Development of 590MPa grade DP GA steel for automotive outer panel use

M. B. Moon, S. W. Lee, S. J. Park

Recently high strength steels with high formability for automotive parts have been being developed to meet the demands of passenger safety and weight reduction of car body. Among these high strength steels, dual phase(DP) steels are regarded as one of the attractive steels due to their excellent mechanical properties including high strength and ductility. However, typical high strength steels contain strengthening elements that forms surface oxide and thus deteriorate galvanizing property. Galvanizing of high strength steel is required to satisfy corrosion resistance of automotive body. Typical outer panel parts requiring anti-dent property are comprised of 340MPa grade bake hardened(BH) steel, but the trend of lightweight car body drives steels to have higher strength for outer panel use. 490MPa grade DP steel is beginning to be applied into some automobiles, and 590MPa grade DP steel is a good candidate for the future outer panel material. In this study, several kinds of alloys for enhancing galvanizability were produced in the laboratory scale, and the effects of continuous annealing conditions in CGL on the mechanical properties were investigated. The microstructure and phase distribution were examined with SEM, EBSD, TEM and so on. Line trial production was conducted with the selected chemical composition of steel. Formability, weldability and CAE analysis of steel sheet was also performed. Through the study, the production of 590MPa grade dual phase galvannealed steels with good formability and galvanizability was shown to be possible.

Keywords:
Dual phase steel, Automotive, Outer panel, Galvannealed, Galvanizability

INTRODUCTION

Car makers are making every effort to enhance the structural design of car body and the fuel efficiency to meet the strengthened safety and environmental regulations. And according to the diversification of the customers' needs, automotive companies are looking for advanced high strength steels with good formability.

Therefore several kinds of new concept high strength steels including dual phase(DP), transformation induced plasticity(TRIP), martensitic(MS) and complex phase(CP) steels were introduced as shown in Figure 11). Among these steels, DP and TRIP steels are intensively being studied by steelmaking companies. These two types of steels have the advantage of higher strength and better formability than the similar grade high strength steels. Especially DP steels are good candidates for the automotive outer panel because they have bake hardening property, which exhibits a significant increase in strength after press forming and subsequent thermal cycle such as a paint-baking operation. Typical steel grade for automotive outer panel is 340MPa BH steel, but the trend of lightweight car body drives steels to have more strength to be applied to the outer panel such as 490MPa DP steel.

Automotive steels also require corrosion resistance because of the extended lifetime of automobile and the increased use of deicing agent on the road, so hot dip galvanized steel is increasingly applied to the automobile parts. High strength steels including DP steels usually contain several kinds of strengthening elements such as Si, Mn and so on, but these strengthening elements also deteriorate the galvanizing property due to the surface oxides formed during annealing process, and these oxides are critical in surface defects of outer panel.

In this study, 590MPa grade DP GA steels for automotive outer panel is being developed. To be successfully applied to the au-

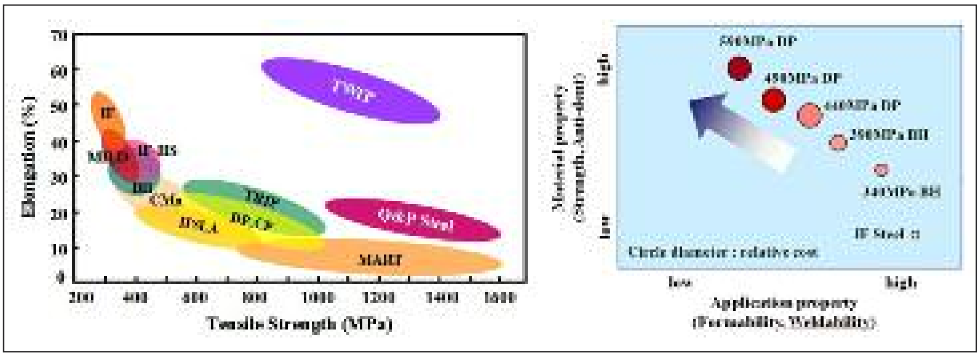

FIG. 1 ***Trend of advanced high strength steel and outer panel for automotive use.***

Tendenza dell'utilizzo di acciai ad alta resistenza per pannelli esterni di impiego automobilistico.

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Alloy	C	Si	Mn	P	Al	Mo	Cr	Ti	N(ppm)	others
E1	0.063	0.11	2.01	0.011	0.039	0.20	0.20	-	62	-
E2	0.064	0.11	2.01	0.042	0.042	0.20	0.20	-	59	-
E3	0.065	0.11	2.00	0.011	0.210	0.20	0.20	-	49	-
E4	0.070	0.11	2.00	0.011	0.220	0.10	0.20	0.022	50	-
E5	0.091	0.11	1.99	0.020	0.210	0.10	-	0.022	51	-
E6	0.092	0.11	2.01	0.020	0.200	0.10	-	0.023	26	-
E7	0.089	0.10	2.02	0.020	0.420	0.10	-	0.022	58	-
E8	0.089	0.11	1.79	0.019	0.210	0.10	0.19	0.022	49	-
E9	0.089	0.10	1.96	0.019	0.042	0.10	0.20	-	58	V 0.042
E10	0.087	0.10	1.98	0.020	0.044	0.10	-	0.022	52	B 10ppm

TAB. 1 ***Chemical composition (wt.%) of steels.***
Composizione chimica degli acciai (peso %).

tomotive outer panel, various requirements such as mechanical properties, weldability and press formability have to be satisfied. So, the alloy design was focused on lowering Si concentration down to 0.1wt.% and adding Cr, Mo, Al instead to satisfy desired mechanical property and to enhance galvanizability. Microstructural analyses were also carried out with scientific equipment such as FEG-SEM and TEM.

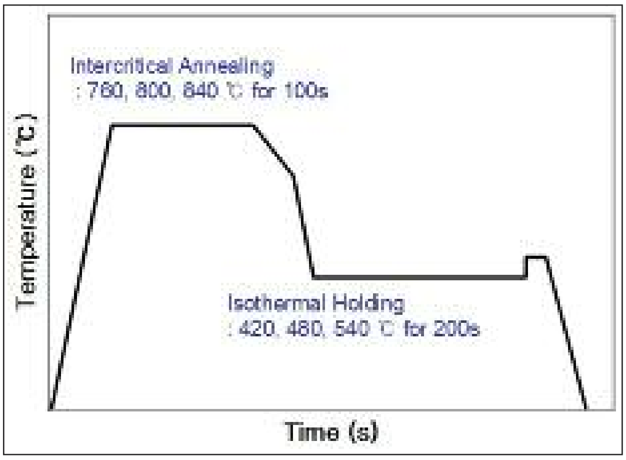


FIG. 2 ***Schematic diagram of intercritical annealing and isothermal holding process of DP steels.***

Diagramma schematico dei processi di ricottura intercritica e mantenimento isotermico degli acciai bifasici.

EXPERIMENTS

Materials

Ten kinds of experimental ingots were made in laboratory by vacuum induction furnace. They were reduced into 25 mm thick slab, homogenized at 1200° and then hot rolled to 3 mm. Finishing temperature after rolling was 900° and samples were hold at 620° for 30 minutes to simulate the coiling temperature. After pickling in 10% hydrochloric solution at 80°, steel sheets are then cold rolled to 0.7 mm thick.

Heat treatment simulation

To evaluate the intercritical annealing and isothermal holding temperature, Thermo-calc software and dilatometric analysis were used. With these data, heat cycle for the heat treatment simulator(CCT-AWT-II, ULVAC, Japan) were set up. Steel sheets were annealed in the intercritical annealing temperature(IAT) range of 760 to 840° and isothermal holding temperature(IHT) range of 420 to 540°.

Analysis of microstructure

Specimens were polished, etched with 2% Nital and LePera so-

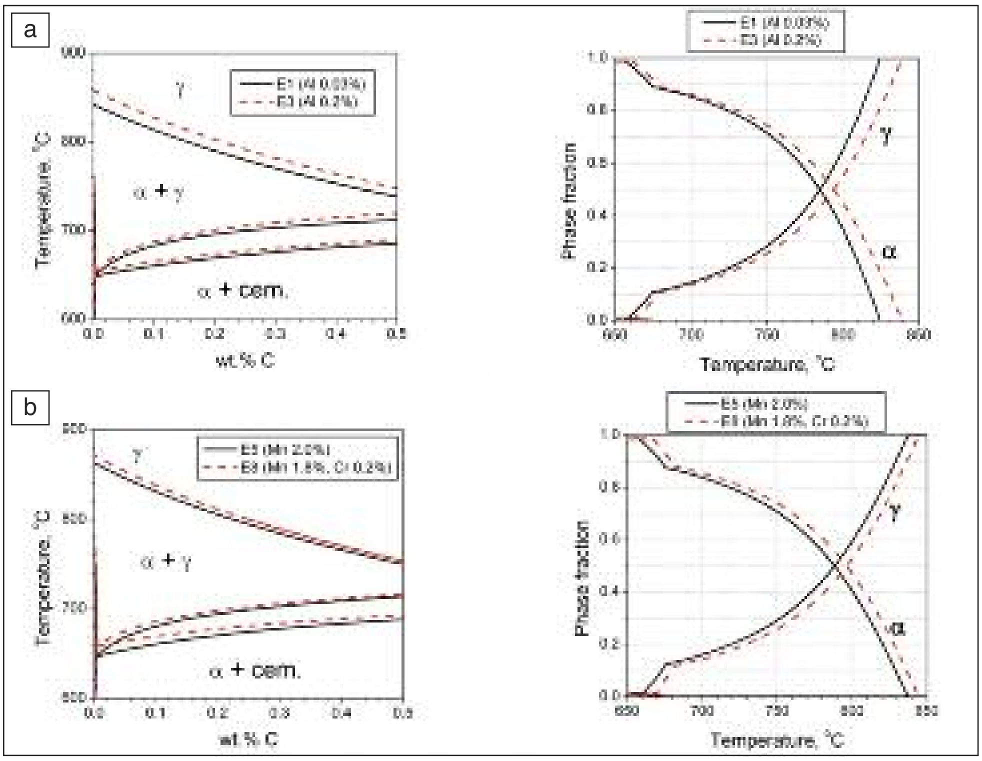


FIG. 3
Effect of alloying elements in equilibrium phase diagram and phase fraction; (a) E1(0.03Al) vs. E3(0.2Al), (b) E5(2.0Mn) vs. E8(1.8Mn, 0.2Cr).

Effetto degli elementi di lega sul diagramma di equilibrio di fase e sulla frazione di fase; (a) E1(0.03Al) vs. E3(0.2Al), (b) E5(2.0Mn) vs. E8(1.8Mn, 0.2Cr).

FIG. 4
Austenite fraction of various samples (a) E1 vs. E3 (effect of Al) (b) E5 vs. E8 (effect of Mn).

Frazione austenitica dei vari provini. (a) E1 vs. E3 (effetto di Al) (b) E5 vs. E8 (effetto di Mn).

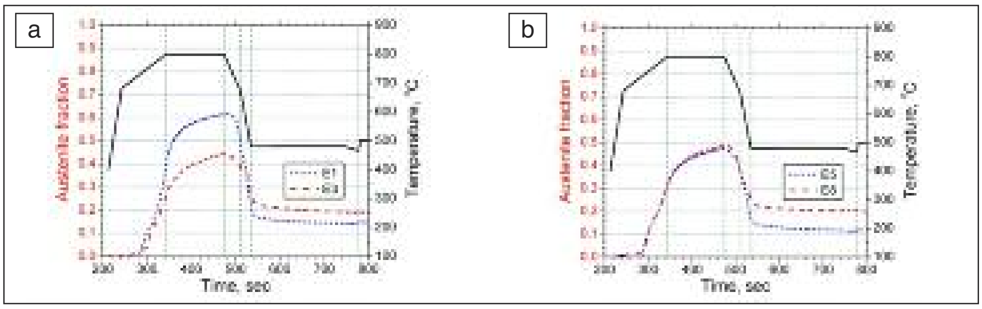
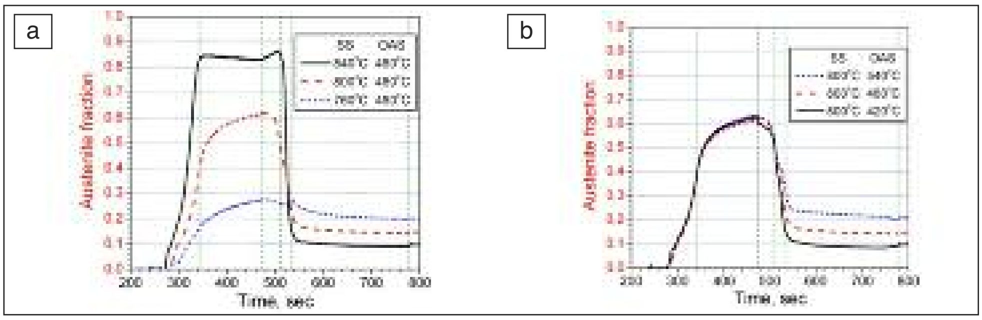


FIG. 5
Effect of (a) IAT(760~840) and (b) IHT(420~540) on austenite fraction in E1 steel.

Effetto di (a) IAT(760~840) e (b) IHT(420~540) sulla frazione austenitica nell'acciaio E1.



lution, and then examined with optical microscope. Etching for 5 seconds with LePera solution made the martensite phase bright, enabling the calculation of volume fraction by image analysis. EBSD analysis was performed with electrolytic polished samples, TEM was used for the surface oxide analysis.

RESULTS AND DISCUSSIONS

Thermodynamic calculation

The alloys were annealed in intercritical region where both ferrite and austenite phase exist together, followed by quenching. This intercritical annealing is crucial in determining the austenite fraction, which transforms into martensite phase. So, we calculated Ae1 and Ae3 temperature in the phase diagram and the austenite fraction in intercritical temperature by Thermocalc software.

In Fig. 3(a), increased Al concentration elevates both Ae1 and Ae3 line, so in the same annealing temperature, specimen E3 is expected to exhibit less austenite fraction compared with specimen E1. In Fig. 3(b), Mn addition lowers the transformation temperature, because Mn is an austenite stabilizing element. So, specimen E8 exhibit high Ae1 and Ae3 temperature compared with specimen E5, thus have less austenite fraction also.

Dilatometric analysis

Dilatometric analysis was performed to examine the phase transformation behavior during heat treatment. Austenite phase formed during intercritical annealing partially transforms into ferrite or bainite until cooled down to isothermal holding temperature, followed by martensitic transformation of the rest of austenite in the final cooling stage. Fig. 4 illustrates the change of austenite volume fraction according to the alloying elements measured by dilatometric analysis when IAT was 800 and IHT was 480 . In Fig. 4(a), E1(low Al) and E3(high Al) specimens were compared. Austenite fraction of E3 specimen is low in the intercritical annealing stage, but it shows less transformation to ferrite during cooling, resulting in higher austenite fraction at the end of isothermal holding stage. In Fig. 4(b), E5(high Mn) and E8(low Mn) specimens were compared. Austenite fraction during IA stage was almost same, but the austenite stability of E8 specimen was better, resulting in higher fraction.

Effect of heat treatment on the phase transformation was assessed by dilatation. Specimen E1 experienced IAT of 760, 800, 840 and IHT of 420, 480, 560 during dilatation. In Fig. 5(a), higher intercritical annealing temperature promotes larger fraction of austenite, but the fraction drops rapidly during cooling, thus making less austenite than lower IAT case. This is because lower fraction of austenite holds more carbon, thus hindering ferrite phase transformation during cooling. Fig. 5(b) shows that lower isothermal holding temperature makes less austenite, because bainitic transformation is progressed at around 500 .

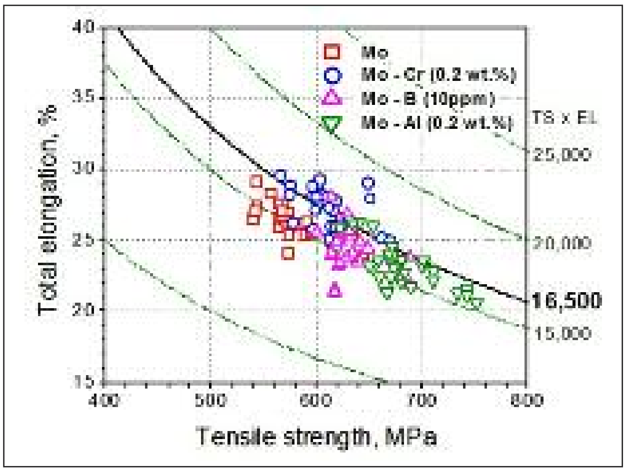


FIG. 6 ***Mechanical properties of specimens according to micro-alloy elements.***

Proprietà meccaniche dei provini a seconda degli elementi microleganti.

Mechanical properties and microstructure analysis according to heat treatment

Fig. 6 shows the mechanical properties of specimens according to micro-alloying elements. Increase in strength is achieved more by addition of Mo+ (Cr, B, Al) elements rather than addition of Mo alone. Especially, Mo-Cr addition can increase both strength and elongation. Mo-B addition can increase tensile strength and yield strength also, resulting in higher yield ratio which is undesirable in DP steel. Mo-Al addition can increase

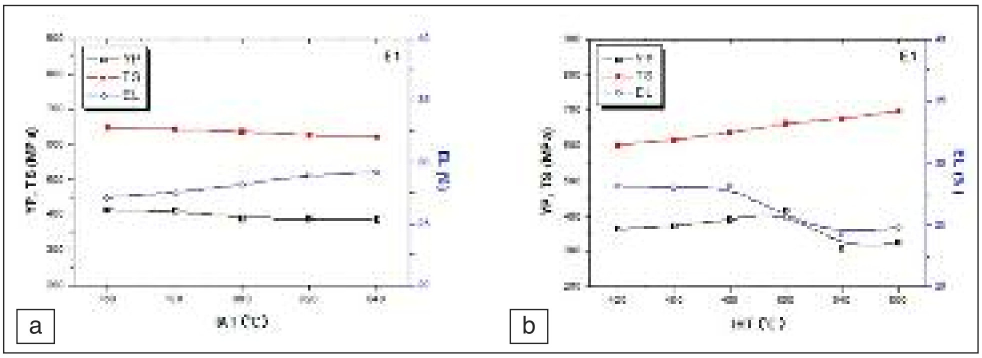


FIG. 7
Mechanical properties of E1 specimen according to a) IAT (at IHT 480°C) and b) IHT(IAT 800°C).

Caratteristiche meccaniche dei provini di acciaio E1 secondo: a) IAT (at IHT 480°C) e b) IHT(IAT 800°C).

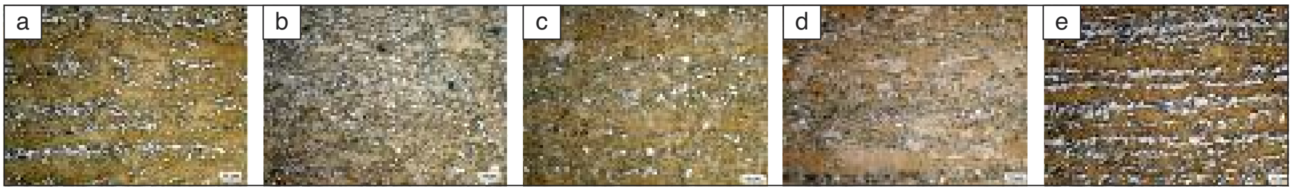


FIG. 8 ***Microstructure of E1 specimen (LePera solution etched, bright white:martensite); (a) IAT 760°& IHT 480°, (b) IAT 800° & IHT 480°, (c) IAT 840° & IHT 480°, (d) IAT 800° & IHT 420°, (e) IAT 800° & IHT 540°.***

Microstruttura dei provini di acciaio E1 (attacco chimico con soluzione LePera, in bianco brillante: la martensite)); (a) IAT 760°& IHT 480°, (b) IAT 800° & IHT 480°, (c) IAT 840° & IHT 480°, (d) IAT 800° & IHT 420°, (e) IAT 800° & IHT 540°.

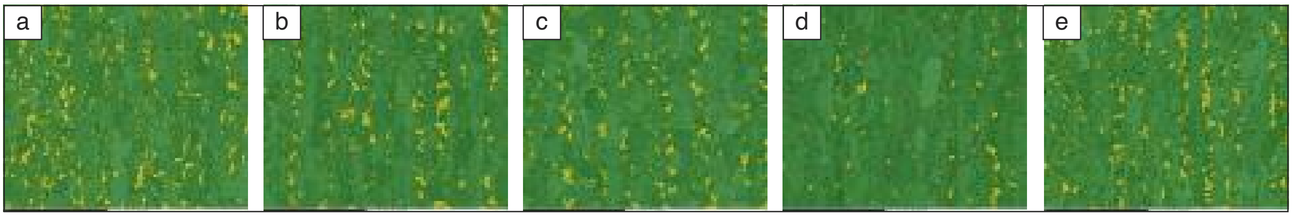


FIG. 9 ***EBSD phase map of E1 specimen5) (yellow:martensite); (a) IAT 760° & IHT 480°, (b) IAT 800° & IHT 480°, (c) IAT 840° & IHT 480°, (d) IAT 800 & IHT 420 , (e) IAT 800° & IHT 540°.***

Mappa di fase con EBSD sul campione E1 (martensite in giallo) (a) IAT 760° & IHT 480°, (b) IAT 800° & IHT 480°, (c) IAT 840° & IHT 480°, (d) IAT 800 & IHT 420 , (e) IAT 800° & IHT 540°.

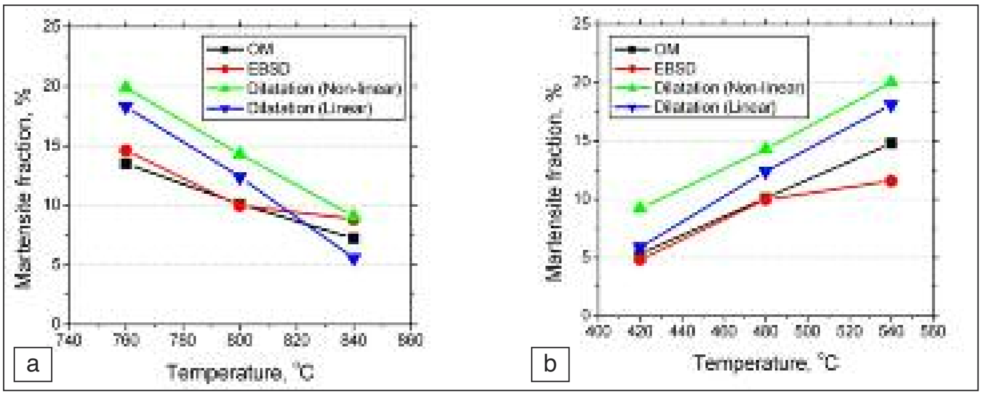


FIG. 10
Martensite volume fraction of E1 specimen according to IAT and IHT; (a) Effect of IAT (b) Effect of IHT.

Frazione in volume della martensite nel provino E1 in funzione di IAT e IHT (a) Effetto di IAT (b) Effetto di IHT.

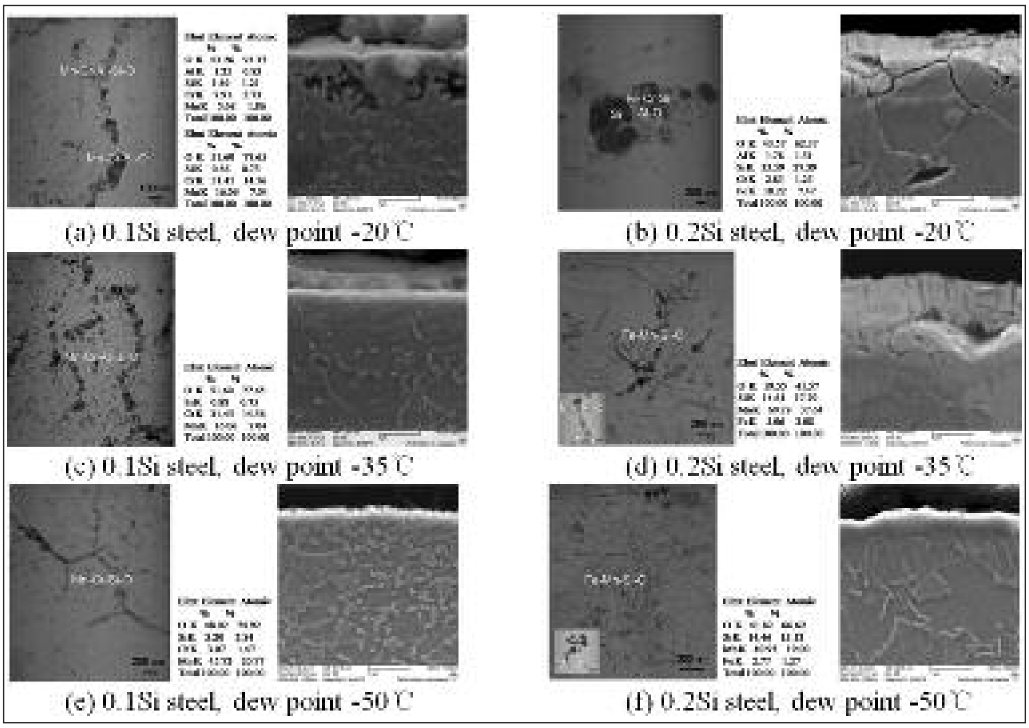
tensile strength, but decrease elongation. Fig. 7 shows the mechanical property according to IAT and IHT.
Martensite volume fraction was evaluated by optical microscope4) and EBSD analysis. Microstructure according to heat treatment was shown in Fig. 8. In accordance with the dilatation results, it is shown that lower IAT and higher IHT makes more martensitic transformation. EBSD results are shown in Fig. 9.
Fig. 10 shows the summary of martensite fraction analysis. Martensite volume fraction of the specimens using optical microscope and EBSD show similar results, whereas non-linear dilatation results2,3) are approximately 5% higher than those. All of these measurements show the same tendency that martensite fraction is increased as IAT is lower and IHT is higher, resulting in higher tensile strength and lower elongation.

Hot dip galvanizability

Surface oxide formed during heat treatment was analyzed by TEM, and crosssection of coating layer was analyzed by SEM. Surface morphology of specimens containing 0.1wt.% and 0.2wt.% Si are annealed in atmosphere with dew point of -20, -35, -50 as shown in Fig. 11.
On the surface of 0.1wt.% Si specimens, macro cracks are found

FIG. 11
TEM of surface oxides and SEM cross-section according to Si concentration and Dew Point.

Ossidi superficiali al TEM e sezione trasversale al SEM in funzione della concentrazione di Si e del Dew Point.



TAB. 2
Surface oxide and wettability according to Si concentration and dew point.

Ossidi di superficie e bagnabilità in funzione della concentrazione di Si e del dew point.

Condition	Welding current (kA)	Applying time (ms)	Pressure (N)	Cycle time (ms)
Test1	6	300	4,500	350
Test2	7	300	5,000	350
Test3	8	350	5,000	400
Test4	9	350	5,000	400
Test5	8	400	5,000	450
Test6	8	400	4,500	450
Test7	9	300	5,000	350

at the dew point of -20 , whereas cracks are diminished at the dew point of -35 . In case of 0.2wt.% Si specimens, cracks are found at the dew point of -20 and -35 . In both cases above, cracks are not found at the dew point of -50 . The cracks are due to the oxides formed along grain boundary, and the oxide and crack become diminished as dew point gets lower.
Table 2 shows the summary of surface oxide analysis result according to Si concentration and dew point. Chemical composition and dew point determine the oxide formed on the surface, thus affect the wettability in molten zinc. When dew point is too low, Si oxide forms preferentially, so that the wetting angle can be increased. In this study, steel with 0.1~0.2wt.% of Si in dew point of -20~-35 were shown to be able to suppress the Si oxide formation, and improve the wettability6).

Weldability
Spot welding test was performed by DC spot welding machine. Table 3 shows the welding condition performed. Many variables such as welding current, applying time, pressure and cycle time was considered. Tensile test of welded specimens showed that the welded spot had enough strength so that the failure occurred in the substrate, not in the welding point.

Press formability (Computational analysis)
Fig. 13 shows the computational analysis result of press forming simulation in actual process condition(500ton press machine, cushion press 8.3ton). Auto-Form software was used in this simulation, and it was shown that strain contour is under the forming limit area. Good formability and surface appearance was confirmed by actual press test as Fig. 13(c).

CONCLUSIONS
In this study, following results are obtained.
1. Influence of heat treatment on the mechanical properties was investigated. Martensite fraction is increased as IAT is decreased and IHT is increased, resulting in higher tensile strength and lower elongation. This result corresponds with the martensite fraction measured by dilation, optical microscope and EBSD analysis.
2. Surface oxides were analyzed by TEM. By reducing Si concentration to 0.1~0.2 wt.%, it was shown to be possible to restrain Si oxide formation on the surface in the annealing atmosphere with dew point of -20~-35 , also possible to enhance the wettability in molten zinc and thus improve galvanizability.
3. 590MPa grade DP steel developed in this study was estimated to have acceptable properties including formability and weldability as automotive outer panel.

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Condition	Welding current (kA)	Applying time (ms)	Pressure (N)	Cycle time (ms)
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Test4	9	350	5,000	400
Test5	8	400	5,000	450
Test6	8	400	4,500	450
Test7	9	300	5,000	350

TAB. 3
Spot welding condition.
Parametri di saldatura a punti.

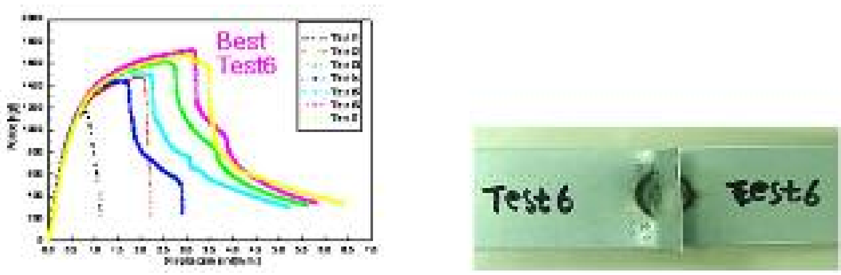

FIG. 12
Tensile test result of spot welded specimens.
Risultati della prova di trazione dei provini sottoposti a saldatura a punti.

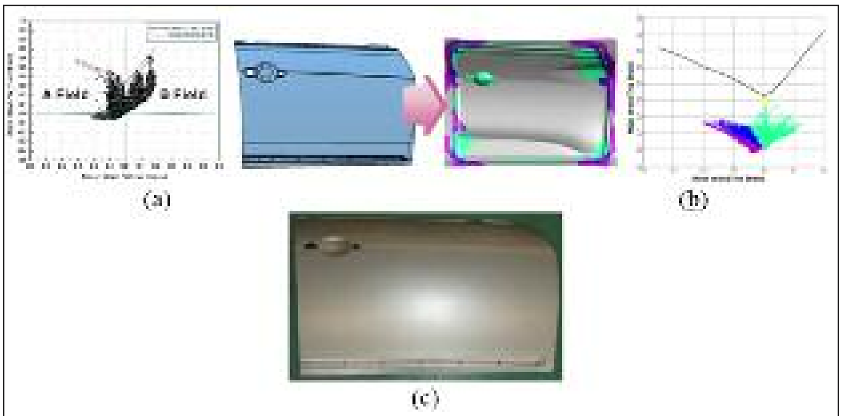

FIG. 13
(a) FLD analysis, (b) CAE simulation of Door Outer and (c) actual press test result.
Analisi FLD (a), simulazione CAE (b) di pannello esterno di portiera e (c) risultati della prova di pressione effettiva.

Abstract

Sviluppo di acciaio 590MPa grado DP GA per impiego nei pannelli esterni degli autoveicoli

Parole chiave:

Recentemente, al fine di soddisfare le esigenze di sicurezza dei passeggeri e i requisiti di riduzione del peso del corpo vettura, sono stati sviluppati acciai ad alta resistenza con elevata formabilità per parti della carrozzeria. Tra questi acciai ad alta resistenza, quelli bifasici (Dual-Phase - DP) sono considerati particolarmente promettenti grazie alle loro eccellenti proprietà meccaniche, segnatamente per la loro elevata resistenza e duttilità.
Tuttavia, i tipici acciai ad alta resistenza contengono elementi di lega che formano un ossido superficiale e ne consegue il deterioramento del comportamento nel trattamento galvanico che, negli acciai ad alta resistenza, è necessaria per ottenere buon comportamento verso la corrosione della carrozzeria.
Le parti tipiche del pannello esterno, per le quali sono necessarie caratteristiche anti-indentazione, sono costituite da gradi di acciaio 340MPa indurito (BH), ma la tendenza verso una carrozzeria più leggera porta ad impiegare acciai con maggiore resistenza nei pannelli esterni. In alcune automobili si inizia ad utilizzare acciaio bifasico di grado 490MPa e l' acciaio bifasico di grado 590MPa è un buon candidato per divenire il materiale futuro per i pannelli esterni. In questo studio, diversi tipi di leghe sono stati prodotti su scala di laboratorio per migliorare le applicazioni galvaniche, e sono state investigati gli effetti sulle proprietà meccaniche delle condizioni di ricottura continua nella CGL. La distribuzione della microstruttura e delle fasi sono stati esaminati mediante SEM, EBSD, TEM ecc.. E' stata condotta una prova di produzione in linea con la composizione chimica dell' acciaio oggetto dello studio. Inoltre sono state eseguite indagini sulla lavorabilità, saldabilità e CAE sul laminato. Attraverso lo studio è stata dimostrata essere possibile la produzione di acciaio bifasico 590MPa galvanizzato con buona formabilità e trattabilità superficiale.