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(54) **METHOD OF ROLL-FORMING
HIGH-STRENGTH ALUMINUM ALLOY AND
ROLL-FORMED PRODUCT USING THE
SAME**

(71) Applicants: **Hyundai Motor Company**, Seoul
(KR); **Kia Motors Corporation**, Seoul
(KR)

(72) Inventor: **Kyu-Hwan OH**, Sokcho-si (KR)

(73) Assignees: **Hyundai Motor Company**, Seoul
(KR); **Kia Motors Corporation**, Seoul
(KR)

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(57) **ABSTRACT**

A method of roll-forming a high-strength aluminum alloy, may include processing an aluminum alloy plate to form a square bar, pressing the plate so that deformation begins in a cross section thereof; and forming the square bar having at least one bent portion by completion of the deformation, wherein the method further includes partially performing a heat treatment on the bent portion before forming the square bar.

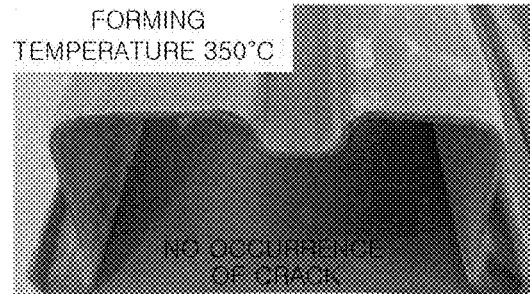
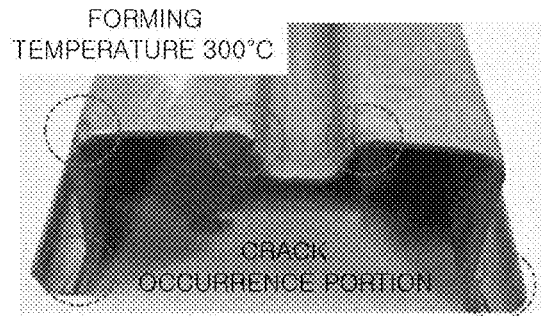
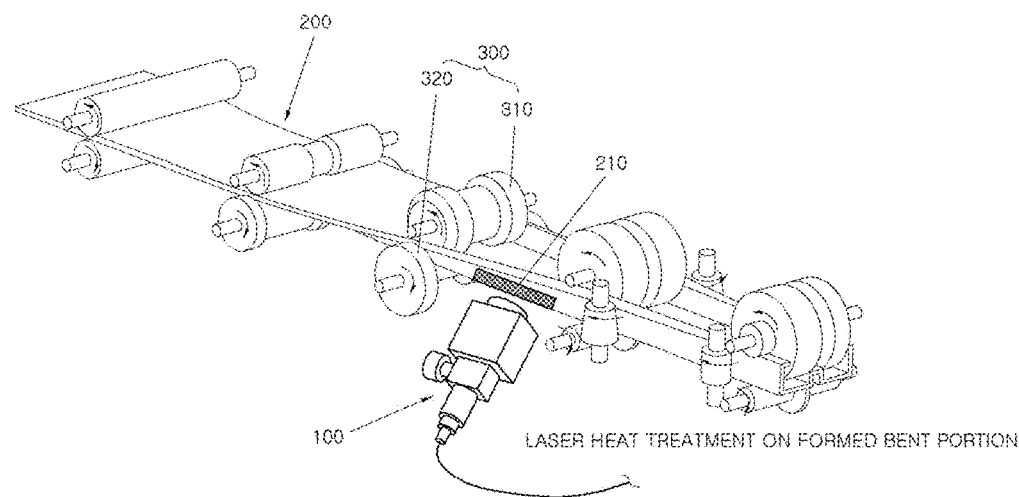


FIG.1



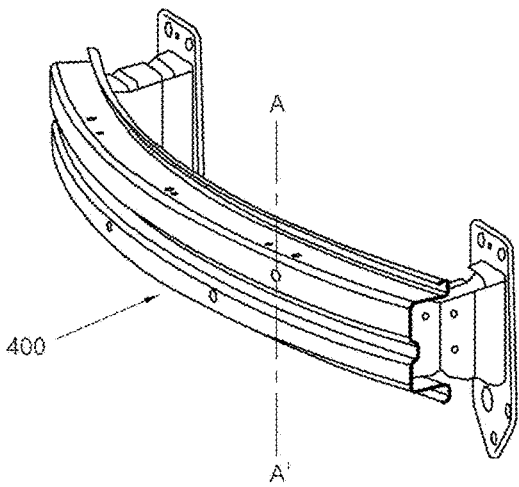
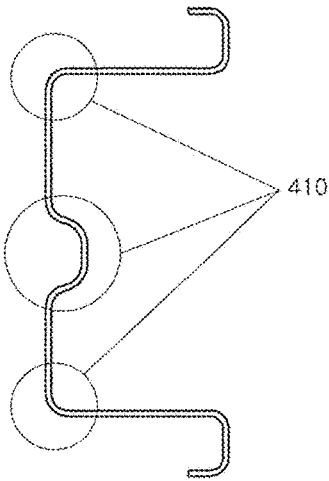


FIG. 2A



[A - A']

FIG. 2B

FIG.3

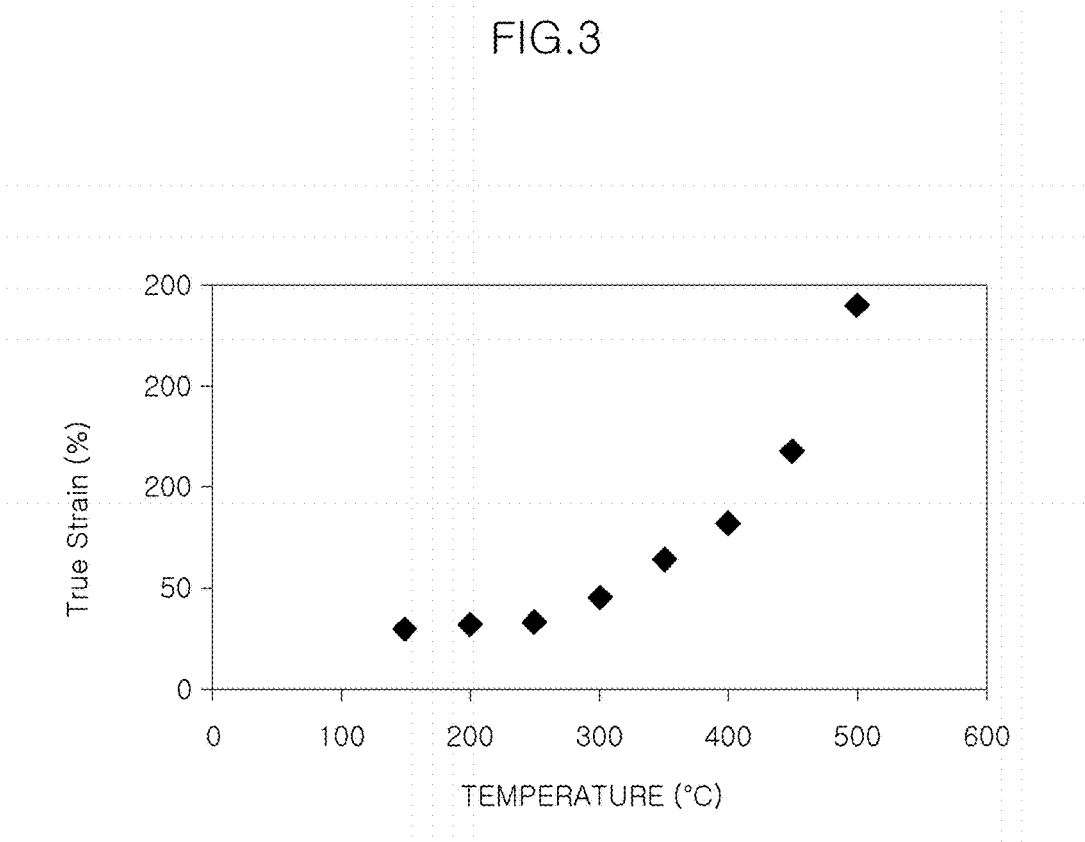
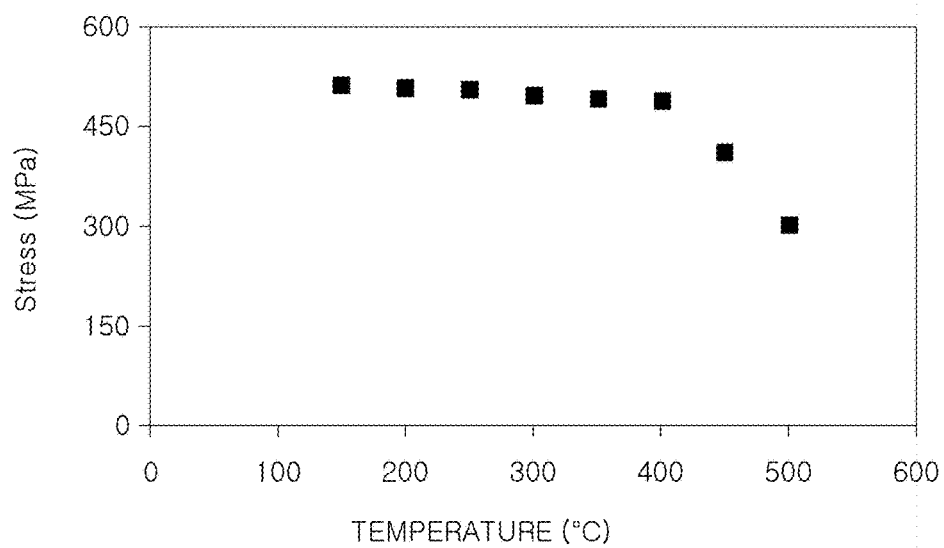


FIG. 4



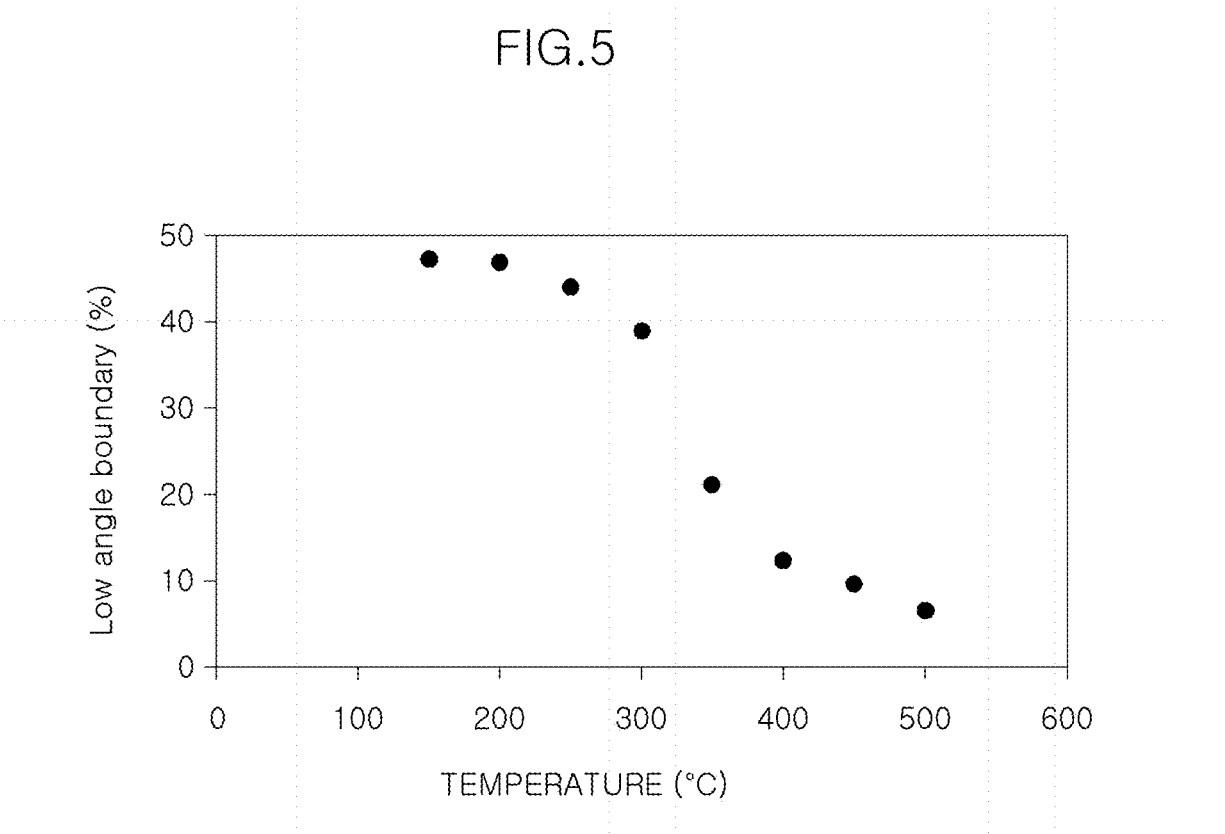


FIG.6

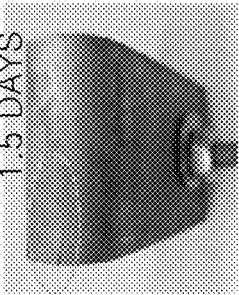
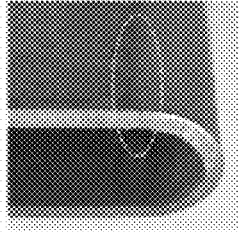
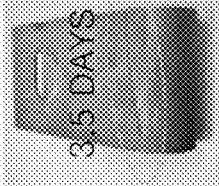
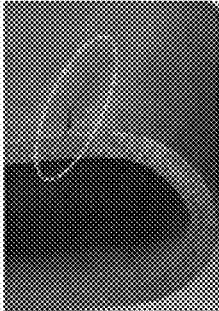
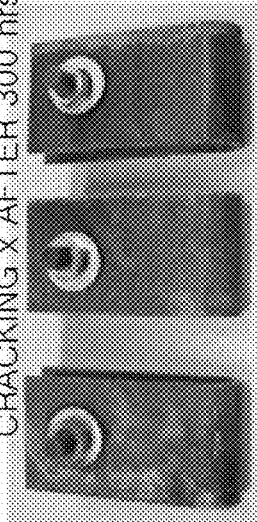
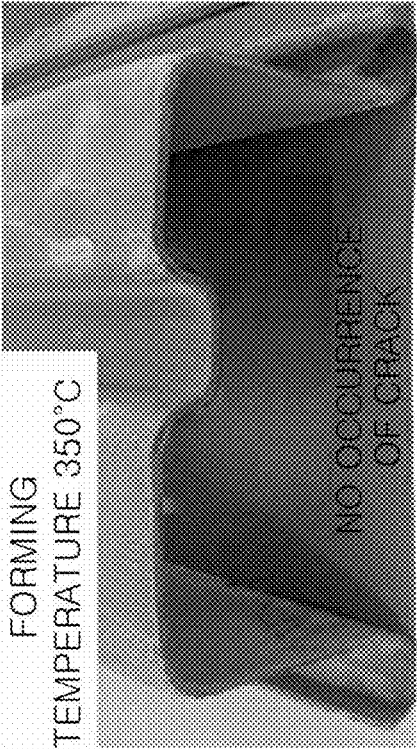
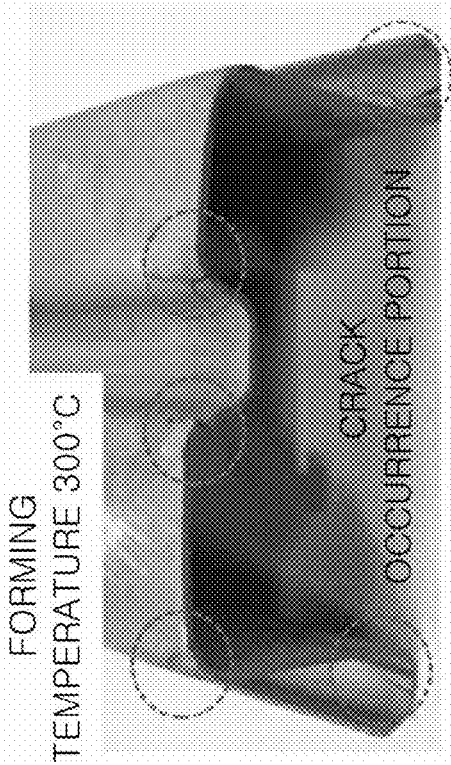
TEMPERATURE	EVALUATION RESULT	
250°C	1.5 DAYS 	2 DAYS 
300°C	3.5 DAYS 	5 DAYS 
350°C	CRACKING x AFTER 300 hrs 	

FIG.7



**METHOD OF ROLL-FORMING
HIGH-STRENGTH ALUMINUM ALLOY AND
ROLL-FORMED PRODUCT USING THE
SAME**

**CROSS-REFERENCE(S) TO RELATED
APPLICATIONS**

[0001] The present application claims priority to Korean Patent Application No. 10-2016-0173538, filed on Dec. 19, 2016, the entire contents of which is incorporated herein for all purposes by this reference.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] Exemplary The present invention relates to a method of roll-forming a high-strength aluminum alloy and a roll-formed product using the same; and, more particularly, to a method of locally softening and roll-forming a high-strength aluminum alloy, configured to enhance a formability of the alloy by performing a local heat treatment process on a bent portion, on which stress is concentrated, during the forming process and improves a resistance against stress corrosion cracking by removing internal residual stress from the bent portion, and a roll-formed product using the same.

Description of Related Art

[0003] An aluminum alloy is conventionally expressed as a 4-digit number from 1000 to 8000 series according to an alloying element thereof.

[0004] A strength of the aluminum alloy is determined by the alloying elements. The alloying elements including copper (Cu), manganese (Mn), zinc (Zn), and silicon (Si) have increasing solubility as a temperature of the aluminum alloy increases. Accordingly, the alloying elements may be precipitated and hardened by a heat treatment and a solution treatment. In the present case, the aluminum alloy with the alloying elements added thereto is referred to as a heat-treated aluminum alloy.

[0005] A 7000 series aluminum alloy is an Al—Zn—(Mg and/or Cu) alloy, and is a high-strength heat-treated alloy that includes Zn as a main component and Mg added thereto. In particular, Al 7075 alloy has the highest strength, namely a tensile strength of 550 MPa, from among the aluminum materials.

[0006] However, there is a problem in that the aluminum alloys lack a desired formability due to having a high strength during a cold forming process as well as having a very low resistance to a stress corrosion cracking due to residual stress.

[0007] Due to the stress corrosion cracking, aircraft products have been manufactured by cutting bulk materials instead of forming processes, including pressing, even when the 7000 series aluminum alloy is applied.

[0008] The information disclosed in this Background of the Invention section is only for enhancement of understanding of the general background of the invention and should not be taken as an acknowledgement or any form of suggestion that this information forms the prior art already known to a person skilled in the art.

BRIEF SUMMARY

[0009] Various exemplary embodiments of the present invention are directed to providing a method of locally softening and roll-forming a high-strength aluminum alloy, configured to enhance a formability of the alloy by performing a local heat treatment process on a bent portion, on which stress is concentrated, during the forming process as well as improves a resistance to stress corrosion cracking by removing residual stress in the bent portion, and a roll-formed product using the same.

[0010] Other objects and advantages of the present invention can be understood by the following description, and become apparent with reference to the exemplary embodiments of the present invention. Also, it is obvious to those skilled in the art to which the present invention pertains that the objects and advantages of the present invention can be realized by the means as claimed and combinations thereof.

[0011] In accordance with various exemplary embodiments of the present invention, a method of roll-forming high-strength aluminum alloy includes processing an aluminum alloy plate to form a square bar, pressing the plate wherein deformation begins in a cross section thereof, and forming the square bar having at least one bent portion by completion of the deformation process, wherein the method may further include partially performing a heat treatment on the bent portion before the forming of the square bar.

[0012] The heat treatment may be performed by irradiating the bent portion with a laser for a predetermined time period.

[0013] The heat treatment may be performed by heating the bent portion at a temperature of 350 to 400° C.

[0014] The aluminum alloy may be a 7000 series aluminum alloy.

[0015] In accordance with various exemplary embodiments of the present invention, a roll-formed product of a high-strength aluminum alloy, the roll-formed product including an aluminum alloy and having a bent portion formed thereon, the roll-formed product is formed by partially performing a heat treatment on the bent portion to remove a residual stress which is partially generated in the bent portion during the forming process.

[0016] The heat treatment may be performed by irradiating the bent portion with the laser for a predetermined time period.

[0017] The heat treatment may be performed by heating the bent portion at a temperature of 350 to 400° C.

[0018] The aluminum alloy may be a 7000 series aluminum alloy.

[0019] The product may be configured wherein a microstructure thereof includes a ratio of a low angle boundary with a tilt angle equal to or greater than 2° and less than 15° is equal to or less than 21%.

[0020] The product may be a bumper beam for a vehicle.

[0021] The methods and apparatuses of the present invention have other features and advantages which will be apparent from or are set forth in more detail in the accompanying drawings, which are incorporated herein, and the following Detailed Description, which together serve to explain certain principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] FIG. 1 is a view schematically illustrating a method of roll-forming a high-strength aluminum alloy according to an exemplary embodiment of the present invention;

[0023] FIG. 2A is a view schematically illustrating a roll-formed product of a high-strength aluminum alloy and a bent portion of the product according to an exemplary embodiment of the present invention;

[0024] FIG. 2B is a cross-sectional view taken along line A-A' of FIG. 2A;

[0025] FIG. 3 is a graph illustrating a change of true strain according to a heat treatment temperature in a method of roll-forming a high-strength aluminum alloy according to an exemplary embodiment of the present invention;

[0026] FIG. 4 is a graph illustrating a change of strength according to a heat treatment temperature in a method of roll-forming a high-strength aluminum alloy according to an exemplary embodiment of the present invention;

[0027] FIG. 5 is a graph illustrating a change of low angle boundary ratio according to a heat treatment temperature in a method of roll-forming a high-strength aluminum alloy according to an exemplary embodiment of the present invention;

[0028] FIG. 6 illustrates a result of stress corrosion cracking according to a heat treatment temperature in a method of roll-forming a high-strength aluminum alloy according to an exemplary embodiment of the present invention; and

[0029] FIG. 7 illustrates an incidence of cracks on cross-sectional portions according to a heat treatment temperature in a roll-formed product of a high-strength aluminum alloy and a bent portion of the product according to an exemplary embodiment of the present invention.

[0030] It should be understood that the appended drawings are not necessarily to scale, presenting a somewhat simplified representation of various features illustrative of the basic principles of the invention. The specific design features of the present invention as disclosed herein, including, for example, specific dimensions, orientations, locations, and shapes will be determined in part by the particular intended application and use environment.

[0031] In the figures, reference numbers refer to the same or equivalent parts of the present invention throughout the several figures of the drawing.

DETAILED DESCRIPTION

[0032] Reference will now be made in detail to various embodiments of the present invention(s), examples of which are illustrated in the accompanying drawings and described below. While the invention(s) will be described in conjunction with exemplary embodiments, it will be understood that the present description is not intended to limit the invention(s) to those exemplary embodiments. On the contrary, the invention(s) is/are intended to cover not only the exemplary embodiments, but also various alternatives, modifications, equivalents and other embodiments, which may be included within the spirit and scope of the invention as defined by the appended claims.

[0033] Prior to description of exemplary embodiments of the present invention, various aspects of the present invention are directed to providing a stress removal and formability improvement with respect to a bent portion during roll-forming of a 7000 series aluminum alloy plate. In general, after a solution heat treatment is performed on the

7000 series aluminum alloy at a temperature of approximately 490 to 530° C. for a solution of alloying elements including Cu, Mg, and Si, the 7000 series aluminum alloy is rapidly cooled to room temperature, obtaining a supersaturated solid solution. As such, a second phase is precipitated by performing an artificial or a natural aging treatment on the supersaturated solid solution, wherein the 7000 series aluminum alloy has a maximum strength.

[0034] However, the 7000 series aluminum alloy lacks formability due to having a high strength and is prone to stress corrosion cracking (SCC) due to internal stress generated in portions of the alloy in a forming process. The stress corrosion cracking is a phenomenon in which cracks occur and spread when a tensile stress is applied to a specific material in a specific corrosion environment, and occurs when conditions of corrosion environment, sensitive alloy, and stress are simultaneously satisfied. In particular, it is known that the stress corrosion cracking occurs when the element Cu of a high-strength 7000 series aluminum alloy (Al—Zn—Mg—Cu) forms an intermetallic compound, including $MgCu_2$ or $AlMgCu_2$, and pitting corrosion is induced in the corrosion environment.

[0035] The present invention is directed to prevent stress corrosion cracking by mitigating the stress condition from among the above three conditions, and the method thereof will be described later.

[0036] FIG. 1 is a view schematically illustrating a method of roll-forming a high-strength aluminum alloy according to an exemplary embodiment of the present invention.

[0037] Referring to FIG. 1, the method of roll-forming the high-strength aluminum alloy according to the exemplary embodiment of the present invention is a roll-forming method of processing an aluminum alloy plate 200 to form a square bar, and includes a step of pressing the plate 200 wherein deformation begins in a cross section thereof, and a step of forming the square bar having at least one bent portion 410 by completion of the deformation process. In the present case, the method may further include a step of partially performing a heat treatment 210 only at the bent portion 410, which is formed by bending the plate 200, before the square bar is formed having a predetermined shape and after the plate 200 is bent, wherein the deformation begins in the cross section thereof.

[0038] The method of roll-forming the aluminum alloy is continuously performed wherein the rolled plate 200 has a constant thickness and passes between upper and lower rollers 310 and 320 to have the predetermined shape. However, when the plate 200 is bent at a time at a desired angle, the plate may be cracked due to the strength thereof. Therefore, after the deformation of the plate 200 begins, the method allows the plate to be sequentially deformed through a plurality of shape rolling rollers 300, finally forming a desired shaped square bar.

[0039] In a case where a square bar having a plurality of bent portions 410 is formed by bending a 7000 series aluminum alloy plate, due to the strength thereof and as in an exemplary embodiment of the present invention, the 7000 series aluminum alloy lacks a desired formability in a forming process and the stress corrosion cracking also occurs in a final molded product due to stress concentrated on the bent portions.

[0040] Accordingly, the method according to the exemplary embodiment of the present invention improves the formability while curing dislocations caused during the

forming by partially heating **210** only the bent portion **410** on which stress is concentrated in the forming process, and prevents cracks from occurring in the stress concentration portion in the corrosion environment by removing internal stress therefrom.

[0041] The provided heat treatment **210** step should be performed within a short time due to the roll-forming process which is continuously performed, and may be performed through accurate control of only a desired portion at an accurate temperature. The bent portion **410** is preferably irradiated with a laser **100** for a certain time in the exemplary embodiment of the present invention. In the instant case, since the laser which is usable in conjunction with a 6-axis robot is configured to carry out rapid heating and has a variety of beam sizes, it is configured to freely adjust a range of heat treatment.

[0042] When the local heat treatment **210** is performed on the bent portion **410** at too high a temperature, the solution heat treatment as a mechanism for reinforcing the 7000 series aluminum alloy is released, which may lead to a low strength, as described above. On the other hand, when the local heat treatment is performed at too low a temperature, the removal effect of residual stress may be very slight. Accordingly, the heat treatment step is preferably performed wherein the bent portion is heated at a temperature of 350 to 400° C. in the exemplary embodiment of the present invention.

[0043] Typically, a material may be irradiated with the laser **100** for approximately 2 seconds, according to a process speed of roll forming, and is then cooled slowly in the continuous roll forming process.

[0044] FIG. 2 is a view schematically illustrating a roll-formed product of a high-strength aluminum alloy **400** and a bent portion **410** of the product **400** according to an exemplary embodiment of the present invention.

[0045] Referring to FIG. 2, the roll-formed product of high-strength aluminum alloy **400** according to the exemplary embodiment of the present invention is a roll-formed product that includes an aluminum alloy and has the bent portion **410** formed thereon. The core technique of the roll-formed product of high-strength aluminum alloy **400** according to the exemplary embodiment of the present invention the present invention performs partial heat treatment on the bent portion **410** to remove residual stress which is concentrated on the bent portion **410** during the forming.

[0046] As described above, the heat treatment is performed by irradiating the bent portion **410** with the laser **100** for a certain time and heating the bent portion **410** at a temperature of 350 to 400° C. The bent portion **410** may be typically irradiated with laser for about 2 seconds according to the process speed of roll forming, but the irradiation time is adjustable according to the process speed. For example, the irradiation time is not limited as long as the temperature is suitably adjusted.

[0047] In addition, the product **400** is characterized wherein the microstructure thereof, the boundary where a difference in orientation of adjacent crystal grains is equal to or greater than 2° and less than 15° is defined as a low angle boundary, and a ratio of the low angle boundary is equal to or less than 21%.

[0048] The greater the ratio of the low angle boundary, the smaller a diameter of each subgrain generated in the particles. As seen in the following Equation 1, the smaller the diameter of the subgrain, the greater the residual stress in a material. Accordingly, the ratio of the low angle boundary is preferably equal to or less than 21% as illustrated in Table

1. In the present case, it can be seen that the residual stress is adequately removed from the bent portion **410** to suppress the stress corrosion cracking.

$$S_r = \alpha \frac{\gamma}{D}, \quad [\text{Equation 1}]$$

[0049] (where α is a geometric constant, γ is a boundary energy, and D is the diameter of subgrain).

[0050] The following Table 1 indicates the stress corrosion cracking, formability, strength, and the low angle boundary ratio according to a heat treatment temperature.

[0051] In exemplary embodiments of the present invention and comparative examples, crystal grain orientations are measured using an Electron Back Scattering Diffraction (EBSD) analyzer. Since crystalline materials have different orientations for each crystal grain, a diffraction of backscattered electrons is changed when specimens are irradiated with electron beams generated by an electron microscope. Each of the crystal grain orientations is analyzed using kikuchi patterns of the backscattered electrons. In addition, as described above, the boundary where the difference in orientation of adjacent crystal grains is equal to or greater than 2° and less than 15° is defined as the low angle boundary, and the low angle boundary is measured in an exemplary embodiment of the present invention. It can be seen from Table 1 that when the low angle boundary ratio is equal to or less than 21%, the stress corrosion cracking is suppressed by removal of residual stress.

[0052] As seen in Table 1 and FIG. 4, according to a result of an evaluation of tensile strength after the heat treatment is performed on the aluminum plate with the laser for 2 seconds, it can be seen that the strength is maintained to a temperature of 400° C., but it is significantly lowered at a temperature of 500° C. This is because solution heat treatment for a 7000 series aluminum alloy is released at high temperature and the 7000 series aluminum alloy has a low strength.

[0053] As seen in Table 1 and FIG. 3, the strain is meaningfully improved at a temperature equal to or greater than 300° C. In FIG. 5, after a pre-strain of 5% is applied to an aluminum plate and a heat treatment is performed on the aluminum plate with the laser for 2 seconds, residual stress is measured using the EBSD analyzer. In the present case, the residual stress begins to be reduced at a temperature of 250° C. and is significantly reduced at a temperature of approximately 350° C.

[0054] In FIG. 6, whether cracks occur in a bent portion is evaluated by a reproduction evaluation method to verify whether stress corrosion cracking occurs according to removal of residual stress. According to a result of checking whether cracks occur in a bent specimen in a corrosion environment, i.e. in a solution of 3.5% NaCl for 300 hours, the bent specimen is cracked after 1.5 days at a temperature of 250° C. and after 3 days at a temperature of 300° C., yet the bent specimen is not cracked even after 300 hours at a temperature of 350° C. This means that the residual stress is relieved to suppress stress corrosion cracking in the condition in which heat treatment is performed at a temperature equal to or higher than 350° C., and is because the stress corrosion cracking is prevented by removal of stress from among three factors that cause the stress corrosion cracking.

[0055] In FIG. 7, the stress corrosion cracking is tested on an actual bumper beam member in the same conditions. In the present case, a crack occurs in a bent portion at a temperature of 300° C., but no stress corrosion cracking occurs when the bent portion is formed at a temperature of 350° C. As a result, the present bumper beam member exhibits the same results as the above specimen.

TABLE 1

Sort	Comp. Example 1	Comp. Example 2	Comp. Example 3	Comp. Example 4	Present Example 1	Present Example 2	Comp. Example 5	Comp. Example 6
Heat Treatment Temperature (° C.)	150	200	250	300	350	400	450	500
True Strain (%)	30	32	33	45	64	82	118	190
Stress (MPa)	510	506	503	495	489	485	410	300
Low Angle Boundary Ratio (%)	47	47	44	39	21	12	9.3	6.3
Formability	X	X	X	○	○	○	○	○
SCC	X	X	X	X	○	○	○	○

[0056] As described above, in the exemplary embodiment of the present invention, the stress concentration portion, i.e. The bent portion is locally heated with the laser at a temperature of 350 to 400° C. in a conventional roll-forming process, with the consequence that it is possible to improve the resistance against stress corrosion fatigue by removing residual stress and thus to enhance the formability.

[0057] In accordance with exemplary embodiments of the present invention, it is possible to enhance a formability by performing a local heat treatment on a bent portion, on which stress is concentrated, during the forming process.

[0058] In addition, it is possible to improve resistance against stress corrosion cracking by removing residual stress which is concentrated on the bent portion.

[0059] Furthermore, it is possible to reduce a thicknesses and weight of products to be manufactured, and thus to improve a fuel efficiency by application of a high-strength aluminum material thereto.

[0060] Moreover, it is possible to improve quality and dimensional accuracy of products by removing the residual stress from the bent portion.

[0061] For convenience in explanation and accurate definition in the appended claims, the terms “upper”, “lower”, “up”, “down”, “upwards”, “downwards”, “internal”, “outer”, “inside”, “outside”, “inwardly”, “outwardly”, “internal”, “external”, “front”, “rear”, “back”, “forwards”, and “backwards” are used to describe features of the exemplary embodiments with reference to the positions of such features as displayed in the figures.

[0062] The foregoing descriptions of specific exemplary embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teachings. The exemplary embodiments were chosen and described to explain certain principles of the invention and their practical application, to enable others skilled in the art to make and utilize various exemplary embodiments of the present invention, as well as various alternatives and modifications

thereof. It is intended that the scope of the invention be defined in the Claims appended hereto and their equivalents.

What is claimed is:

1. A method of roll-forming an aluminum alloy by processing an aluminum alloy plate to form a square bar, the method comprising:

pressing the plate so that deformation begins in a cross section thereof; and

forming the square bar having at least one bent portion by completion of the deformation, and partially performing a heat treatment on the bent portion before forming the square bar.

2. The method of claim 1, wherein the heat treatment is performed by heating the bent portion at a temperature of 350 to 400° C.

3. The method of claim 2, wherein the heat treatment is performed by irradiating the bent portion with a laser for a predetermined time period.

4. The method of claim 1, wherein the aluminum alloy is a 7XXX series aluminum alloy.

5. A roll-formed product of an aluminum alloy, the roll-formed product including the aluminum alloy and having a bent portion formed thereon, wherein the roll-formed product is formed by partially performing a heat treatment on the bent portion to remove residual stress which is partially generated in the bent portion during the forming.

6. The roll-formed product of claim 5, wherein the heat treatment is performed by heating the bent portion at a temperature of 350 to 400° C.

7. The roll-formed product of claim 6, wherein the heat treatment is performed by irradiating the bent portion with a laser for a predetermined time period.

8. The roll-formed product of claim 5, wherein the aluminum alloy is a 7XXX series aluminum alloy.

9. The roll-formed product of claim 5, wherein the product is configured such that in a microstructure having a ratio of an angle boundary with a tilt angle equal to or greater than 2° and less than 15° is equal to or less than 21%.

10. The roll-formed product of claim 5, wherein the product is a bumper beam for a vehicle.

* * * * *