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Development of 980MPa Grade Galvannealed Advance High Strength Steel Sheets for Automobile

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Main issues in the automotive industry are the reduction of vehicle body weight for energy savings and improvement of crashworthiness for passenger safety. In order to address both these issues, there has recently been increasing application of galvannealed advance high strength steel (GA AHSS) sheets for automobiles. However, GA AHSS sheets have some surface defects such as coating bare spots due to the addition of solid-solution strengthening elements, which result in the deterioration of the galvannealing reaction. In this study, the effects of galvannealed manufacturing conditions on surface and mechanical properties, resistance spot weldability on a laboratory scale, and GA 980 MPa steel sheets produced by commercial continuous galvannealing line (CGL) were investigated.

Keywords *: DP, GA AHSS, Wetting, Weldability*

1. Introduction

In recent years, the automotive industry has been required to apply advance high strength steel (AHSS) sheets to automobile bodies to improve fuel economy and crashworthiness. In order to meet this demand, AHSS sheets with tensile strength greater than 590 MPa have been intensively applied to structural and reinforced parts. Furthermore, galvannealed steel sheets have been extensively used for automobile bodies to provide corrosion resistance.[1] Therefore a variety of GA AHSS sheets, including DP (dual phase), TRIP (transformation-induced plasticity), CP (complex phase), and MS (martensitic), have been adopted.

Among these AHSS sheets, DP steel sheets consisting of embedded martensite and ferrite as a matrix show larger elongations than precipitation, solid-solution hardened steel sheets with the same grade.[2] Particularly, DP steel sheets exhibit excellent features in terms of formability, low spring-back, elongation, and shape fixability, which result from their low yield point.[3] In addition, DP steel sheets have a larger absorbed energy at high strain rates than other materials of the same grade.[4] It is difficult to obtain DP GA AHSS sheets because the DP microstructure is required to cool rapidly below the martensite starting temperature. However, steel sheets in a CGL are immersed in a zinc pot. After galvanizing, they are subjected to a galvannealing treatment. Therefore, when compared to a continuous annealing line (CAL), the critical cooling rate (rapid cooling) required to obtain the DP structure is difficult to achieve in a CGL process. Hence, production of DP GA AHSS sheets through the control of chemical composition and manufacturing conditions is important.

Typically, GA AHSS sheets are strengthened through the addition of alloying elements, which detrimentally affect coating properties and weldability. It is well known that the addition of manganese (Mn) and silicon (Si), which have low standard Gibbs free energy, tends to segregate selective oxide formation on the steel sheets during annealing.[5)-6] In addition, oxides that are formed by these elements interfere with the wettability of the steel sheets with molten zinc, causing bare spots and other surface defects in the galvanizing process.[7)-8] The addition of phosphorous (P) and sulfur (S), which embrittle the weld nugget, makes the steel sheets more susceptible to interfacial fracture at spot-welded joints. Therefore, the addition of

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these elements should be minimized to achieve good weldability.

In this study, to obtain 980 MPa grade DP GA AHSS sheets, the effects of the manufacturing conditions on the mechanical properties of the material are investigated. Based on laboratory investigation, 980 MPa grade DP GA AHSS sheets are produced by a commercial CGL. Properties such as weldability, galvanizability, and formability of a commercial CGL are also described.

2. Experimental

In the present investigation, 980 MPa grade galvannealed steel sheets were produced using a laboratory simulator and a CGL. The chemical compositions of the steel used for this study is provided in Table 1.

The heat cycle used to manufacture the 980 MPa galvannealed steel sheets is shown in Fig. 1. In order to investigate the effect of the annealing and galvannealing temperatures, the cold rolled steel sheets were annealed at various temperature ranges between 750 ℃ and 830 ℃ for 130 sec. After they were cooled at 470 ℃ and dipped in a molten zinc pot at 460 ℃, they were then galvannealed between 460 ℃ and 500 ℃. The annealed steel sheets were finished with a skin-pass mill with elongation of 1.0%. Testing of the mechanical properties was carried out in a Zwick Z100 tensile test machine at a constant crosshead speed of 10 mm/min using JIS No 5 specimens in a direction transverse to the rolling direction. Scanning electron microscopy (SEM) observation was carried out using a Philips XL30 combined with energy dispersive X-Ray spectroscopy (EDS).

Spot weldability was evaluated by the tensile-shear strength and nugget size of the steel sheets using varying

Table 1. The chemical compositions of the steels used in this study (wt%)

C	Si	Mn	P	S	Al
0.0711	0.1911	2.76	0.0254	0.0019	0.0409

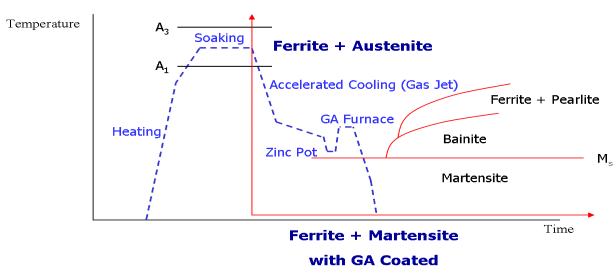

Fig. 1. Heat cycle for advance high strength steel sheets.

Table 2. Spot welding conditions

Electrode material	Copper-Chrome
Electrode type	Dome
Electrode force	400 kgf
Welding current	5~9 KA
Welding time	15 cycles (60 Hz)

welding currents and forces. The evaluation was performed under the spot welding conditions listed in Table 2. After performing peeling tests on the spot welding specimens, the nugget size was measured using an optical microscope. The tensile-shear strengths of the spot welding specimens were measured. A continuous spot welding test was carried out with a welding current of 8.0 KA and a welding force of 400 kgf, which resulted in neither shear fracture in the peeling test nor expulsion in the tensile-shear test. In order to evaluate formability, cross-forming tests of the DP GA AHSS sheets were performed at various cushion forces.

3. Results

3.1 Mechanical properties

Fig. 2 shows the effects of annealing temperature on the mechanical properties. It is revealed that both the yield strength and the tensile strength decrease with an increase in the annealing temperature, while elongation increases with an increase in the annealing temperature. Annealing temperature microstructures are shown in Fig. 3. Fig. 4 shows the effects of galvannealing temperature on the mechanical properties. It could be seen that neither the yield strength nor the tensile strength changed; however, elongation of the steel sheets slightly decreased with an increase in the galvannealing temperature. It was found that the

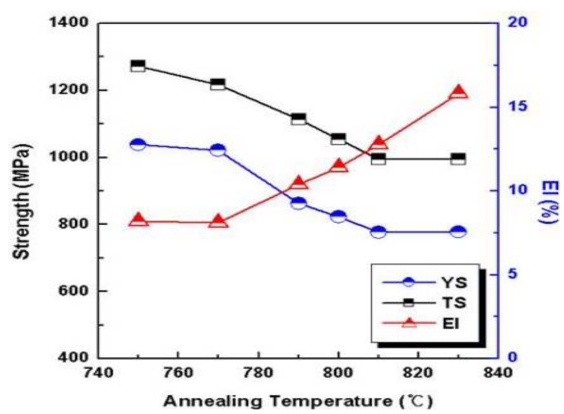

Fig. 2. Effects of annealing temperature on mechanical properties.

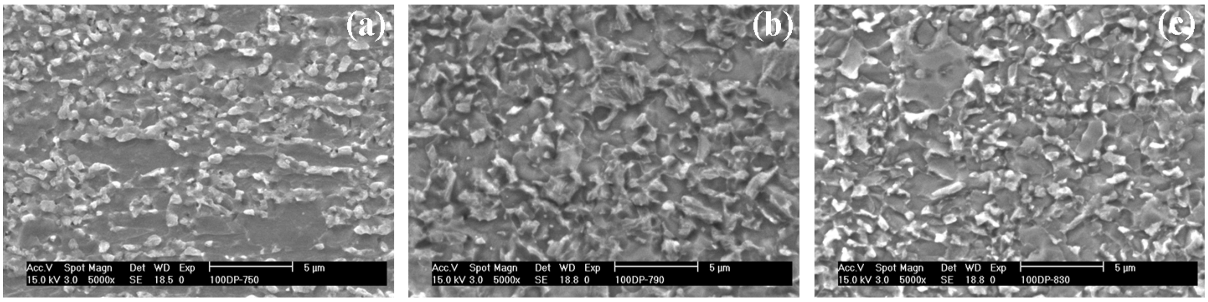

Fig. 3. SEM images according to annealing temperature: (a) 750℃, (b) 790℃, (c) 830℃.

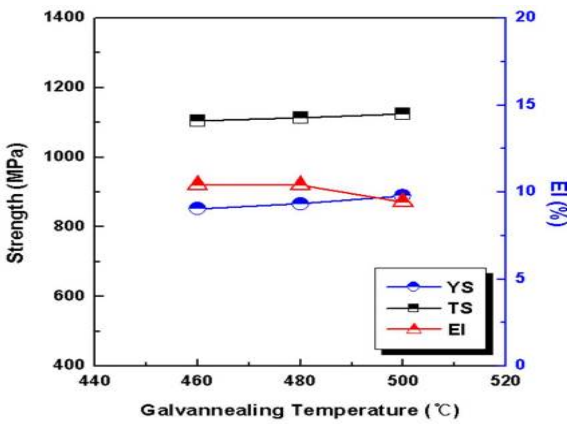

Fig. 4. Effects of galvannealing temperature on mechanical properties.

galvannealing temperature effects were minor when compared to the annealing temperature effects.

The production of 980 MPa grade DP GA AHSS sheets was carried out based on a laboratory investigation. The conditions for the production are summarized as follows: the reduction of cold rolling was 40%, and the annealing and galvannealing temperatures in the CGL were 810 and 490 ℃, respectively. The mechanical properties of the steel sheets produced by the commercial CGL process are

Table 3. The mechanical properties produced by CGL

TS (MPa)	YS (MPa)	El (%)
1073.0	692.5	12.64

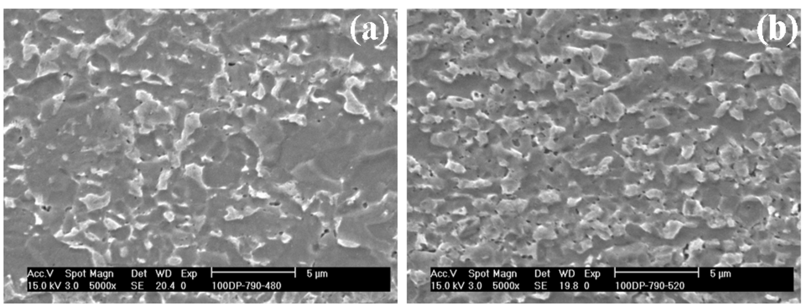

Fig. 5. SEM images according to galvannealing temperature: (a) 460℃, (b) 500℃.

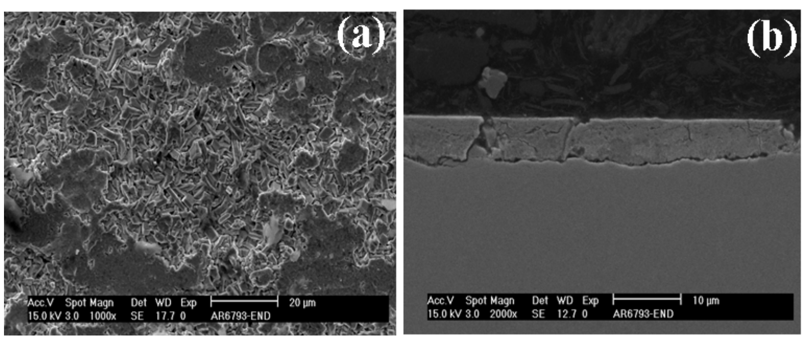

Fig. 6. SEM images of DP GA AHSS (a) surface appearance, and (b) cross-section.

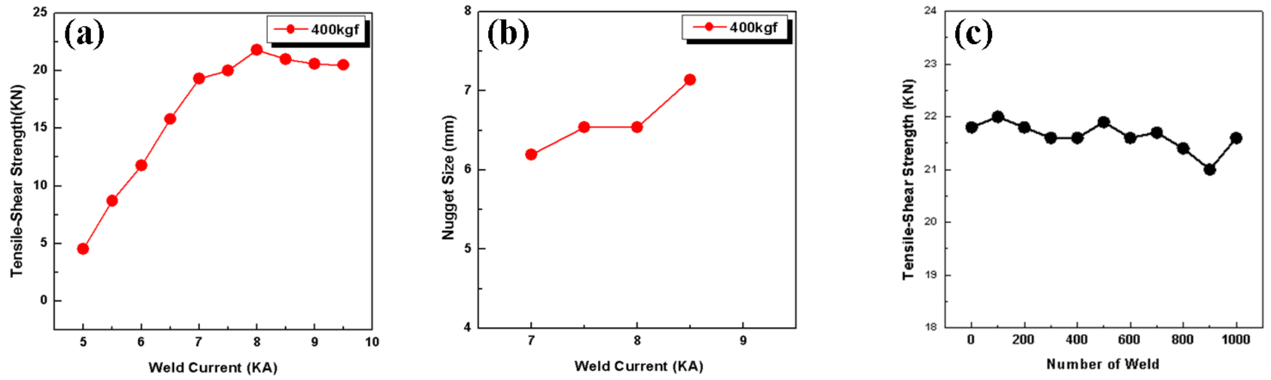

Fig. 7. Weldability of DP GA AHSS: (a) relationship between tensile-shear strength and weld current, (b) relationship between nugget size and weld current, and (c) change in the tensile-shear strength with the number of weld.

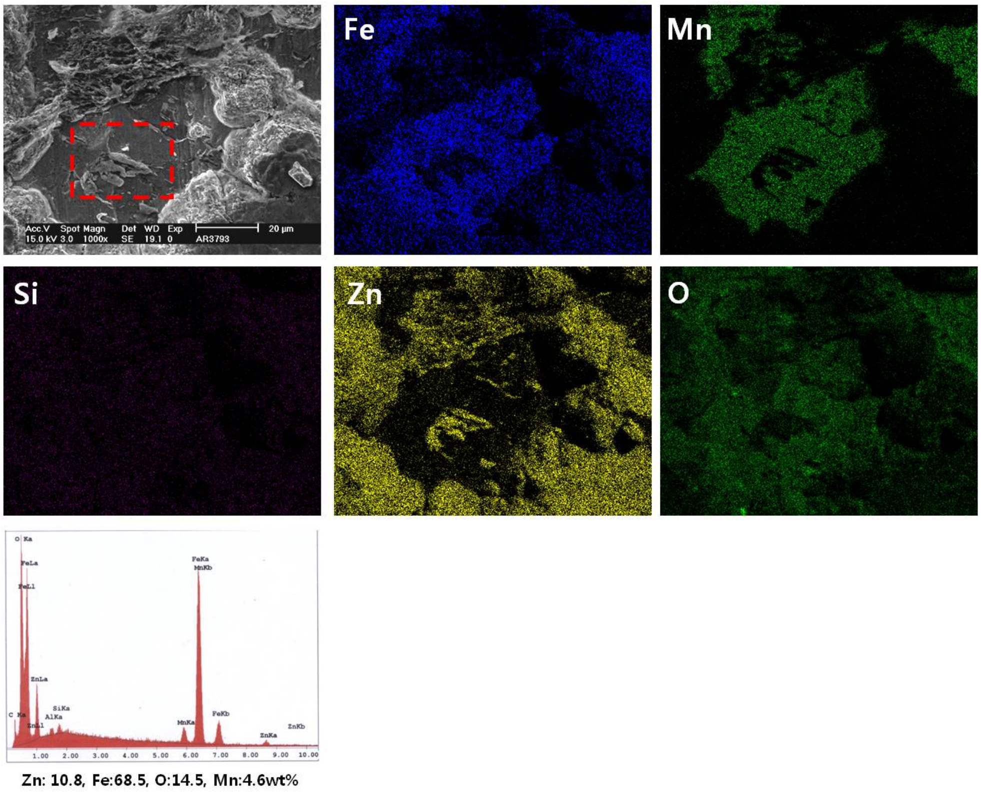

Fig. 8. Results of the bare spot analysis.

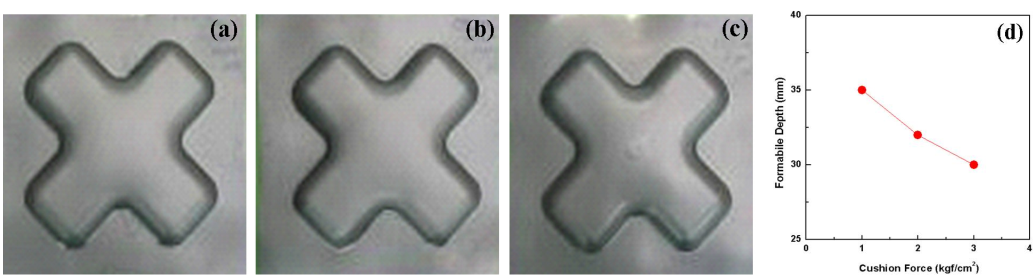

Fig. 9. Results of formability: cushion force (a) 1.0, (b) 2.0, (c) 3.0, and (d) the relationship between formable depth and cushion force.

listed in Table 3. Fig. 6 shows SEM images obtained from the surface of the steel sheets and a cross section of the coating layer. In zinc coating, the coating weight was 45 g/m^2 per side and the iron (Fe) content ranged from 9.5 to 10.1%.

3.2 Weldability

Fig. 7(a) shows the relationship between the tensile-shear strength and the welding current. The tensile-shear strength increased with the welding current. When the welding current was above 9.0 KA, expulsion varied greatly in the tensile-shear tests. Furthermore, no significant decrease in strength was confirmed, even after expulsion. These results indicate that the steel sheets produced in this investigation achieved excellent joining performance. The available welding current range was 1.7 KA, which is almost equal to that of conventional high strength steel sheets. Fig. 7(b) shows the change in the nugget size with the welding current used in the spot welding. Nuggets were formed when the welding current was above 7.0 KA, and the tensile-shear strength reached 19.3 KN. Fig. 7(c) shows the results of the continuous spot welding tests. No change in the tensile-shear strength was observed after 1,000 consecutive spot welding tests.

3.3 Wetting

The addition of alloying elements such as Mn and Si is necessary to increase strength. It is well known that these elements cause selective oxide formation on the steel sheets. As a result, GA AHSS sheets develop surface defects such as bare spots, which result from deterioration of the galvannealing reaction. Fig. 8 shows bare spots on GA AHSS sheets containing Mn. EDS mapping reveals the distribution of Fe, Mn, Zn, and O on the steel sheets. From Fig. 8, it can be seen that the GA AHSS sheets exhibit a contrasting distribution of Mn. These results clarify that the bare spot region fits with the Mn-concentrated regions, measured by EDS mapping. In this study, therefore, the formation of Mn oxide resulted in bare spots on the GA AHSS sheets.

Fig. 9 shows the results of the cross-forming tests that involved press forming using 980 MPa DP GA AHSS sheets. The conditions of the cross-forming tests are summarized as follows: the cushion stroke was 220 mm, the cushion force ranged from 1 to 3 kgf/cm^2, and the spm was 8 stroke/min. The cushion force increased with a decrease in the formable depth.

4. Summary

To obtain 980 MPa grade DP GA AHSS sheets, the effects of annealing and galvannealing temperatures on the mechanical properties of the material were investigated. The performance of 980 MPa grade DP GA AHSS sheets, produced by commercial CGL, was investigated. The following results were obtained:

1) The yield strength and tensile strength decrease with increasing annealing temperature, while the elongation increases with increasing annealing temperature. With the increase of galvannealing temperature, the yield strength and tensile strength does not change, but the elongation slightly decreases.

2) The available welding current range is approximately 1.7 KA. The 980 MPa grade DP GA AHSS sheets have a weldability as good as that of conventional high strength steel sheets.

3) The 980 MPa grade DP GA AHSS sheets show excellent formability. Cross forming tests indicate that formable depth decreases with increasing cushion force.

4) This investigation demonstrated the possible production of 980 MPa grade DP GA AHSS sheets with good weldability and formability.

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