolling at the reduction rate of 0.8%. Further, as substantial alloying process, these steel sheets were heated to a temperature of 900 to 1,000°C, retained for 5 minutes at this temperature, thereafter subjected to press forming with dies of the  
20 room temperature, and then subjected to the investigation on the properties. The investigation on material properties was carried out by cutting out specimens from the portions which were rapidly cooled at the press and applying a tensile test thereto. The test was carried  
25 out by cutting the specimens into No. 5 test pieces according to JIS-Z2201 and following the test method described in JIS-Z2241. The evaluation results are shown in Table 7.

30 [Tables 6 and 7]

Table 6

| Steel No. | C    | Si   | Mn   | S     | P     | Al    | N      | Cr   | Mo   | Cr+7×Mo | Remarks             |
|-----------|------|------|------|-------|-------|-------|--------|------|------|---------|---------------------|
| 1         | 0.16 | 0.20 | 0.72 | 0.006 | 0.020 | 0.035 | 0.0025 | 1.00 | 0.18 | 2.260   | Invented example    |
| 2         | 0.21 | 0.21 | 0.68 | 0.008 | 0.018 | 0.032 | 0.0030 | 0.95 | 0.15 | 2.000   | Invented example    |
| 3         | 0.50 | 0.25 | 0.75 | 0.006 | 0.020 | 0.026 | 0.0028 | 0.98 | 0.17 | 2.170   | Invented example    |
| 4         | 0.23 | 0.20 | 1.50 | 0.010 | 0.015 | 0.030 | 0.0030 | 0.32 | 0.00 | 0.320   | Invented example    |
| 5         | 0.22 | 0.45 | 2.20 | 0.009 | 0.010 | 0.038 | 0.0035 | 0.00 | 0.05 | 0.350   | Invented example    |
| 6         | 0.23 | 0.15 | 0.30 | 0.008 | 0.012 | 0.032 | 0.0026 | 1.90 | 0.00 | 1.900   | Invented example    |
| 7         | 0.21 | 0.20 | 0.50 | 0.008 | 0.010 | 0.033 | 0.0028 | 0.00 | 0.80 | 5.600   | Invented example    |
| 8         | 0.22 | 0.21 | 0.65 | 0.006 | 0.015 | 0.032 | 0.0030 | 0.10 | 0.02 | 0.240   | Invented example    |
| 9         | 0.22 | 0.20 | 0.70 | 0.008 | 0.014 | 0.025 | 0.0025 | 0.25 | 0.00 | 0.250   | Invented example    |
| 10        | 0.21 | 0.18 | 0.45 | 0.010 | 0.012 | 0.028 | 0.0025 | 0.00 | 0.03 | 0.210   | Comparative example |

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Table 7

| Steel No. | Coiling temperature (°C) | Annealing temperature (°C) | Kind of plating       | TS before forming (Mpa) | Heating temperature before forming (°C) | YP (MPa) | TS (MPa) | Bare corrosion resistance | After-painting corrosion resistance | Remarks             |
|-----------|--------------------------|----------------------------|-----------------------|-------------------------|-----------------------------------------|----------|----------|---------------------------|-------------------------------------|---------------------|
| 1         | 630                      | 780                        | Aluminum plating      | 565                     | 980                                     | 1080     | 1280     | ○                         | ○                                   | Invented example    |
|           | 620                      | 780                        | Aluminum-zinc plating | 560                     | 980                                     | 1090     | 1270     | ○                         | ○                                   | Invented example    |
| 2         | 650                      | 770                        | Aluminum plating      | 605                     | 950                                     | 1290     | 1560     | ○                         | ○                                   | Invented example    |
|           | 650                      | 765                        | Aluminum-zinc plating | 600                     | 950                                     | 1285     | 1580     | ○                         | ○                                   | Invented example    |
| 3         | 635                      | 740                        | Aluminum plating      | 725                     | 930                                     | 1705     | 1890     | ○                         | ○                                   | Invented example    |
|           | 630                      | 750                        | Aluminum-zinc plating | 750                     | 930                                     | 1700     | 1900     | ○                         | ○                                   | Invented example    |
| 4         | 645                      | 775                        | Aluminum plating      | 500                     | 950                                     | 1390     | 1610     | ○                         | ○                                   | Invented example    |
|           | 650                      | 780                        | Aluminum-zinc plating | 508                     | 950                                     | 1400     | 1600     | ○                         | ○                                   | Invented example    |
| 5         | 630                      | 770                        | Aluminum plating      | 603                     | 950                                     | 1300     | 1550     | ○                         | ○                                   | Invented example    |
|           | 630                      | 770                        | Aluminum-zinc plating | 605                     | 950                                     | 1320     | 1555     | ○                         | ○                                   | Invented example    |
| 6         | 650                      | 770                        | Aluminum plating      | 654                     | 950                                     | 1390     | 1620     | ○                         | ○                                   | Invented example    |
|           | 640                      | 760                        | Aluminum-zinc plating | 660                     | 950                                     | 1380     | 1620     | ○                         | ○                                   | Invented example    |
| 7         | 640                      | 770                        | Aluminum plating      | 780                     | 950                                     | 1320     | 1510     | ○                         | ○                                   | Invented example    |
|           | 650                      | 760                        | Aluminum-zinc plating | 774                     | 950                                     | 1325     | 1520     | ○                         | ○                                   | Invented example    |
| 8         | 630                      | 765                        | Aluminum plating      | 553                     | 950                                     | 1320     | 1580     | ○                         | ○                                   | Invented example    |
|           | 635                      | 760                        | Aluminum-zinc plating | 555                     | 950                                     | 1310     | 1570     | ○                         | ○                                   | Invented example    |
| 9         | 640                      | 770                        | Aluminum plating      | 558                     | 950                                     | 1340     | 1575     | ○                         | ○                                   | Invented example    |
|           | 645                      | 770                        | Aluminum-zinc plating | 562                     | 950                                     | 1350     | 1585     | ○                         | ○                                   | Invented example    |
| 10        | 630                      | 765                        | Aluminum plating      | 554                     | 950                                     | 1350     | 1595     | ×                         | ×                                   | Comparative example |
|           | 640                      | 760                        | Aluminum-zinc plating | 550                     | 950                                     | 1330     | 1530     | ×                         | ×                                   | Comparative example |

Specimens were cut out from the portions which underwent working during press forming and bare corrosion resistance and after-painting corrosion resistance were evaluated as the surface properties after high temperature forming. The bare corrosion resistance was evaluated by subjecting the specimens to a moisture tank test (relative humidity: 95%, temperature: 40°C) for 3 days, and the after-painting corrosion resistance was evaluated by subjecting the specimens to a salt spray test (JIS-Z2134) for 30 days after the specimens were cut in a cross shape. A cationic electrodeposition paint was adopted as the painting in this case and the painting thickness was 15  $\mu\text{m}$ . The bare corrosion resistance was judged from the appearance using a mark O or X, and the evaluation criteria were: X for the occurrence of red rust and O for no red rust. Likewise, the after-painting corrosion resistance was judged from the appearance using a mark O,  $\Delta$  or X, and the evaluation criteria were: O for blistering of not more than 2 mm,  $\Delta$  for blistering from more than 2 mm to not more than 4 mm, and X for blistering of more than 4 mm. Nos. 1 to 9 steels are the steels having the components within the range specified in the present invention, and all steel sheets produced on the conditions within the range specified in the present invention can secure high strength after high temperature forming, and moreover have no problem with respect to both the bare corrosion resistance and the after-painting corrosion resistance. In case of the No. 10 steel, the steel composition deviates from the range specified in the present invention and therefore the bare corrosion resistance and the after-painting corrosion resistance are not secured.

#### Example 4

Hot dip aluminum plating was applied to pickled steel sheets (1.8 mm in thickness) and cold-rolled steel

5 sheets (1.2 mm in thickness) as the materials having  
steel compositions shown in Table 8 and being produced  
through regular hot-rolling and cold-rolling processes.  
Nos. 1, 3, 5 and 7 in Table 8 are cold-rolled steel  
10 sheets, and the rest are hot-rolled steel sheets. In the  
hot dip aluminum plating, a line of non-oxidizing  
furnace-reducing furnace type was used, a deposit amount  
of plating was adjusted to 80 g/m<sup>2</sup> per both sides by the  
gas wiping method after plating, and, after that, the  
15 steel sheets were cooled and subjected to a zero-spangle  
treatment. The plating bath composition at the time was  
Al-10%Si-2%Fe. Fe in the bath is a component unavoidably  
supplied from the plating apparatus and the steel sheets  
in the bath. Plating appearance was good without having  
20 non-plating defects or the like. The properties are  
shown in Table 9.

The hardenability and workability of the hot dip  
aluminum plated steel sheets thus produced were  
evaluated. The workability was evaluated by heating an  
20 aluminum plated steel sheet at 950°C for 10 minutes under  
the atmosphere, as substantial alloying process,  
thereafter cooling it while inserting it between dies  
made of steel (cooling rate: about 30°C/sec.), cooling it  
to the room temperature, and thereafter subjecting it to  
25 an impact test. Further, Vickers hardness at the cross-  
section of a steel sheet was measured by imposing a load  
of 100 g.

Evaluation criteria of workability

- 30           ○: No exfoliation  
            △: Cracks generated  
            ×: Powdery exfoliation generated

[Tables 8 and 9]

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Table 8

| No. | Chemical composition (wt%) |      |      |      |       |      |       |      |      |      |        |
|-----|----------------------------|------|------|------|-------|------|-------|------|------|------|--------|
|     | C                          | Si   | Mn   | P    | S     | Al   | N     | Ti   | Cr   | Mo   | B      |
| 1   | 0.23                       | 0.12 | 1.21 | 0.02 | 0.009 | 0.03 | 0.004 | 0.02 | 0.13 | -    | 0.002  |
| 2   | 0.21                       | 0.20 | 0.81 | 0.02 | 0.007 | 0.05 | 0.004 | 0.22 | 0.20 | -    | -      |
| 3   | 0.17                       | 0.15 | 1.24 | 0.01 | 0.008 | 0.03 | 0.003 | 0.01 | 1.10 | -    | 0.0008 |
| 4   | 0.23                       | 0.31 | 1.54 | 0.02 | 0.007 | 0.05 | 0.003 | 0.02 | 0.44 | -    | 0.002  |
| 5   | 0.25                       | 0.18 | 1.22 | 0.01 | 0.01  | 0.04 | 0.003 | 0.02 | 0.66 | 0.20 | 0.005  |
| 6   | 0.24                       | 0.2  | 0.95 | 0.01 | 0.02  | 0.05 | 0.004 | 0.09 | 0.5  | 0.15 | 0.01   |
| 7   | 0.2                        | 0.2  | 2.43 | 0.01 | 0.01  | 0.04 | 0.003 | 0.09 | 0.21 | -    | 0.0008 |
| 8   | 0.04                       | 0.1  | 1.4  | 0.02 | 0.01  | 0.03 | 0.004 | 0.25 | 0.15 | -    | 0.0003 |

Table 9

| No. | Workability | Al amount in Fe-Al coating (%) | Vickers hardness |
|-----|-------------|--------------------------------|------------------|
| 1   | ○           | 15                             | 515              |
| 2   | ○           | 15                             | 480              |
| 3   | ○           | 15                             | 405              |
| 4   | ○           | 15                             | 511              |
| 5   | ○           | 15                             | 548              |
| 6   | ○           | 15                             | 539              |
| 7   | ○           | 15                             | 466              |
| 8   | ○           | 15                             | 209              |

5                   When the C amount is rather low as in the No. 8 steel, the strength is rather low. In general, a value close to the tensile strength (MPa) of a material is obtained by multiplying a Vickers hardness by 3, and, in this case, a strength of only 600 MPa class at the most is obtained. In case of Nos. 1 to 7 steels, both strength and workability show good results. The Al amount in the Fe-Al coating layer in this case is quantitatively analyzed using an EPMA, and the value is around 15%. Here, the value is obtained by analyzing 5 portions in a cross-section of a specimen after quenching in the range from the surface to the depth of 10  $\mu$ m and averaging the analysis data.

10                   Next, No. 1 steel sheet of this Example in Table 8 was plated with a metal mainly composed of Al-10%Si-2%Fe and the deposit amount of the plating was varied from 60

to 200 g/m<sup>2</sup> per both sides. The samples thus obtained were heated at 950°C under the atmosphere with the retention time being changed, the workability was evaluated with an impact test, and the Al amount in the Fe-Al coating layer was measured by the method described in the item 1 of Example 4. As shown in Table 10, the workability depends on the Al amount in the Fe-Al coating layer, and, when the Al amount is not more than 35%, good workability is obtained. Further, the Al amount in the Fe-Al coating layer depends on the deposit amount and the retention time, and it can be understood that, the smaller the deposit amount is and the longer the retention time is, the more the diffusion proceeds and the smaller the Al amount in the Fe-Al coating layer is.

[Table 10]

Table 10

| No. | Deposit amount<br>(g/m <sup>2</sup> ) | Retention<br>time | Al amount in<br>Fe-Al coating (%) | Workability |
|-----|---------------------------------------|-------------------|-----------------------------------|-------------|
| 1   | 60                                    | 0                 | 36                                | △           |
| 2   | 60                                    | 1                 | 29                                | ○           |
| 3   | 60                                    | 2                 | 17                                | ○           |
| 4   | 80                                    | 0                 | 38                                | ×           |
| 5   | 80                                    | 1                 | 35                                | △           |
| 6   | 80                                    | 2                 | 20                                | ○           |
| 7   | 120                                   | 2                 | 42                                | ×           |
| 8   | 120                                   | 4                 | 36                                | ×           |
| 9   | 120                                   | 6                 | 15                                | ○           |
| 10  | 200                                   | 5                 | 44                                | ×           |
| 11  | 200                                   | 10                | 38                                | ×           |
| 12  | 200                                   | 15                | 37                                | ×           |

#### Example 5

Hot dip Al-Si-Mg plating was applied to pickled steel sheets (1.8 mm in thickness) and cold-rolled steel sheets (1.2 mm in thickness) as the materials, having steel compositions shown in Table 11 and being produced through regular hot-rolling and cold-rolling processes.

A, C, E and G in Table 11 are cold-rolled steel sheets, and the rest are hot-rolled steel sheets. In the hot dip plating, a line of non-oxidizing furnace-reducing furnace type was used, a deposit amount of plating was adjusted to 40 g/m<sup>2</sup> per one side by the gas wiping method after plating, and, after that, the steel sheets were cooled and subjected to a zero-spangle treatment. The plating bath composition at the time was Al-8%Si-6%Mg-1%Fe-0.1%Ca. Fe in the bath is a component unavoidably supplied from the plating apparatus and the steel sheets in the bath. Plating appearance showed a spangle pattern and was good without having non-plating defects or the like. The production conditions in this case are shown in Table 12.

The hardenability and corrosion resistance of the hot dip plated steel sheets thus produced were evaluated. The evaluation methods are described below. The hot dip plated steel sheets were subjected to 5% tensile stress, then heated at 950°C for 5 minutes, and, as substantial alloying process, thereafter cooled while inserted between steel sheets. The cooling rate was about 30°C/sec. The heat resistance was evaluated by visually observing the specimens after cooling. Then, the bare corrosion resistance was evaluated by subjecting the specimens to a moisture tank test (relative humidity: 95%, temperature: 40°C) for 3 days, and the after-painting corrosion resistance was evaluated by subjecting the specimens to a salt spray test (JIS-Z2134) for 30 days after the specimens were cut in a cross shape. A cationic electrodeposition paint was adopted as the painting in this case and the painting thickness was 15 μm. Further, the Vickers hardness of a steel sheet was measured by imposing a load of 100 g.

Evaluation criteria of heat resistance

○: Good

△: Crack-shaped patterns generated on the

surface

×: Red scales generated

Evaluation criteria of bare corrosion resistance

○: Good

5

△: Red rust generated

Evaluation criteria of after-painting corrosion resistance

◎: Paint blister not more than 1 mm

○: Paint blister not more than 2 mm

10

△: Paint blister 2 to 4 mm

×: Paint blister more than 4 mm

[Tables 11 and 12]

Table 11

| Steel code | C    | Si   | Mn   | P    | S     | Al   | N     | Ti    | Cr   | Mo   | Ni   | B      |
|------------|------|------|------|------|-------|------|-------|-------|------|------|------|--------|
| A          | 0.21 | 0.20 | 0.81 | 0.02 | 0.007 | 0.05 | 0.004 | 0.05  | 0.20 | -    | -    | 0.0005 |
| B          | 0.17 | 0.15 | 1.24 | 0.01 | 0.008 | 0.03 | 0.003 | 0.15  | 1.10 | -    | -    | 0.0008 |
| C          | 0.42 | 0.7  | 2.41 | 0.01 | 0.009 | 0.01 | 0.003 | 0.46  | 0.21 | -    | -    | 0.001  |
| D          | 0.23 | 0.31 | 1.54 | 0.02 | 0.007 | 0.4  | 0.003 | 0.24  | 0.44 | -    | -    | 0.002  |
| E          | 0.25 | 0.18 | 1.22 | 0.01 | 0.01  | 0.04 | 0.003 | 0.003 | 0.66 | 0.20 | -    | 0.005  |
| F          | 0.24 | 0.2  | 0.95 | 0.01 | 0.02  | 0.05 | 0.004 | 0.001 | -    | 0.15 | 0.33 | 0.01   |
| G          | 0.08 | 0.1  | 1.4  | 0.02 | 0.01  | 0.03 | 0.004 | 0.25  | 0.15 | -    | -    | 0.0003 |
| H          | 0.24 | 0.10 | 0.31 | 0.01 | 0.008 | 0.03 | 0.004 | 0.21  | 0.03 | -    | -    | 0.0001 |

15

Table 12

| No. | Code of applied steel | Bare corrosion resistance | After-painting corrosion resistance | Vickers hardness |
|-----|-----------------------|---------------------------|-------------------------------------|------------------|
| 1   | A                     | ○                         | ○                                   | 485 (○)          |
| 2   | B                     | ○                         | ○                                   | 401 (○)          |
| 3   | C                     | ○                         | ○                                   | 769 (○)          |
| 4   | D                     | ○                         | ○                                   | 509 (○)          |
| 5   | E                     | ○                         | ○                                   | 544 (○)          |
| 6   | F                     | ○                         | ○                                   | 540 (○)          |
| 7   | G                     | ○                         | ○                                   | 289 (×)          |
| 8   | H                     | ○                         | ○                                   | 301 (×)          |

When the C amount is too small as in the No. 7 steel sheet, sufficient strength is not obtained. In general,

a value close to material strength (MPa) is obtained by multiplying a Vickers hardness by 3, and, in this case, a strength of only 800 MPa class at the most is obtained. Further, when the amounts of the elements effective in quenching, such as Mn, B, etc., are small as in No. 8 steel sheet, the quenching effect is not obtained even though the C amount is large. In case of Nos. 1 to 6 steel sheets wherein the addition amounts of the elements in the steels are properly controlled, both strength and corrosion resistance show good results in either the case of the Mn-B-system or the Mo-Cr-Ni-system.

Then, using steel E in Table 11, the relation between the plating compositions and the properties of the plated steel sheets was investigated with the compositions in the plating bath of the hot dip plating line being varied. The relation between the compositions of the plated layers and the properties thereof after plating is summarized in Table 13. Here, the Vickers hardness was in the range from 470 to 510 in each case.

In case of a No. 8 steel sheet, which is of Mg-Zn-system, corrosion resistance is poor. On the other hand, Nos. 4 to 7 steel sheets, which are of Si-Mg-system, show excellent corrosion resistance. Likewise, Nos. 1 to 3 steel sheets, which are of Si-Mg-Zn-system, show excellent corrosion resistance.

[Table 13]

Table 13

| No. | Composition of plated layer (mass %) |     |    |     | Bare corrosion resistance | After-painting corrosion resistance |
|-----|--------------------------------------|-----|----|-----|---------------------------|-------------------------------------|
|     | Si                                   | Mg  | Zn | Ca  |                           |                                     |
| 1   | 2                                    | 3   | 40 | 0.1 | ○                         | ◎                                   |
| 2   | 5                                    | 7   | 20 | 0.1 | ○                         | ◎                                   |
| 3   | 8                                    | 6   | 10 | -   | ○                         | ◎                                   |
| 4   | 12                                   | 8   | -  | 0.1 | ○                         | ◎                                   |
| 5   | 8                                    | 6   | -  | 0.1 | ○                         | ◎                                   |
| 6   | 6                                    | 3   | -  | -   | ○                         | ◎                                   |
| 7   | 9                                    | 0.5 | -  | -   | ○                         | ◎                                   |
| 8   | -                                    | 1   | 3  | -   | ×                         | ×                                   |

## Example 6

Hot dip aluminum plating was applied to cold-rolled steel sheets (1.2 mm in thickness) as the materials, having a steel composition shown in Table 14 and being produced through regular hot-rolling and cold-rolling processes. In the hot dip aluminum plating, a line of non-oxidizing furnace-reducing furnace type was used, a deposit amount of plating was adjusted to 60 g/m<sup>2</sup> per one side by the gas wiping method after plating, and, after that, the steel sheets were cooled and subjected to a zero-spangle treatment. The plating bath composition at the time was Al-10%Si-2%Fe. Fe in the bath is a component unavoidably supplied from the plating apparatus and the steel sheets in the bath. The plating appearance was good without having non-plating defects or the like. The aluminum plated steel sheets thus produced were heated to 950°C, and, as substantial alloying process, the workability (exfoliation resistance) of the plated layers during air-cooling was evaluated.

At this time, the thickness of the ferrite layers was varied by varying the heating times and heating patterns. Working was applied by an impact test, the exfoliation state was visually judged with the working temperature being varied during cooling, and the workability of the plated layers was evaluated at the

lowest temperature where the exfoliation of a plated layer did not occur. Here, in case of this steel, the hardenability was good even at the cooling rate of 10°C/sec. and a structure mainly composed of martensite was obtained even in case of air-cooling. The relation between the thickness of the intermediate ferrite layer and the lowest temperature where good working can be obtained in this case is shown in Fig. 8.

As shown in Fig. 8, it is understood that, when the thickness of a ferrite layer is not less than 2  $\mu\text{m}$ , preferably not less than 4  $\mu\text{m}$ , the exfoliation resistance of a plated layer improves. When the thickness of a ferrite layer is about 0.5  $\mu\text{m}$ , powdery exfoliation of a plated layer is observed even in the case of the working at 800°C. Further, as substantial alloying process, the workability of a plated layer depends on the deposit amount of plating. Even though the thickness of a ferrite layer is 2  $\mu\text{m}$ , when the deposit amount is 30 g/m<sup>2</sup> per one side, the lowest temperature where good working is obtained is about 500°C. Further, the structure of the base steel at the time was analyzed by the observation with an optical microscope and the subsequent image analysis, and not less than 80% of the structure was composed of martensite under all conditions.

[Table 14]

Table 14

| C    | Si   | Mn   | P    | S     | Al    | N     | Ti    | Cr   | Mo   | B      |
|------|------|------|------|-------|-------|-------|-------|------|------|--------|
| 0.36 | 0.21 | 0.65 | 0.02 | 0.006 | 0.027 | 0.003 | 0.002 | 1.01 | 0.16 | 0.0001 |

#### Example 7

Hot dip aluminum plating was applied to pickled steel sheets (1.8 mm in thickness) and cold-rolled steel sheets (1.2 mm in thickness) as the materials, having steel compositions shown in Table 15 and being produced through regular hot-rolling and cold-rolling processes.

Nos. 1, 3 and 5 in Table 15 are cold-rolled steel sheets, and the rests are hot-rolled steel sheets. In the hot dip aluminum plating, a line of non-oxidizing furnace-reducing furnace type was used, a deposit amount of plating was adjusted to 60 g/m<sup>2</sup> per one side by the gas wiping method after plating, and, after that, the steel sheets were cooled and subjected to a zero-spangle treatment. The plating bath composition at the time was Al-10%Si-2%Fe. Plating appearance was good without having non-plating defects or the like. The hot dip aluminum plated steel sheets thus produced were heated to 950°C, and, as substantial alloying process, thereafter subjected to press forming at the time when the temperature reached about 600°C while cooled by water-cooled dies. The exfoliation state of a plated layer at the portion to which bending working was applied was visually judged and the exfoliation of a plated layer was not observed for all steel sheets. At the time, the thickness of the ferrite layers was 10 to 20 μm, and the martensite percentage in all base steels was not less than 80%. Here, the cooling rate was about 150°C/sec.

[Table 15]

Table 15

| No. | C    | Si   | Mn   | P    | S     | Al    | N     | Ti    | Cr   | Mo    | B      |
|-----|------|------|------|------|-------|-------|-------|-------|------|-------|--------|
| 1   | 0.22 | 0.20 | 0.94 | 0.02 | 0.007 | 0.025 | 0.003 | 0.22  | 0.05 | 0.002 | 0.0017 |
| 2   | 0.16 | 0.17 | 0.69 | 0.02 | 0.007 | 0.037 | 0.004 | 0.002 | 0.98 | 0.17  | 0.0001 |
| 3   | 0.20 | 0.20 | 0.67 | 0.02 | 0.006 | 0.033 | 0.003 | 0.002 | 0.96 | 0.17  | 0.0002 |
| 4   | 0.22 | 0.15 | 0.88 | 0.03 | 0.007 | 0.022 | 0.004 | 0.55  | 0.12 | 0.01  | 0.0005 |
| 5   | 0.25 | 0.55 | 0.72 | 0.02 | 0.009 | 0.025 | 0.003 | 0.31  | 0.58 | 0.12  | 0.0020 |

#### Example 8

Hot dip aluminum plating was applied to cold-rolled steel sheets (1.2 mm in thickness) as the materials, having a steel composition shown in Table 16 and being produced through regular hot-rolling and cold-rolling processes. In the hot dip aluminum plating, a line of non-oxidizing furnace-reducing furnace type was used, the

deposit amounts of plating were adjusted to 30 to 80 g/m<sup>2</sup> per one side by the gas wiping method after plating, and, after that, the steel sheets were cooled and subjected to a zero-spangle treatment. The plating bath composition at the time was Al-10%Si-2%Fe. Fe in the bath is a component unavoidably supplied from the plating apparatus and the steel sheets in the bath. Plating appearance was good without having non-plating defects or the like. The hardness after quenching, the thickness of the intermetallic compounds, weldability, heat resistance and after-painting corrosion resistance of the aluminum plated steel sheets thus produced were evaluated. The quenching was applied by heating a steel sheet at 950°C for 0.5 to 20 minutes in the atmosphere, and, as substantial alloying process, thereafter pressing the steel sheet in the state of a plane sheet with dies and cooling it. At the time, the cooling rate was about 300°C/sec. By so doing, quenched steel sheets having alloy layers different in thickness and alloyed up to the surface were obtained by changing the deposit amounts and heating times. Here, the appearance of all steel sheets was almost homogenous. The evaluation methods and the evaluation criteria of the properties are shown below.

[Table 16]

Table 16

| Number | C    | Si   | Mn   | P    | S     | Al    | N     | Ti   | Cr   | Mo    | B      |
|--------|------|------|------|------|-------|-------|-------|------|------|-------|--------|
| 1      | 0.22 | 0.20 | 0.94 | 0.02 | 0.007 | 0.025 | 0.003 | 0.22 | 0.05 | 0.002 | 0.0017 |

[Hardness]

Vickers hardness was measured at the center portion in the cross-section of a steel sheet by imposing a load of 100 g.

[Thickness of intermetallic compound]

The thickness of an intermetallic compound was measured by observing the cross-section of a steel sheet using a microscope, then etching it with 2% nitral, and

thereafter analyzing the structure using an EPMA. An example of the analysis is shown in Fig. 9. The reference numeral 1 shows the layer composed of Al: 26.85%, Si: 9.83%, Fe: 59.92%; the reference numeral 2 the layer composed of Al: 49.54%, Si: 3.11%, Fe: 44.87%; the reference numeral 3 the layer composed of Al: 30.75%, Si: 8.88%, Fe: 56.91%; and the reference numeral 4 the layer composed of Al: 9.59%, Si: 2.92%, Fe: 84.02%.  
[Weldability]

Spot weldability was evaluated on the following conditions:

Electrode; Dome electrode made of alumina dispersed copper and having an electrode tip of  $6\phi$ -40R,  
Pressure; 600 kgf,  
Welding current; 10 kA,  
Welding time; 12 cycles (60 Hz).

Evaluation criteria

○: Consecutive spot welding of more than 2,000 cycles

△: Consecutive spot welding of 1,200 to 2,000 cycles

×: Consecutive spot welding of less than 1,200 cycles

[After-painting corrosion resistance]

A steel sheet was subjected to a chemical treatment for about 2 minutes in a chemical treatment liquid, which was commonly used for aluminum plating a steel sheet and zinc plating, then coated with a cationic electrodeposition paint of 20  $\mu$ m in thickness, baked at 140°C for 20 minutes, and thereafter subjected to a salt spray test for 20 days after cut in a cross shape, and the after-painting corrosion resistance was judged by the corrosion depth at the portion cut in a cross shape. Here, the depth of the cut in a cross shape with a cutter was about 50  $\mu$ m. Therefore, a value obtained by subtracting 50  $\mu$ m from a measured value is a true

corrosion depth.

The evaluation results are summarized in Table 17.

Evaluation criteria

O: Corrosion depth not more than 80  $\mu\text{m}$

5

X: Corrosion depth more than 80  $\mu\text{m}$

[Table 17]

Table 17

| No. | Thickness of alloy layer ( $\mu\text{m}$ ) | Hardness of base material (Hv) | Spot weldability | After-painting corrosion resistance |
|-----|--------------------------------------------|--------------------------------|------------------|-------------------------------------|
| 1   | 2                                          | 397                            | O                | X                                   |
| 2   | 5                                          | 395                            | O                | O                                   |
| 3   | 10                                         | 399                            | O                | O                                   |
| 4   | 17                                         | 401                            | O                | O                                   |
| 5   | 25                                         | 398                            | $\triangle$      | O                                   |
| 6   | 32                                         | 399                            | $\triangle$      | O                                   |
| 7   | 38                                         | 397                            | X                | O                                   |

10 As shown in Table 17, when the thickness of an alloy layer is small, the steel sheet tends to be excellent in spot weldability but to be inferior in after-painting corrosion resistance. When the thickness is too thin like No. 1 steel sheet, the steel sheet is inferior in after-painting corrosion resistance, and when the thickness is too heavy like No. 7 steel sheet, the steel sheet is inferior in spot weldability. In case of Nos. 5 and 6 steel sheets too, the steel sheets tend to be inferior in spot weldability. Therefore, when spot weldability is regarded as important, it is desirable to make the thickness of an alloy layer rather thin.

#### Example 9

25 Steel sheets made of the steels shown in Table 18 were plated with a metal mainly composed of Al-10%Si-2%Fe, and good plating appearance was obtained. The thickness of the alloyed layers after quenched on the same conditions as the item 1 of Example 7 was measured

and the values were within the range from 8 to 15  $\mu\text{m}$ .  
 With respect to those steel sheets, the same evaluation  
 items as the item 1 of Example 7 were evaluated. As a  
 result, all of the steel sheets obtained the evaluation  
 5 results which correspond to the evaluation rank O of  
 Example 1, and showed good weldability and good after-  
 painting corrosion resistance.

[Table 18]

10

Table 18

| No. | C    | Si   | Mn   | P    | S     | Al    | N     | Ti    | Cr   | Mo    | B      |
|-----|------|------|------|------|-------|-------|-------|-------|------|-------|--------|
| 1   | 0.22 | 0.20 | 0.94 | 0.02 | 0.007 | 0.025 | 0.003 | 0.22  | 0.05 | 0.002 | 0.0017 |
| 2   | 0.16 | 0.17 | 0.69 | 0.02 | 0.007 | 0.037 | 0.004 | 0.002 | 0.98 | 0.17  | 0.0001 |
| 3   | 0.20 | 0.20 | 0.67 | 0.02 | 0.006 | 0.033 | 0.003 | 0.002 | 0.96 | 0.17  | 0.0002 |
| 4   | 0.36 | 0.21 | 0.65 | 0.02 | 0.006 | 0.027 | 0.003 | 0.002 | 1.01 | 0.16  | 0.0001 |
| 5   | 0.22 | 0.15 | 0.88 | 0.03 | 0.007 | 0.022 | 0.004 | 0.55  | 0.12 | 0.01  | 0.0005 |
| 6   | 0.25 | 0.55 | 0.72 | 0.02 | 0.009 | 0.052 | 0.003 | 0.31  | 0.58 | 0.12  | 0.0020 |
| 7   | 0.23 | 0.18 | 0.21 | 0.03 | 0.007 | 0.025 | 0.003 | 0.27  | 0.03 | 0.01  | 0.0022 |

#### Example 10

Hot dip aluminum plating was applied to cold-rolled  
 steel sheets (1.2 mm in thickness) as the materials  
 15 having a steel composition shown in Table 19 and being  
 produced through regular hot-rolling and cold-rolling  
 processes. In the hot dip aluminum plating, a line of  
 non-oxidizing furnace-reducing furnace type was used, a  
 deposit amount of plating was adjusted to 60 g/m<sup>2</sup> per one  
 20 side by the gas wiping method after plating, and, after  
 that, the steel sheets were cooled and subjected to a  
 zero-spangle treatment. The plating bath composition at  
 the time was Al-10%Si-2%Fe. Fe in the bath is a  
 component unavoidably supplied from the plating apparatus  
 25 and the steel sheets in the bath. The plating appearance  
 was good without having non-plating defects or the like.  
 The hot dip aluminum plated steel sheets thus produced  
 were heated in the atmosphere, then retained at various  
 temperatures, and formed into the shape shown in Fig. 10.  
 30 At the time, the steel sheets were cooled with water-

cooled dies. The heating rate was about 5 to 10°C/sec., and the cooling rate was, though it varied with the portions, about 100°C/sec. at a portion where cooling rate was high and about 20°C/sec. at a portion where cooling rate was low. The workability (exfoliation resistance) of a plated layer at the time was evaluated. The exfoliation of the plated layers was formed in a shape of streak or in a shape of spot on the compressed surface. The relation between the heating conditions and the state of the exfoliation of the plated layers is shown in Table 20. Further, the heating conditions according to the present invention are shown in Fig. 11.

[Tables 19 and 20]

Table 19

| C    | Si   | Mn   | P    | S     | Al    | N     | Ti    | Cr   | Mo   | B      |
|------|------|------|------|-------|-------|-------|-------|------|------|--------|
| 0.24 | 0.21 | 0.95 | 0.02 | 0.006 | 0.027 | 0.003 | 0.002 | 1.01 | 0.16 | 0.0018 |

Table 20

| No. | Heating temperature<br>(°C) | Heating time<br>(min.) | Adhesiveness |
|-----|-----------------------------|------------------------|--------------|
| 1   | 800                         | 20                     | △            |
| 2   | 850                         | 15                     | ○            |
| 3   | 900                         | 13                     | ○            |
| 4   | 950                         | 8                      | ○            |
| 5   | 1000                        | 6                      | ○            |
| 6   | 1050                        | 4                      | ○            |
| 7   | 1100                        | 2                      | ○            |
| 8   | 900                         | 5                      | ×            |
| 9   | 1000                        | 2                      | ×            |

#### Evaluation criteria of adhesiveness

- : No exfoliation of plated layer  
 △: Cracks generated partially in plated layer  
 ×: Exfoliation of plated layer generated

As shown in Table 20, the adhesiveness is not regarded yet as perfect even after heating for 20 minutes when the temperature is as low as 800°C as substantial

alloying process. When a heating temperature rises, good adhesiveness is obtained with a retention time of not more than 10 minutes. Adhesiveness is still insufficient when the retention time is 5 minutes at 900°C, or 2  
5 minutes at 1,000°C as substantial alloying process.

#### Industrial Applicability

As stated above, the present invention provides a hot press method for forming a high-strength automotive  
10 part, and will greatly contribute to the weight reduction of an automobile in the future.

CLAIMS

1. A high-strength alloyed aluminum-system plated steel sheet excellent in after-painting corrosion resistance, characterized by having an Fe-Al-system coating containing Mn and Cr of more than 0.1% in total on the surface of the steel sheet.

2. A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance, characterized by having an Fe-Al-system coating containing, in mass, Mn and Cr of more than 0.1% in total on the surface of the steel containing, in mass, C: 0.05 to 0.7%, Si: 0.05 to 1%, Mn: 0.5 to 3%, P: not more than 0.1%, S: not more than 0.1% and Al: not more than 0.2%, and, in addition, one or more element(s) selected from among Ti: 0.01 to 0.8%, Cr: not more than 3% and Mo: not more than 1%, so as to satisfy the following expression (1):

$$\text{Ti} + 0.5 \times \text{Mn} + \text{Cr} + 0.5 \times \text{Mo} > 0.4 \dots 1$$

3. A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to claim 2, characterized in that the steel further contains, in mass, one or more element(s) selected from among N: not more than 0.1%, Nb: not more than 0.1%, V: not more than 0.1%, Ni: not more than 1%, Cu: not more than 1%, B: 0.0003 to 0.03%, Sn: not more than 0.1% and Sb: not more than 0.1%.

4. A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to claim 1, characterized in that the steel contains, in mass, C: 0.15 to 0.55%, Si: not more than 0.5%, Mn: 0.2 to 3%, P: not more than 0.1%, S: not more than 0.04%, Al: 0.01 to 0.1% and N: not more than 0.01%, and also one or more element(s) selected from among B: 0.0002 to 0.0050%, Ti: 0.01 to 0.8%, Cr: not more than 2%, Mo: not more than 1%, Ni: not more than 1%, Cu: not more than 0.5% and Sn: not

more than 0.2%.

5. A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to any one of  
5 claims 1 to 4, characterized in that the Fe-Al-system coating further contains Si of 1 to 20%.

6. An alloyed aluminum-system plated steel sheet for high-strength automotive members according to any one of claims 1 to 5, characterized in that Al concentration  
10 in the Fe-Al-system coating layer is not more than 35% in weight.

7. A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to any one of  
15 claims 1 to 6, characterized in that the Fe-Al-system coating further contains either one or both of Zn: 1 to 50% and Mg: 0.1 to 10%.

8. A high-strength alloyed aluminum-system plated steel sheet excellent in heat resistance and after-painting corrosion resistance according to any one of  
20 claims 1 to 7, characterized in that the thickness of the Fe-Al-system coating layer is 3 to 35  $\mu\text{m}$ .

9. An alloyed aluminum-system plated steel sheet for high-strength automotive members, characterized by  
25 having: a coating layer mainly composed of Fe-Al on the surface of the steel sheet; a ferrite layer having a thickness from not less than 2  $\mu\text{m}$  to not more than one tenth of the steel sheet thickness at the underside of the coating layer; and the base steel mainly composed of  
30 martensite at the underside of the ferrite layer.

10. An alloyed aluminum-system plated steel sheet for high-strength automotive members according to claim 9, characterized in that the alloyed aluminum-system plated layer on the surface of the steel sheet and the  
35 ferrite layer at the underside of the intermetallic compound layer contain Si.

11. An alloyed aluminum-system plated steel sheet for high-strength automotive members according to claim 9 or 10, characterized in that the hardness of the ferrite phase is not higher than 200.

5 12. A high-strength automotive part formed by press forming, at least a portion of which is composed of a steel according to any one of claims 1 to 11.

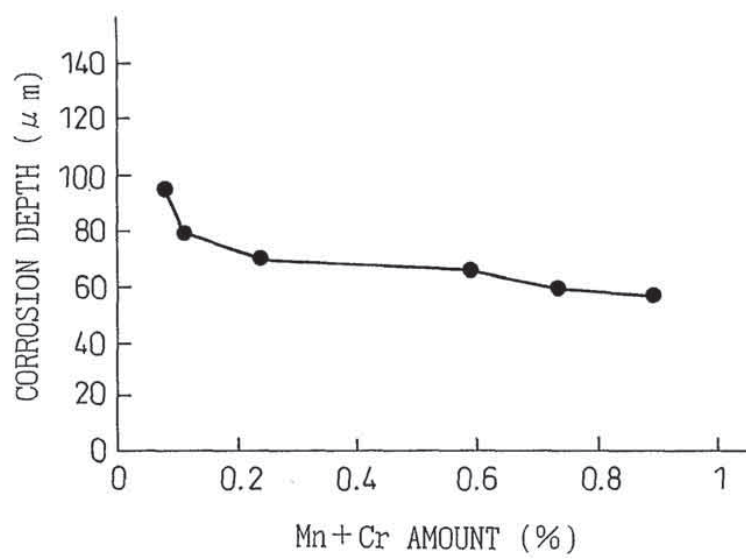
10 13. A high-strength automotive part according to claim 12, characterized by having a coated film 1 to 200  $\mu\text{m}$  in thickness on at least a part of the surface.

14. A hot press method for a high-strength automotive member, wherein, when the automotive member is produced by a hot press using a steel sheet produced by plating a steel containing C of not less than 0.05% in weight as a steel component with a metal mainly composed of Al, the member is formed by press forming after heated on the heating condition of the longer time period side than the following regions, A, B, C and D, and at least a part of the member is cooled at a cooling rate of not lower than  $10^{\circ}\text{C}/\text{sec}.$ :

A ( $800^{\circ}\text{C}$ , 13 min.), B ( $900^{\circ}\text{C}$ , 6 min.), C ( $1,050^{\circ}\text{C}$ , 1.5 min.), D ( $1,200^{\circ}\text{C}$ , 0.3 min.).

$\frac{1}{7}$ 

Fig.1



$\frac{2}{7}$ 

Fig.2

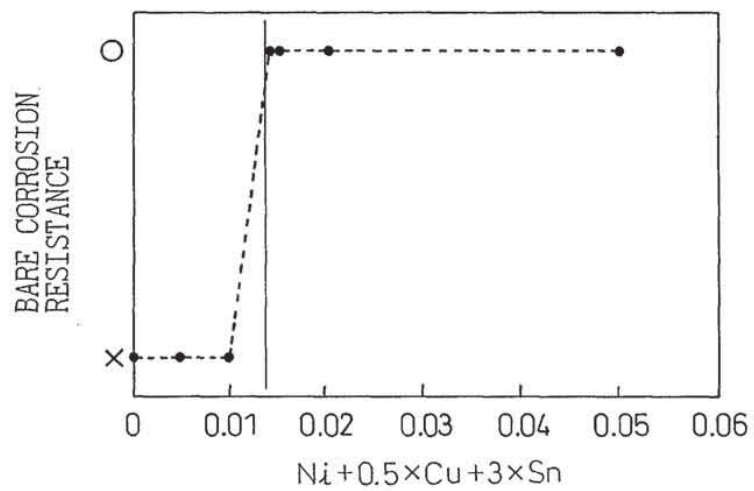
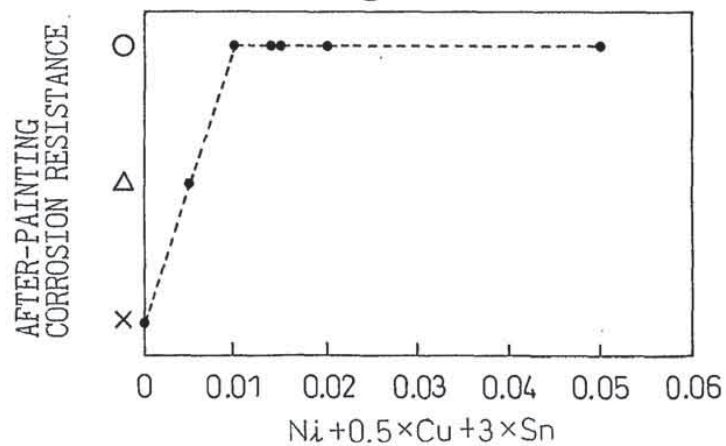


Fig.3



$\frac{3}{7}$ 

Fig.4

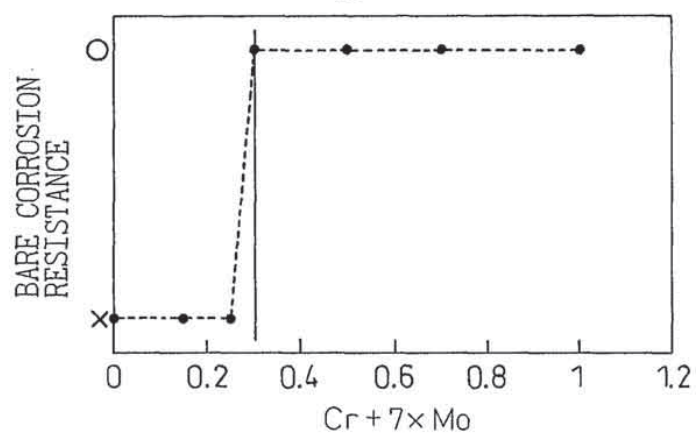
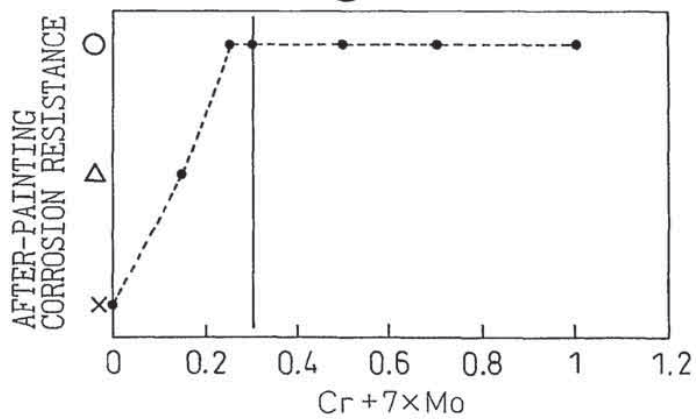
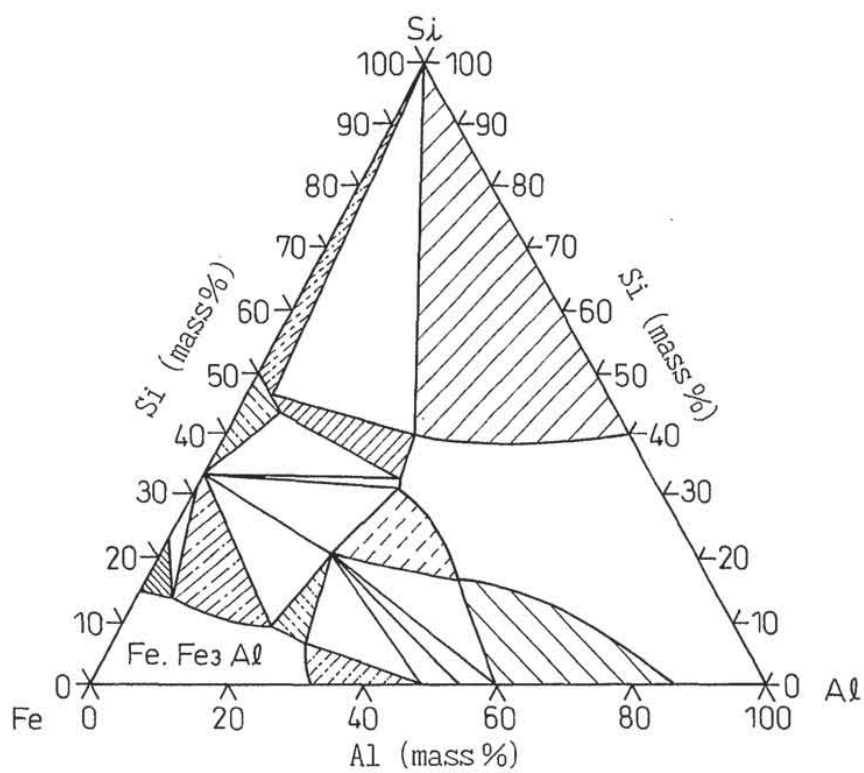


Fig.5



$\frac{4}{7}$ 

Fig.6



$\frac{5}{7}$ 

Fig.7

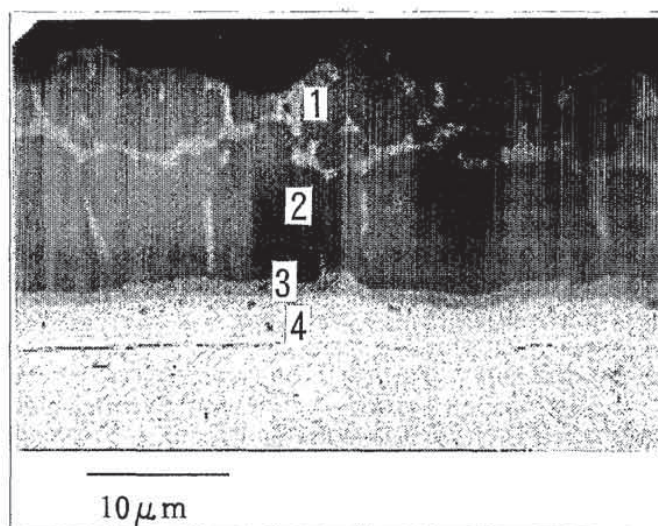
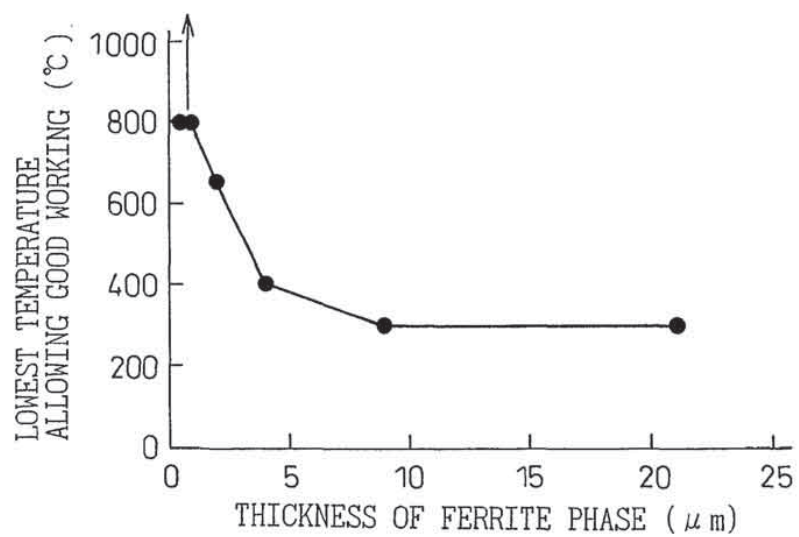
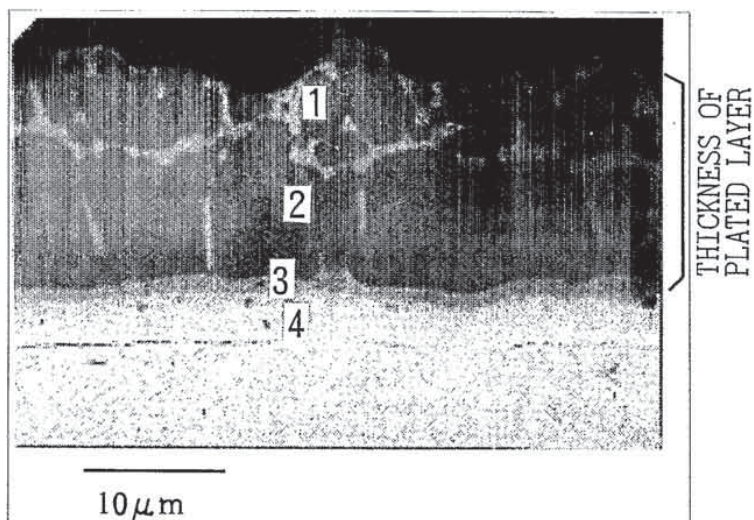


Fig.8



6/7

Fig.9



$\frac{7}{7}$ 

Fig.10

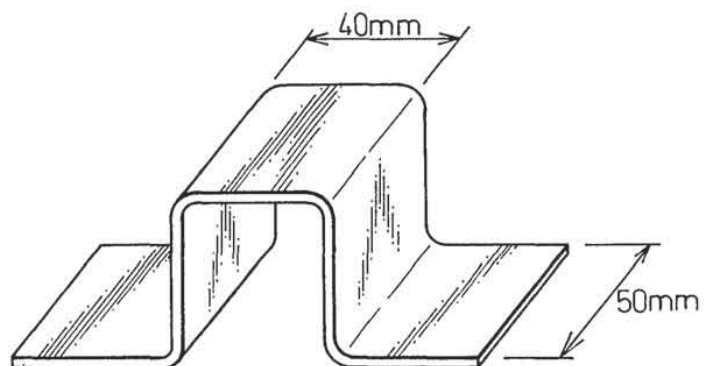


Fig.11

