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Recent Progress of Automotive Galvanized Steels in Korea

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Due to the global warming and economic crisis, automakers are currently focusing on the development of high fuel-efficiency vehicles. To accord with these requirements, steelmakers have been trying to develop advanced high-strength steels with improved automotive-related properties. In addition, galvanizing technologies have been developed to improve coating properties for AHSS (Advanced High Strength Steel) such as pre-oxidation and pre-coating, as well as roll dent prevention. In this paper, newly developed products and technologies for automotive galvanized steel sheet are reviewed.

Keywords *: galvanized steel, AHSS, coating*

1. Introduction

Total production of zinc coated steel sheets in Korea has been rapidly increased since 2000 due to the growth of automotive industry. It is mostly attributed to the increased production of HDG(Hot Dip Galvanized steel sheets), while the production of EG(Electro Galvanized steel sheets) has stagnated (Fig. 1).

Even though the production of galvanized steel sheets decreased due to the economic recession last year, it is expected that the production of the galvanized steel sheets will increase up to 120 million tons in 2018.[1] According to KOSA(Korea Steel Association), galvanized steel sheets were produced about 5.3 million tons in 2008.[2] Among the total production of 2008, POSCO produced 3.5 million tons, 63% for automotives, 11% for appliances, 18% for constructions and the rest for the others.(Fig. 2) Specifically, for the automotive steels from POSCO, the outer panels hold 27% of the production. Due to the increase of automotives' demand, it is expected that the production will be increased continuously in the future.

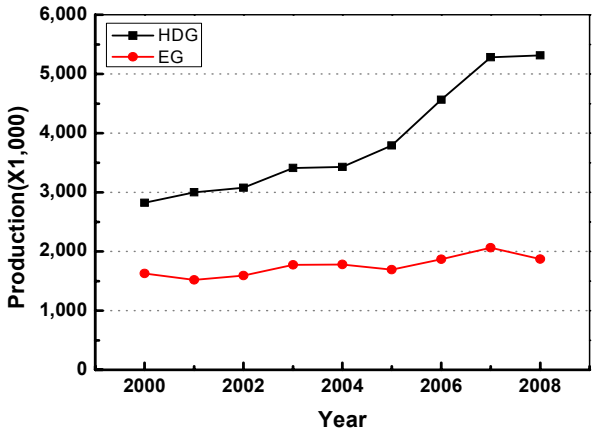

Fig. 1. Production of galvanized steels in Korea, 2008.

2. Automotive steels

As a matter of serious concern for the fuel efficiency and CO_2 emission increases, automakers are trying to in-

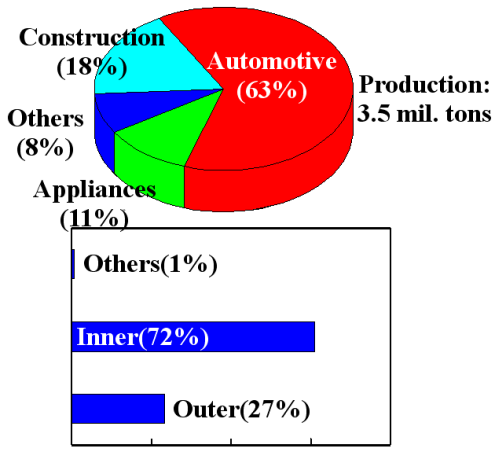

Fig. 2. Production by applications in POSCO.

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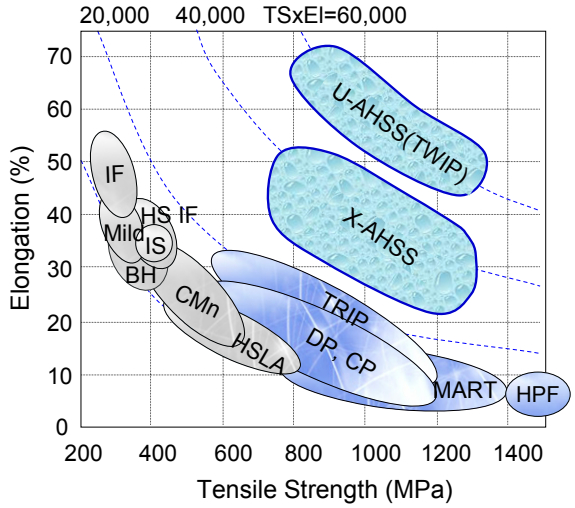

Fig. 3. Banana diagram for automotive steels.

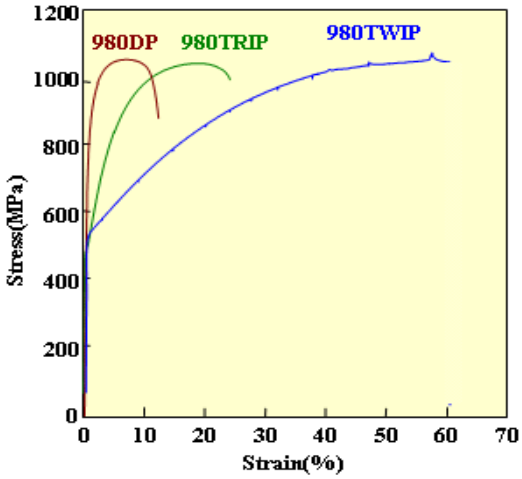

Fig. 4. Mechanical properties of TWIP.

crease the use of AHSS for automotives. During several decades, various automotive steels have been developed. The developing trend of these steels is shown in a banana diagram of Fig. 3. The conventional automotive steels in the banana shape curve including IF steels with or without bake hardenability, HSLA(High Strength Low Alloy) steels and conventional AHSS such as DP(Dual Phase) and TRIP(Transformation Induced Plasticity), CP(Complex Phase) and MART(MARTensite) steels show the product of tensile strength and elongation (TS-El product) lower than 25,000 MPa · %.

For the exposed application, titanium and/or niobium added bake hardening steels have been used in general, however their mechanical properties are not homogeneous and the surface properties are not sufficient. Hence, MAFE(Micro Alloy Free-Exposed) has been developed to improve the surface appearance of bake hardening steel and to reduce the manufacturing cost in POSCO. Moreover, DP steels possessing TS above 490 and 590 MPa have been recently developed for the outer panel, which show superior surface quality compatible with conventional BH steel. For GI(Galvanized Steel), POSCO developed GI-ACE which is a product with excellent surface appearance using the solidification with aerosols charged with electrostatic. Grain size of galvanized steel sheets formed by means of air cooling is about 1,000~2,000 ㎛, whereas by means of aerosols charged with electrostatic or rapid cooling is under 60 ㎛ due to numerous nucleation sites formation (Fig. 5). Moreover, galvanized surface created by ACE method has preferred orientation (0001) and several advantages such as corrosion resistance, weldability, paintability and good appearance (Fig. 6).

For the unexposed application, high strength steels with formability have been developed. For example, the conventional AHSS has a long history of R&D since the oil

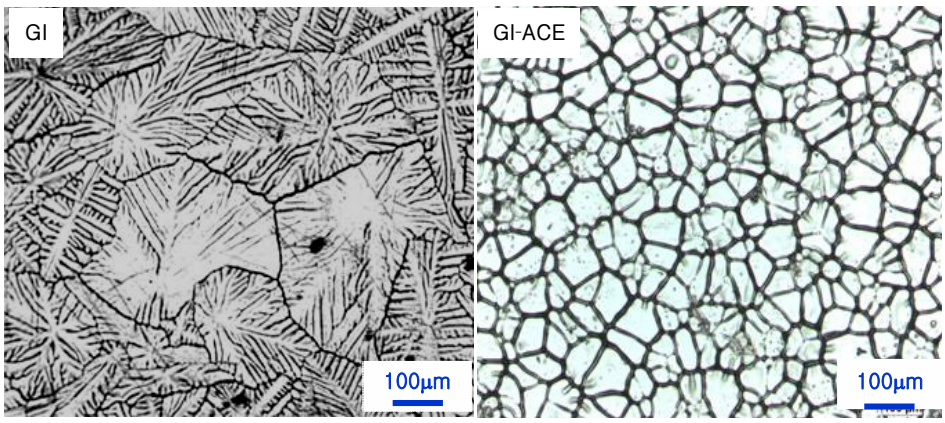

Fig. 5. Surface structure of GI-ACE and GI.

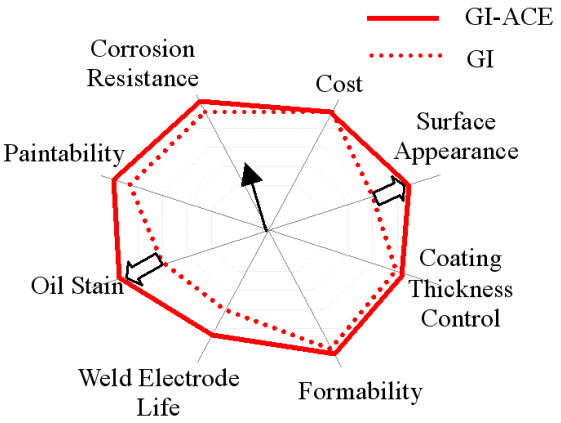

Fig. 6. Characteristics of GI-ACE.

shock of the 1970s, which has been focused on how to utilize the microstructure such as retained austenite and martensite etc, and how to design the thermal cycles to generate the desired microstructure.[3)-8)] AHSS like DP and/or TRIP steels for structural or chassis parts which require high strength, weldability and formability has been applied. A primary advantage of DP steels compared to TRIP steels is weldability due to the relatively low carbon contents and superior surface quality of galvanized steels. In TRIP steels with higher contents of silicon, selective oxides formed during high temperature annealing deteriorate the wettability of galvanized steels. Several researches have been developing to improve the surface quality of zinc coated TRIP steels; substitution of silicon with aluminum, pre-oxidation before annealing or pre-coating to retard oxide formation during annealing. In addition, AHSS with higher hole expansion ratio values has been developed to enhance stretch flangeability and bendability. This can be realized by minimizing the strength difference between the ferrite matrix and the 2nd phase, and controlling the 2nd phase to be finely dispersed. AHSS with bainite microstructure reveals excellent stretch flangeability together with good weldability due to lower carbon contents. 1180 MPa CP steel with excellent bendability and higher yield strength has been developed in POSCO, which is applied for the sill side by automakers in Korea. Recently, global trend of AHSS developments focus on the next generation of advanced high strength steels such as X(eXtra)-AHSS and U(Ultra)-AHSS which are shown in Fig. 3, two additional steel groups above the banana curve of conventional AHSS. Steels with the product of TS and El ranging from 25,000 to 45,000 MPa% are categorized as so called X-AHSS. To meet demands of both extra high strength and enhanced formability, many investigations have been performed with various metallurgical approaches in laboratory such as martensite based TRIP steel (M-TRIP), Super Bainitic TRIP steel(SB-TRIP) and high Mn TRIP steel etc.[9)-14)] U-AHSS shows the TS-El product greater than 50,000 MPa% as shown in Fig. 3, and commercial research of the steels has been performed in a few R&D groups.[15)-18)] For example, TWIP(TWinning Induced Plasticity) is a potential product to obtain the superior balance of tensile strength and elongation. TWIP steel had been successfully trial-produced at POSCO in early ´90s, but the trial was not extended to commercialization due to the limitations of facilities and productivity. (Fig. 4)[15)] Europe steel companies have tried to produce TWIP, but turned out commercially unsuccessful, presumably due to low productivity, high cost and delayed fracture. New approaches to reduce these difficulties are recently performed in order to apply these steels to automotive parts in POSCO.[17)]

3. Galvanizing technologies for ahss

In general, AHSS contains high silicon, manganese, and boron to obtain mechanical properties with low cost. However, these elements deteriorate the wettability so that it causes bare spots.[19,20] So far many technologies have been tried to improve the wettability, and some of them such as pre-oxidation, pre-coating, and dew point control are reported to be effective.

3.1 Pre-oxidation

During hot dip galvanizing of AHSS, selective oxides of alloying elements cannot be removed during the reductive annealing because those oxides are more stable than iron oxide. In addition, diffusivity of silicon and manganese is so fast that complex oxides are formed at first. However, in case of using DFI (Direct Flame Impingement), thick iron oxide layer is formed before annealing and covered the surface so that suppressed the diffusion of silicon and manganese to the surface during annealing.[21)] By this effect, wettability can be improved. Pre-oxidation was tested using pilot plant equipped with DFI in

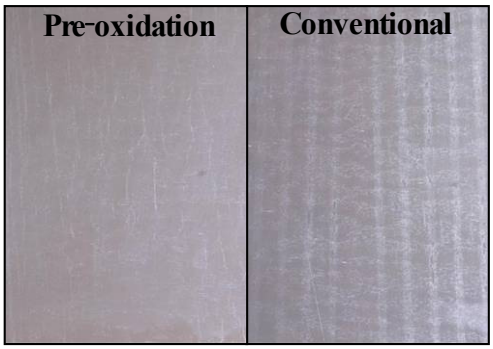

Fig. 7. Comparison of surface appearance.

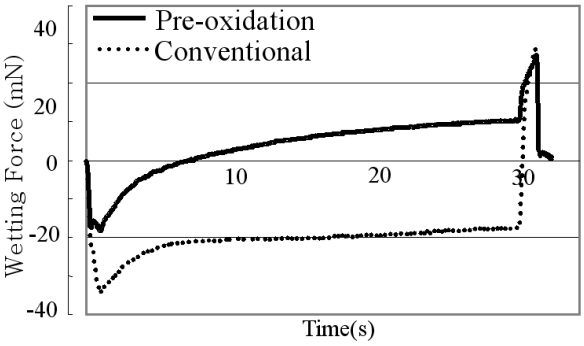

Fig. 8. Wetting force variation after dipping.

Kwangyang Lab. for silicon added TRIP steel, which showed good surface appearance without bare spot.(Fig. 7)

Fig. 8 shows the variation of wettability force of silicon added TRIP steel after dipping in zinc pot. Pre-oxidation treated silicon added TRIP steel is more positive value than conventional method which means good wettability. However, to use pre-oxidation process, the proper thickness control of initial iron oxide layer before annealing should be considered.

3.2 Pre-coating

Another way to improve the wettability is pre-coating before annealing. Pre-coating technology was developed in Japan to improve the wettability for high strength steels.[23] In general, nickel or iron is used as pre-coating elements because those can be coated easily with low costs. Pre-coated layer is formed with the thickness of about 50 nm before annealing. Pre-formed coating layer can suppress the enrichment of silicon, manganese and boron during annealing because coating layer is oxidized in advance. In addition, pre-coated elements can diffuse into the steel and form internal oxides during annealing. By these effects, wettability can be improved.(Fig. 9)

3.3 Roll dent prevention

In case of producing AHSS, dent defects are found on the surface because of selective oxidation. Fig. 10 shows a schematic for the mechanism of dent pick-up. By adding elements such as silicon, manganese and boron, the oxides are formed on steel surface during annealing.[21,22] When these oxides contact to the roll surface repeatedly, the ox-

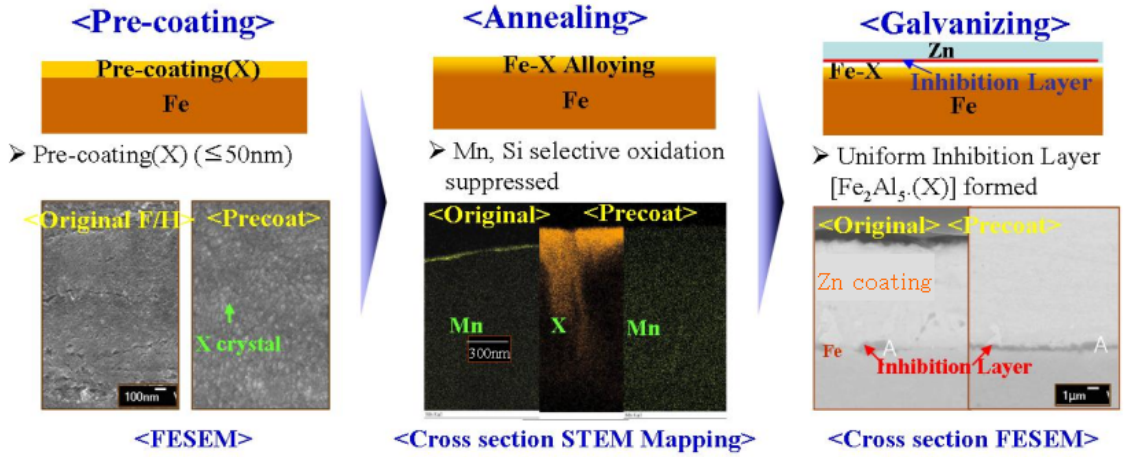

Fig. 9. Schematic diagram of pre-coating process.

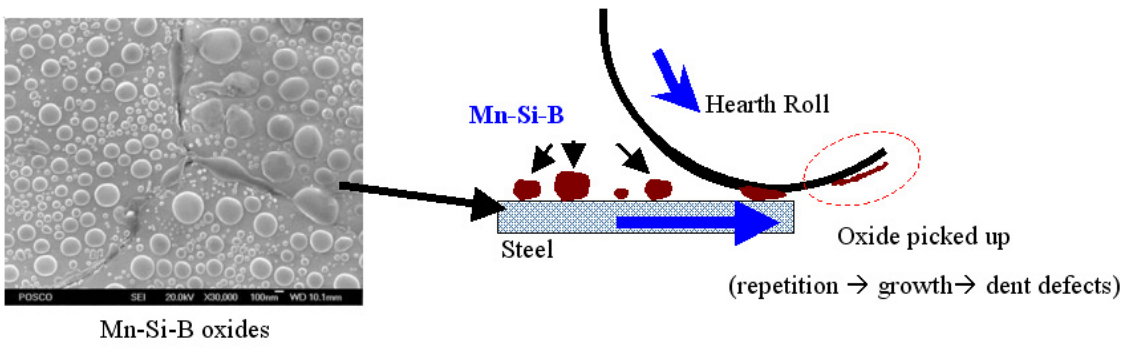

Fig. 10. Schematic diagram of dent pick-up.

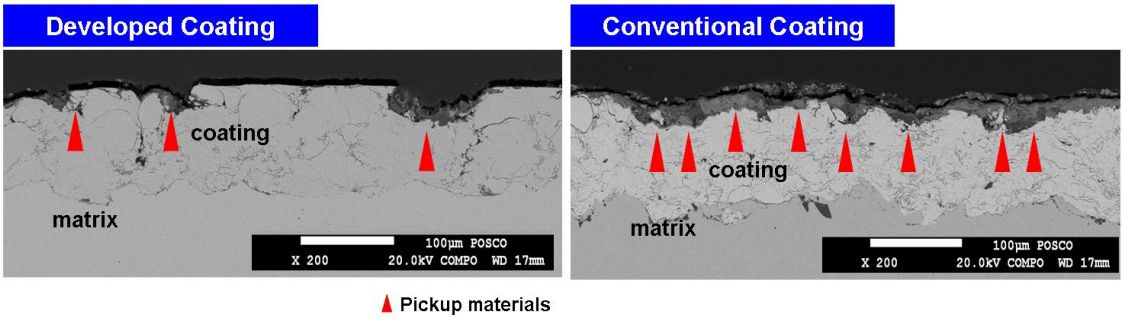

Fig. 11. Cross sections of roll coating after the pick-up simulation.

ides is attached to the surface. These attached oxides cause dent defects and prevent continuous working. Roll pick-up problems can be reduced by controlling steel compositions and annealing conditions as well as using a new roll coating. By adding some elements or controlling the ratio of silicon and manganese, oxide morphology can be changed from coarse to fine oxides. Even though fine oxides are adsorbed to the roll, the size can be negligible so that dent defects can be reduced. Combined with composition controlling, new roll coating is necessary. POSCO is developing new coating material, which is resistant to roll pick-up. Fig. 11 shows the result of pick-up simulation. In conventional roll coating, a lot of pick-up material is absorbed on the roll coating layer, whereas roll pick-up is decreased in new developed.

4. Summary

To help automakers meet stringent fuel economy and greenhouse gas emission standards, steelmakers are developing stronger, lighter and more affordable grades of advanced high-strength steels (AHSS), X-AHSS and U-AHSS as well. Together with the developments of new materials, galvanizing technologies have been developed continuously for improving coating properties. Among the technologies, pre-oxidation and pre-coating technologies are introduced in several CGL, which show good results. By these technical developments, automakers will continue to expand the implementation of these grades to meet the new fuel economy requirements, while maintaining crash safety and affordability.

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