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This Conference is supported by
JSPS KAKENHI Grant Number JP17HP0302 and
Hyuga Memorial Grant for International Conference.

GENERAL INFORMATION

SPEAKER'S INSTRUCTION

1. Time Allotment

Type of Presentation	Presentation	Q & A	TOTAL
Plenary Lecture	40 min.	-	40 min.
Keynote Lecture	30 min. (including Q & A)		30 min.
Invited Lecture	15 min.	5 min.	20 min.
Oral Presentation	15 min.	5 min.	20 min.

2. Equipment

Each presentation room is equipped with

1) LCD Projector with a mini D-sub 15 pin display cable
2) Laser pointer
3) Microphone

Please bring your own laptop PC for presentation and your presentation data by a USB memory stick as a backup. Before the presentation, please make sure that you are familiar with the audiovisual equipment in the session room. A technical staff will be available to help you.

3. Speaker's Seat

Please arrive at your session room by 15 minutes before the session starts. To avoid technical problems, please have your computer checked for the projector connection before the technical session starts. Speakers are requested to be seated at the Speaker's Seat in the front row.

CHAIRPERSON'S INSTRUCTION

1. Chairperson's Seat

Chairpersons are kindly requested to be seated at the chairperson's seat by 15 minutes before the session starts.

2. Chairpersons are requested to check the attendance of speakers of the session. Please let the conference staff know if there are any speakers who do not attend the Chair and Speaker's Meeting.

CHAIR AND SPEAKER'S MEETING

Speakers and chairpersons of Keynote lecture, Invited Lecture and Oral presentation are requested to attend the Chair and Speaker's Meeting on the day of the session that you will present or chair. Light meals will be served at the meeting.
Place: Room ***"Gallery2"*** of Ito International Research Center

Session date	Session code		Meeting date	Meeting time	Meeting place
Nov. 13 (Mon)	A-1, B-1, C-1, D-1	→	Nov. 13 (Mon)	8:00 am - 9:00 am	Gallery2 (B1F)
	A-2, B-2, C-2, D-2 A-3, B-3, C-3, D-3	→		12:40 am - 1:40 pm	
Nov. 14 (Tue)	A-4, B-4, C-4, D-4	→	Nov. 14 (Tue)	7:45 am - 8:30 am	
	A-5, B-5, C-5, D-5 A-6, B-6, C-6, D-6	→		12:20 am - 1:20 pm	
Nov. 15 (Wed)	A-7, B-7, C-7, D-7	→	Nov. 15 (Wed)	8:00 am - 9:00 am	

BANQUET

Place: Hotel Chinzanso Tokyo (P.5)
Time: 19:00-21:00, November 14, 2017
Buses from the University of Tokyo to Chinzanso will be available. Departure Time: 5:30PM - 6:15 PM

POSTER AWARD

Poster Award will be offered to the outstanding posters.1 paper will be selected as the "Best Poster Award" and 9 papers will be selected as the "Excellent Poster Award". The awardees will be announced during the Banquet on November 14th, and will be given prize money.
Prize Money: Best Poster Award – JPY 30,000, Excellent Poster Award – JPY 10,000

PLANT TOUR

The plant tour has been cancelled.

NAME BADGE

All participants must register and wear their name badges during the conference.

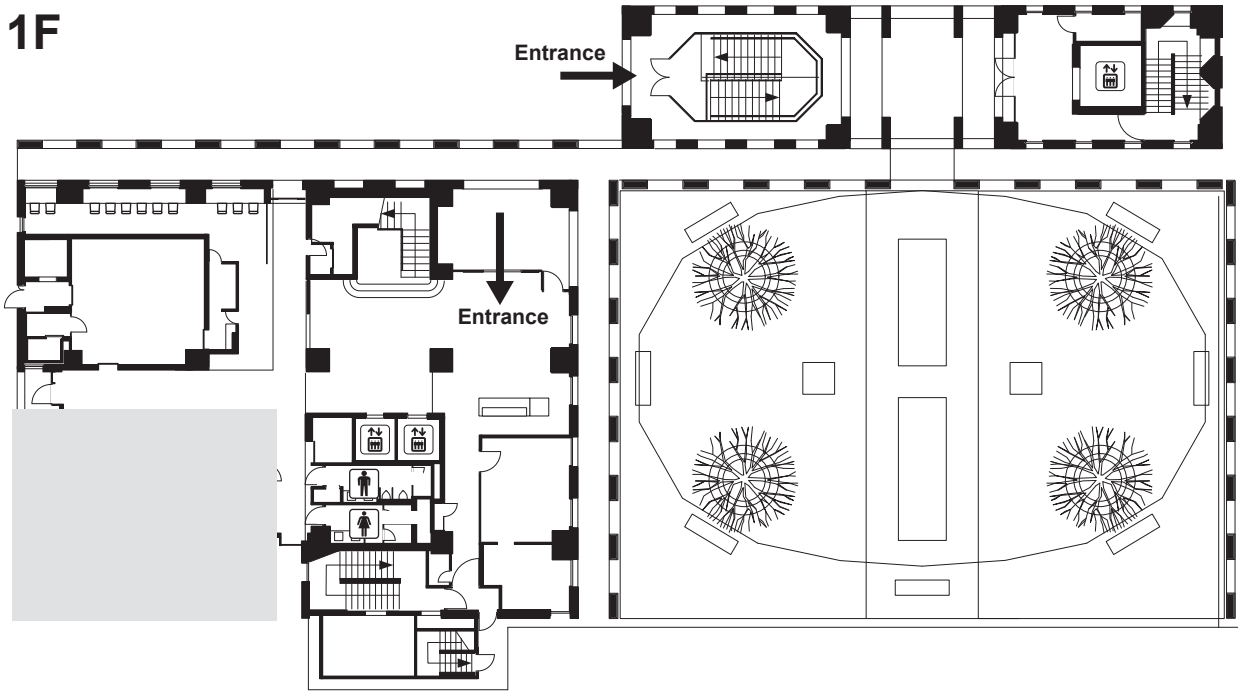
RECORDING

Cameras and any other recording devices are not permitted, unless done by the staff.

FLOOR PLAN

(Ito International Research Center)

1F



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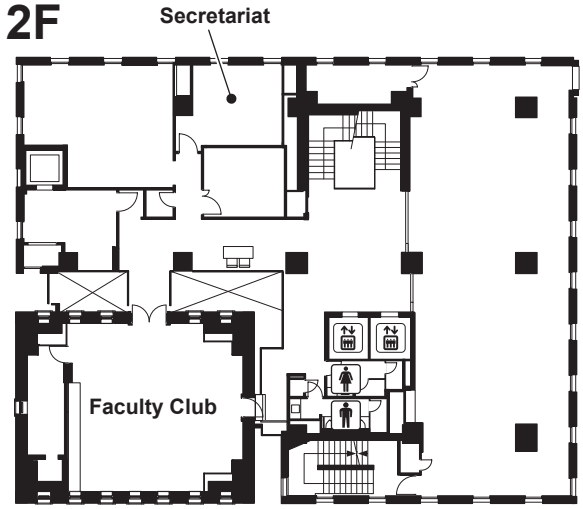

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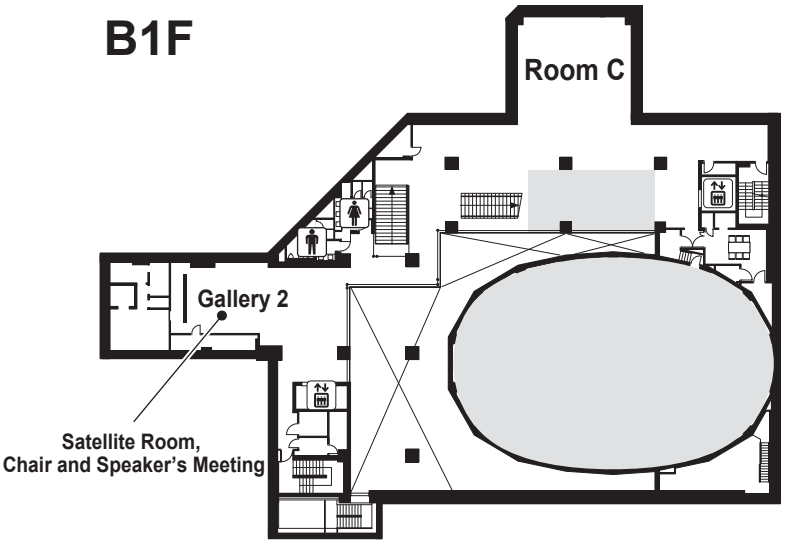

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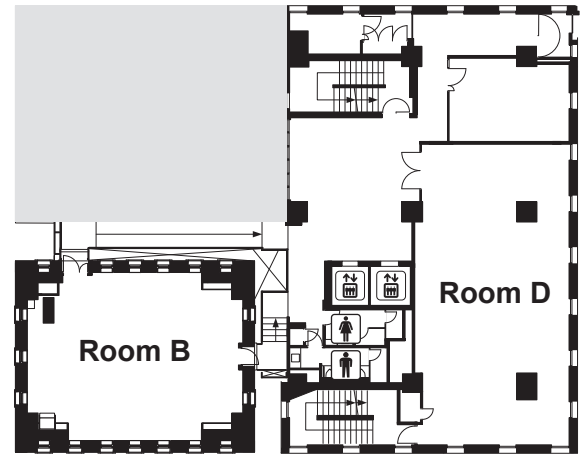

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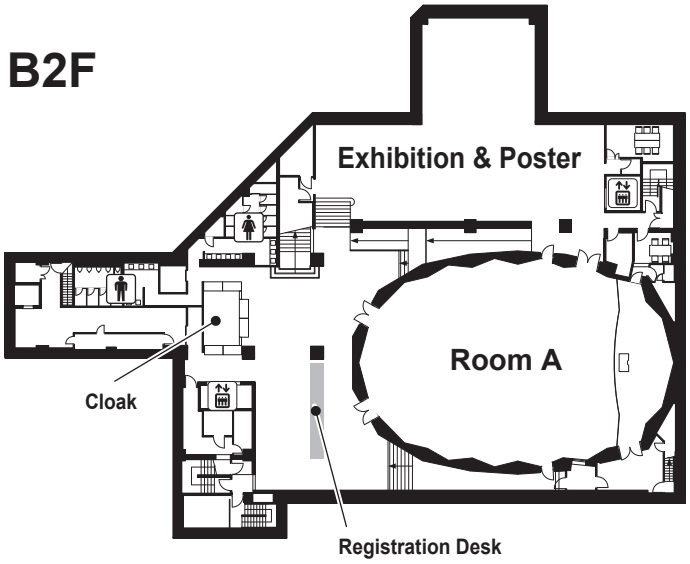

EMERGENCY ROUTE

In case of emergency, please leave the building via the nearest escape route.

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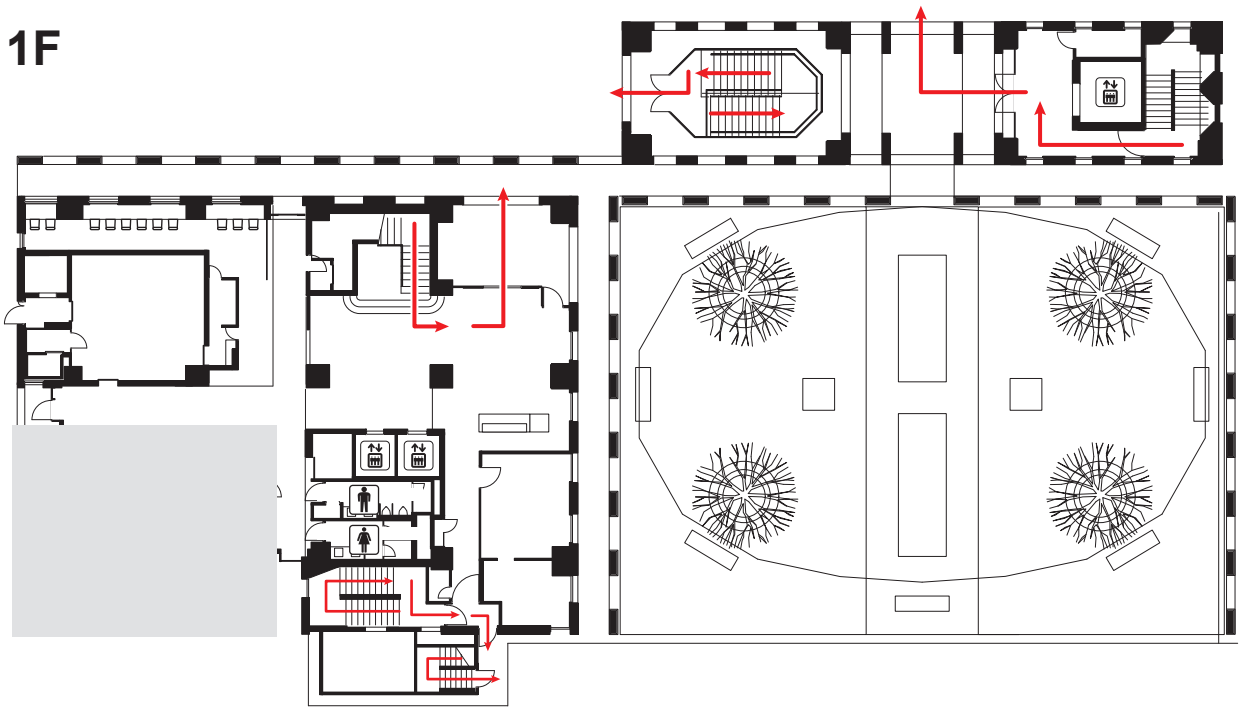

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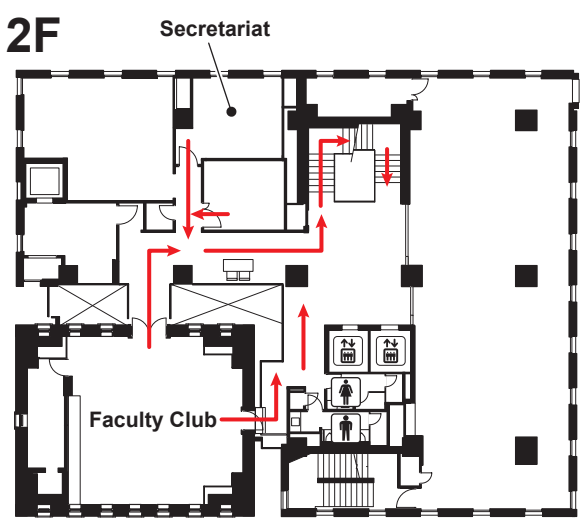

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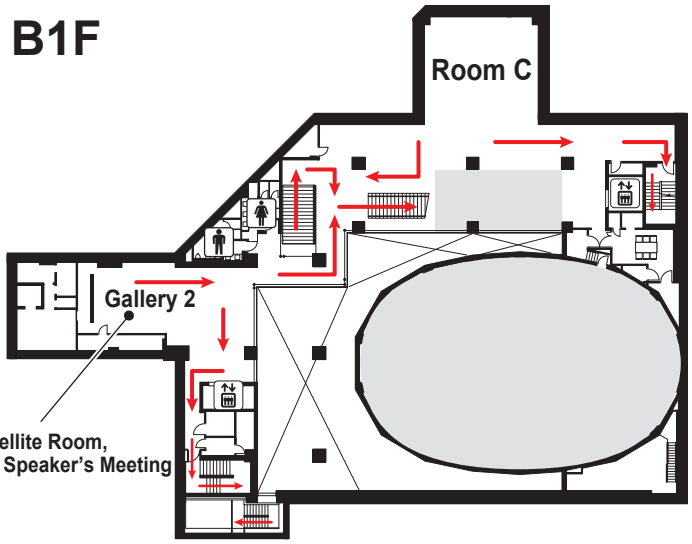

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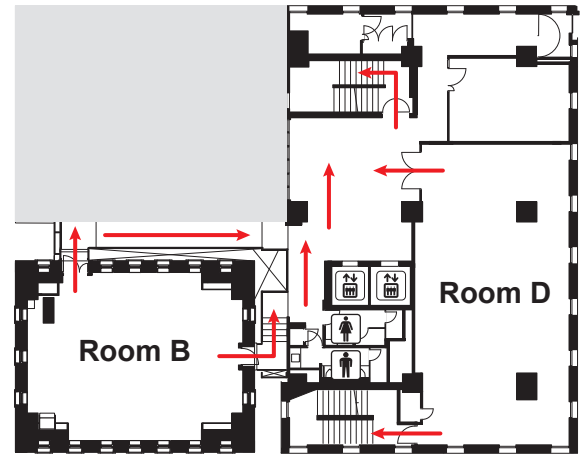

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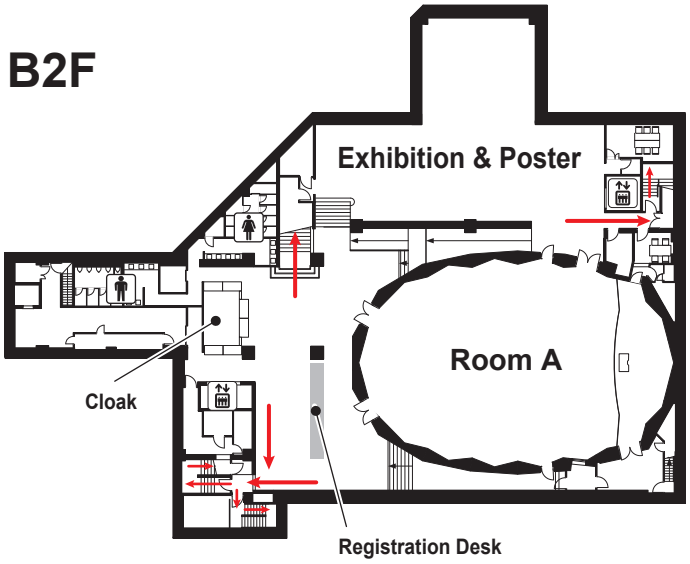

EXHIBITION & POSTER

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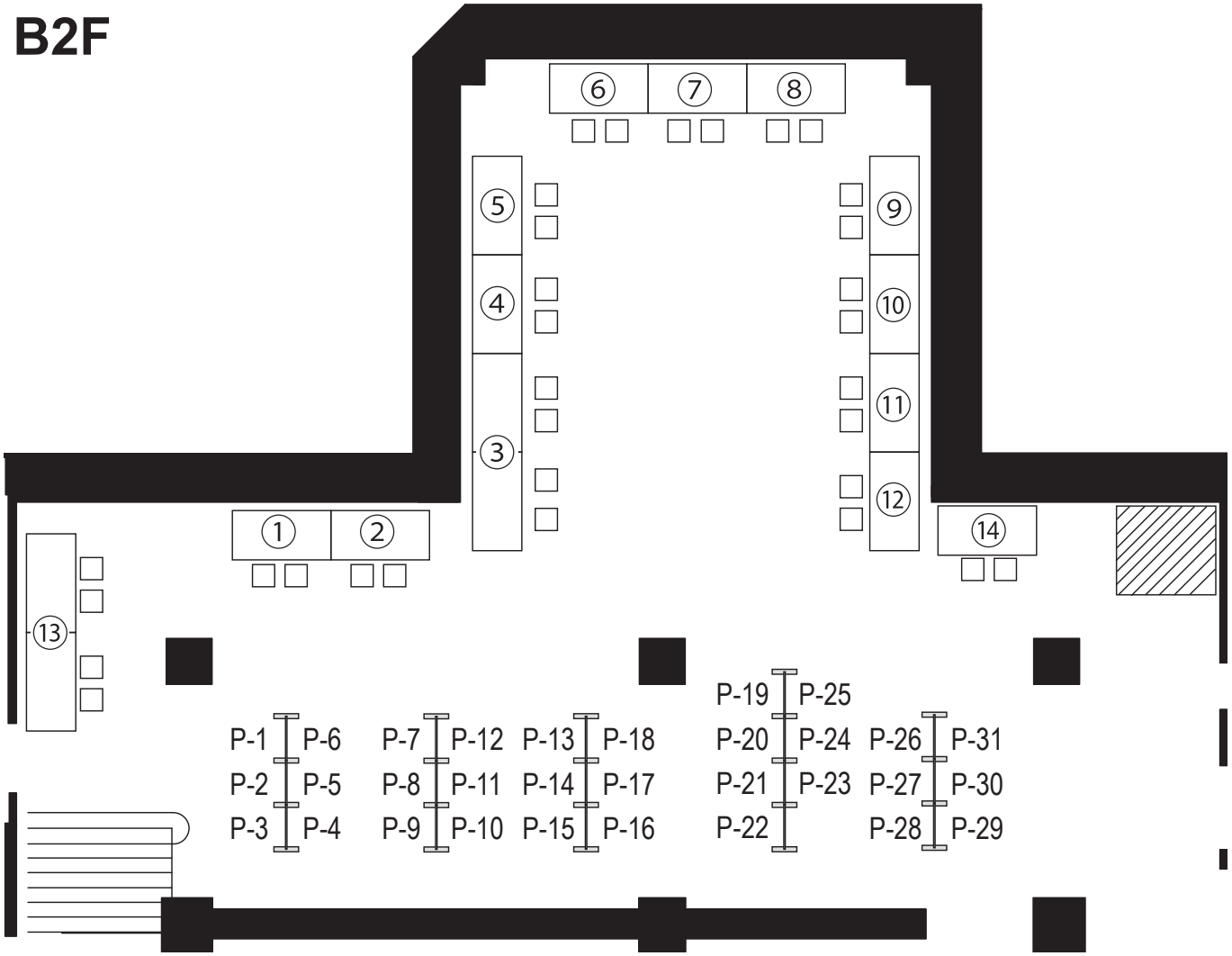
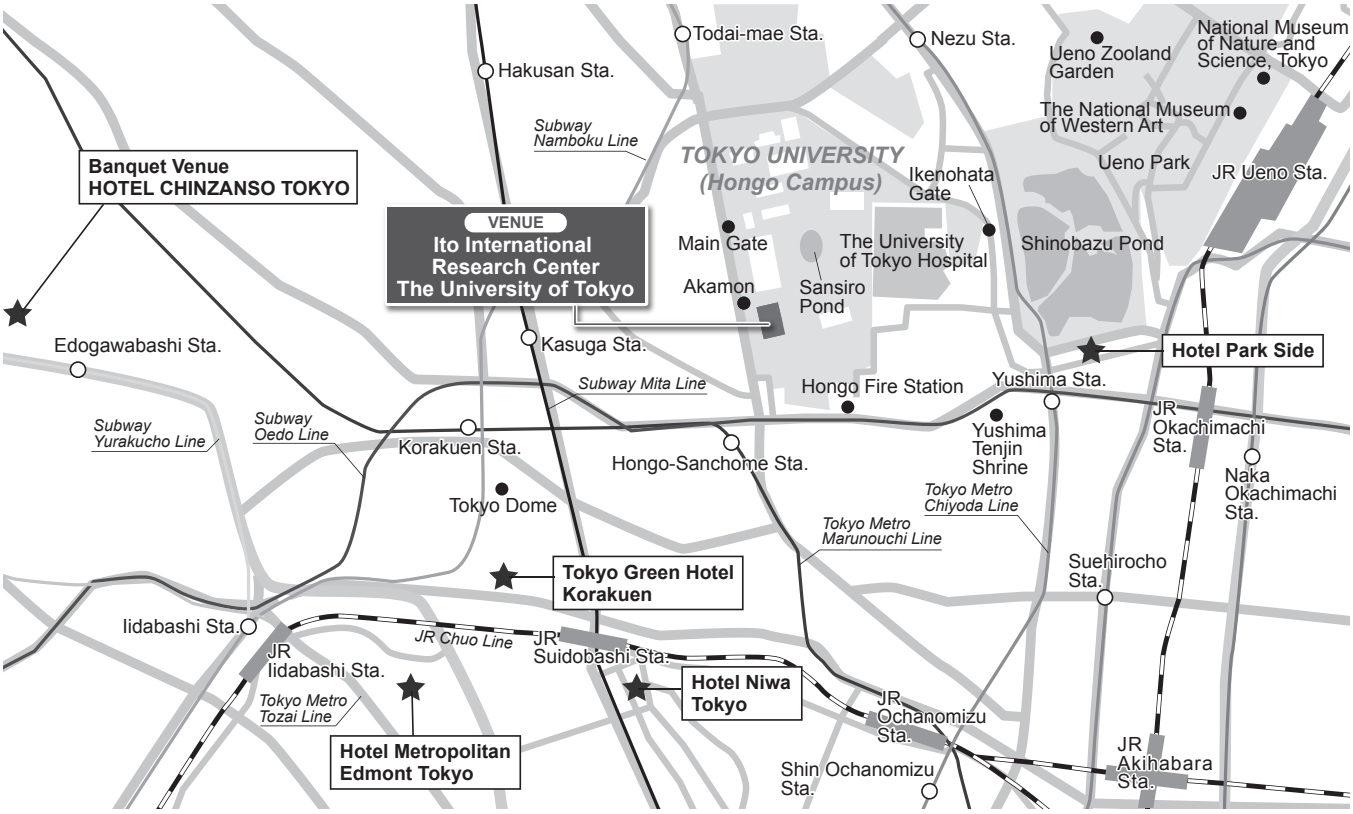


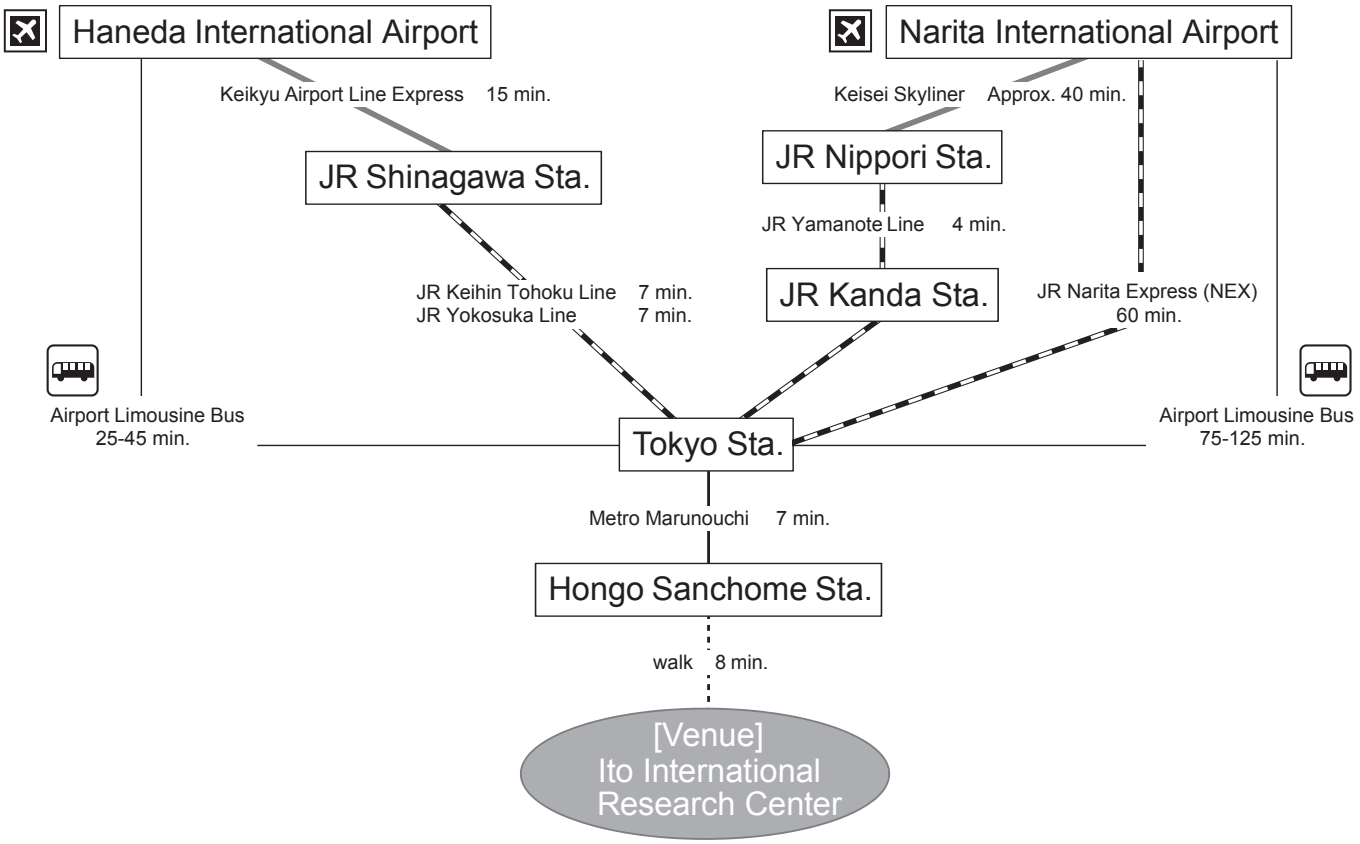
Booth No.	Exhibitor
①	SAMWOO ECO CO.,LTD.
②	Praxair Surface Technologies K.K.
③	TECNAR
④	IMS / NIRECO
⑤	KOBELCO RESEARCH INSTITUTE, INC.
⑥	NIPPON PAINT SURF CHEMICALS CO., LTD.
⑦	TOYO Corporation / Bio-Logic SAS
⑧	Rigaku Corporation
⑨	JFE Techno-Research Corporation
⑩	Bisson Impianti Industriali S.r.l
⑪	JEOL Ltd.
⑫	NIPPON STEEL & SUMIKIN TECHNOLOGY
⑬	QUINLOGIC
⑭	Ajax Tocco Magnethermic Japan Co., LTD.

CONFERENCE VENUE



Nearest station (Subway)	Time required
Hongo-sanchome (Marunouchi Line)	8 minutes' walk
Hongo-sanchome (Oedo Line)	6 minutes' walk
Kasuga (Mita Line)	10 minutes' walk

Access from Airports



TIME SCHEDULE

November 12, Sunday	(Faculty of Engineering Bldg. 4, The University of Tokyo)
10:30-17:00 **Tutorial Lectures** (Room 419)	
	(Ito International Research Center, The University of Tokyo)
16:00-19:00 **Registration** (2nd Basement)	
17:00-19:00 **Welcome Party** (2nd Basement)	

November 13, Monday			(Ito International Research Center, The University of Tokyo)	
8:15-17:50 **Registration** (2nd Basement)				
Room A (2nd Basement)	**Room B** (3rd Floor)	**Room C** (1st Basement)	**Room D** (3rd Floor)	**Poster** (2nd Basement)
9:00-9:30 **Opening Ceremony**				
9:30-10:50 **Plenary Lectures**				
Break				
11:10-12:40【**A-1**】 **Evaluation Methods**	11:10-12:40【**B-1**】 **AHSS, IH, Alloy Plating**	11:10-12:40【**C-1**】 **Metallic Coating on Advanced High-strength Steels I**	11:10-12:40【**D-1**】 **Automotive Applications I**	
Lunch time				
14:00-15:30【**A-2**】 **Thermodynamics, Phase Stability I**	14:00-16:00【**B-2**】 **Air Knife, Quality Control**	14:00-15:00【**C-2**】 **Metallic Coating on Advanced High-strength Steels II**	14:00-15:50【**D-2**】 **Automotive Applications II**	
Break				
15:50-17:20【**A-3**】 **Thermodynamics, Phase Stability II**	16:20-17:50【**B-3**】 **Conversion Coatings and Pre-painted Steels**	15:20-17:10【**C-3**】 **Metallic Coating on Advanced High-strength Steels III**	16:10-17:30【**D-3**】 **Automotive Applications III**	
Break				
				18:00-19:00 **Poster Session**

November 14, Tuesday			(Ito International Research Center, The University of Tokyo)	
8:00-17:30 **Registration** (2nd Basement)				
Room A (2nd Basement)	**Room B** (3rd Floor)	**Room C** (1st Basement)	**Room D** (3rd Floor)	**Poster** (2nd Basement)
8:30-9:50 **Plenary Lectures**				
Break				
10:10-12:20【**A-4**】 **Corrosion Behavior**	10:10-12:00【**B-4**】 **Selective Oxidation**	10:10-12:20【**C-4**】 **Corrosion I**	10:10-12:20【**D-4**】 **Structural Analysis and Property**	
Lunch time				
13:40-15:30【**A-5**】 **Microstructure, Physical Properties I**	13:40-15:00【**B-5**】 **Hot Stamping of Coated Steels**	13:40-15:40【**C-5**】 **Corrosion II**	13:40-15:10【**D-5**】 **Wettability and Surface Quality**	
Break				
15:50-17:30【**A-6**】 **Microstructure, Physical Properties II**	15:40-17:10【**B-6**】 **Forming and Joining Technologies**	16:00-17:30【**C-6**】 **Interfacial Reaction**	15:30-17:30【**D-6**】 **Electrogalvanizing and Dross Control**	
Break				
19:00-21:00 **Conference Banquet** (Hotel Chinzanso Tokyo)				

November 15, Wednesday			(Ito International Research Center, The University of Tokyo)	
8:30-12:00 **Registration** (2nd Basement)				
Room A (2nd Basement)	**Room B** (3rd Floor)	**Room C** (1st Basement)	**Room D** (3rd Floor)	**Poster** (2nd Basement)
9:00-10:20 **Plenary Lectures**				
Break				
10:40-12:10【**A-7**】 **Microstructure, Physical Properties III**	10:40-12:20【**B-7**】 **Air Knife**	10:40-12:50【**C-7**】 **Corrosion III**	10:40-12:40【**D-7**】 **Heat Cycle and Temprature Control**	

Opening Ceremony

Date: Monday, November 13
Time: 9:00-9:30
Venue: Room A
Chair: Sakae Fujita (JFE Techno Research Corporation, Japan)

Shu Yamaguchi
Chairperson, Organizing Committee
The University of Tokyo, Japan

Noboru Masuko
The University of Tokyo, Japan

Plenary Lectures

Date: Monday, November 13
Time: 9:30-10:50
Venue: Room A
Chair: Frank Erik. Goodwin (International Zinc Association, USA)

Plenary Lecture 1 9:30
RECENT PROGRESS AND OUTLOOK FOR ZINC- AND ZINC ALLOY-COATED STEEL SHEETS IN JAPAN

Kazuhiro Seto
JFE Steel Corporation, Japan

Recent progress and the future outlook for zinc- and zinc alloy-coated steel sheets in Japan are outlined, focusing on new products and their back ground technologies. Breakthrough technologies developed in Japan respond to the demands for the suppression of CO_2 emission, environmental protection, information-oriented society and cost-saving. These demands will continue and development of zinc-saving technologies will still be an important issue in the future.

Plenary Lecture 2 10:10
CRYSTAL STRUCTURE AND MECHANICAL PROPERTIES OF INTERMETALLIC COMPOUNDS IN THE Fe-Zn SYSTEM IN THE COAT LAYER OF GALVANIZED STEEL

Haruyuki Inui[1], Norihiko L. Okamoto[1,2]
[1]Kyoto University, Japan, [2]Now at Tohoku University, Japan

We investigate the crystal structure of all intermetallics of the Fe-Zn system by synchrotron X-ray diffraction combined with atomic-resolution scanning transmission electron microscopy, in order to elucidate a basic principle based on which these crystal structures are constructed. Then, we discuss the plastic deformation behavior of these intermetallics, referring to the basic principle of crystal structure construction.

A-1 Evaluation Methods

Date: Monday, November 13
Time: 11:10-12:40
Venue: Room A
Chairs: Achim Walter Hassel (Johannes Kepler University Linz, Austria)
Daisuke Mizuno (JFE Steel Corporation, Japan)

A-1-1 *Keynote* 11:10
APPLICATION OF SCANNING KELVIN PROBE FOR IN-SITU STUDIES OF HYDROGEN PERMEATION IN STEEL

Dominique Thierry, Flavien Vucko, Andrej Nazarov
Institut de la Corrosion / French Corrosion Institute, France

Hydrogen entry conditions during corrosion processes were characterized using the scanning Kelvin probe technique. By this method, the spreading of hydrogen from a local source was visualized on a steel surface. Hydrogen was obtained either by a local galvanic coupling with the zinc coating in the presence of a defect, or by the formation and accumulation of corrosion products, with local acidification under the rust. The diffusion coefficient can be estimated from the potential maps obtained by scanning Kelvin probe.

A-1-2 *Invited* 11:40
EVALUATION OF HYDROGEN ABSORPTION INTO STEEL SHEET IN AUTOMOBILE MOVING ENVIRONMENTS

Shinji Ootsuka
JFE Steel Corporation, Japan

Temperature-compensating hydrogen absorption monitoring system was applied to investigate a behavior of hydrogen absorption into steel in corrosive environments where deicing salt were sprayed. The slack changes of the hydrogen permeation current were observed during long-term parking of the vehicle. These changes indicated that the hydrogen permeation current is influenced by temperature and humidity. On the other hand, drastic changes in hydrogen permeation current were observed when the vehicle was frequently driven. These changes implied that driving state also affects hydrogen permeation current, in particular whether salt contaminated water is splashed from the road or not. Hydrogen absorption behavior into steel sheets in actual use environments has been characterized and clarified.

A-1-3 12:00
SVET-TLI: A NOVEL COMBINATION OF SCANNING VIBRATING ELECTRODE TECHNIQUE AND TIME-LAPSE IMAGING FOR STUDYING THE LOCALISED CORROSION OF SACRIFICIAL ZINC COATINGS

Rebecca Bolton, Justin Searle, Geraint Williams
Swansea University, UK

The integration of in-situ time-lapse imaging with a scanning vibrating electrode technique (SVET) has been successfully achieved by attaching a waterproof camera to the SVET probe assembly via a custom 3D printed friction clamp. The resulting data reveals a strong correlation between the visual evolution of corrosion features with the relevant current density distribution maps obtained via SVET. This paper will compare the corrosion mechanisms of pure zinc coatings produced via traditional hot-dip galvanising, electrogalvanising and physical vapour deposition using this method. It is shown that hot-dip galvanised zinc coatings

promote strong focal anodes with rapid initiation and steady, radial growth. In contrast, anodic features on both EZ and PVD occupy larger areas, with lower anodic current density values. However, systematically varying the concentration of NaCl within the electrolyte promotes significant changes in localised corrosion propagation and physical nature of observed corrosion features for all three coatings.

A-1-4 12:20

IN-SITU TIME-LAPSE MICROSCOPY TO ELUCIDATE THE CORROSION MECHANISM OF ZN-4.8WT.%AL GALVANISING METALLIC COATING; SURFACE AND CUT-EDGE

Callum Gallagher[1], Nathan Cooze[1], James Sullivan[1], Patrick Dodds[2], Peter Barker[2]
[1]Swansea University, UK, [2]TATA Steel, UK

The fundamental corrosion mechanisms on the surface and cut-edge of Zn-4.8wt.%Al galvanising coating have been investigated using an in-situ time-lapse microscopy technique that permits the investigation of the initiation and propagation of corrosion in alloys at a microstructural level. This alloy coating had a microstructure comprised of Zn rich primary dendrites and a lamellar Zn-Al binary eutectic phase. The coating was metallurgically prepared for optical light microscopy and immersed in 1 wt.% NaCl at pH 7 and left for 24 hours with images of the alloy captured every 2 minutes. The images, then rendered into a video, show the initiation of anodic and cathodic sites on the alloy's surface at specific phases within the microstructure and their progression with time providing new insights into the corrosion mechanism. It was seen that during surface corrosion initiation and propagation of corrosion occurs in the binary eutectic (Zn-Al) regions of the microstructure. In contrast, during cut-edge corrosion where the coating galvanically protects exposed steel the site of initiation is in the primary zinc dendritic phase. It is postulated that the mechanism of surface corrosion is due to the electronic properties of the surface oxides associated with Zn and Al containing phases. As zinc oxide is more conductive than the alumina formed on the surface, the path for electron transfer is easiest via the zinc oxide making the areas associated with the Zn dendritic phase more likely to act as the site of cathodic activity (oxygen reduction). The change in mechanism during cut-edge corrosion is thought to be due to the galvanic polarisation of the system where the exposed steel now acts as the primary site for cathodic oxygen reduction and the zinc dendrites become the initial focus of anodic metal dissolution. The path of anodic growth is also shown to follow and accelerate through the primary zinc dendrites.

A-2 Thermodynamics, Phase Stability I

Date: Monday, November 13
Time: 14:00-15:30
Venue: Room A
Chairs: Danie Liu (Teck Metals Ltd., Product Technology Centre, Canada)
Junya Inoue (The University of Tokyo, Japan)

A-2-1 *Keynote* 14:00

PHASE EQUILIBRIA IN THE Fe-Al BINARY ALLOY SYSTEM

Ryosuke Kainuma[1], Kwangsik Han[1], Ikuo Ohnuma[2]
[1]Tohoku Universityi, Japan, [2]National Institute for Materials Science (NIMS), Japan

Information of the Fe-Al binary alloy phase diagram is very important, not only for Al plating on steel, but also for galvanizing, because the Fe-Al inhibition layer formed at the interface with the steel plays an important role in the formation of the Fe-Zn intermetallic compounds in the plating layer. In this paper, recent investigations on the phase equilibria in the Fe-Al system are reviewed and the newest version of the Fe-Al phase diagram is presented.

A-2-2 14:30

HARDNESS OF INTERMETALLIC COMPOUNDS IN THE ZN-FE BINARY SYSTEM

Kwangsik Han[1], Ikuo Ohnuma[2], Kaneharu Okuda[3], Ryosuke Kainuma[1]
[1]Tohoku University, Japan, [2]National Institute for Materials Science (NIMS), Japan, [3]JFE Steel Corporation, Japan

Hardness of intermetallic compounds (IMCs) in Zn-rich portion of the Zn-Fe binary system was re-examined for corresponding microstructures prepared by the alloying method. Obtained results were compared with the literature data measured for the intermetallic compound layers appeared in the hot dipping method at 450 ºC. The hardness of each IMC equilibrated at 450ºC shows a similar tendency to the literature data. The δ_{1k} and δ_{1p} phases were distinguished in this study and their hardness was newly measured, from which the hardness of the ordered-δ_{1k} is higher than that of the disordered-δ_{1p}. Formation of slip bands and peelings around Vickers indentations marked on the IMC phases suggests that the Γ phase has moderate ductility.

A-2-3 14:50

EFFECT OF AL ON THE Ni-Zn PHASE FORMATION IN PRIOR-NI COATED GALVANIZED STEELS

Avik Mondal[1], Anindita Chakraborty[1], Arup Kumar Halder[1], S B Singh[2], Monojit Dutta[1]
[1]Tata Steel, India, [2]Indian Institute of Technology, India

Prior metallic coating before galvanizing has gained much interest because of their influence on improving the galvanized coating property. Prior-Ni coated galvanized steels have been found to improve the coat–ability of AHSS, corrosion resistance of galvanized coatings, control on coating thickness etc. Instead of Fe-Zn phases, Ni-Zn phases forms on the substrate where a thick Prior-Ni coating has been applied. Most of the researches have been focused on the Ni-Zn phase formation in pure Zn bath. In the present study Influence of Al on the Ni-Zn phase formation has been studied. Gibbs energy variation with composition has been

calculated using TermoCalc. The nucleation rate of Ni-Zn phases and the final microstructure have been found to be dependent on the Al concentration of the Zn bath. The coating has been characterised by Scanning Electron Microscope (SEM), Energy Dispersive Spectroscopy (EDS), Electron Probe Micro Analyser (EPMA) and Wavelength Dispersive Spectroscopy (WDS). Aluminium has been found to affect the phase formation kinetics of prior-Ni coated galvanized steels. It affects the nucleation rate of different intermetallic phases such as $NiAl_3$, Ni-Zn delta, Ni-Zn gamma phase etc. Thus the coating microstructure and morphology of the prior-Ni coated galvanized steel has been found to change with Al content in the bath. This study has been focused to understand the phase formation mechanism in prior-Ni coated galvanized steel.

A-2-4 15:10
NEW INSIGHTS IN INTERMETALLIC PHASES AND INTERFACES BETWEEN AL-ALLOYS AND STEEL AND POSSIBLE IMPACT ON IN-USE PROPERTIES

Babs Lemmens[1], Hauke Springer[2], Beril Corlu[3], Joost De Strycker[3], Iris De Graeve[4], Kim Verbeken[1]
[1]Ghent University, Belgium, [2]Max-Planck-Institut für Eisenforschung GmbH, Germany, [3]ArcelorMittal Global R&D Gent, Belgium, [4]Vrije Universiteit Brussel, Belgium

During the dipping of steel in molten Al interdiffusion occurs, giving rise to the formation of intermetallic phases (IMPs). The main challenge is reducing the thickness of the IMPs as they are hard and brittle, which can induce cracking and peeling of the coating. In industrial aluminizing processes, Si is commonly added to the Al bath to reduce the thickness of the IMPs. The mechanism of how Si reduces the thickness of the IMPs still remains under debate. The aim of the work is to give new insights in the mechanism of this growth retardation. Nanoscale investigations were performed to investigate the location of Si in hot-dip aluminized steel by using atom probe tomography (APT). The crystallographic phases were identified in cross section using EBSD. In a second step the effect of the IMPs on the in-use properties was evaluated on a microscopic scale. Scanning Vibrating Electrode Technique (SVET) was able to evaluate the electrochemical properties of the IMPs and from this it was possible to deduce the impact on the corrosion performance of the coating. Finally, the link between the IMPs and the deformation behavior of the coating was investigated. To enable these two setups were used: standard tensile testing to evaluate the outer surface and micro-tensile testing with digital image correlation (DIC) to visualize the local strain.

A-3 Thermodynamics, Phase Stability II

Date: Monday, November 13
Time: 15:50-17:20
Venue: Room A
Chairs: Joost De Strykcer (ArcelorMittal Global R&D, Belgium)
Kwangsik Han (Tohoku Univeristy, Japan)

A-3-1 *Keynote* 16:10
THERMODYNAMIC ASSESSMENT OF THE Zn-Al-Fe-Mn QUATERNARY SYSTEM IN THE Zn CORNER

Daniel Y.H. Liu, Neil Gao
Teck Metals Ltd., Canada

The high Mn content in advanced high-strength steels (AHSS) adds one more degree of freedom to the Zn-based alloy system in the galvanizing process. A number of new phenomena observed in the galvanizing production of AHSS need to be understood using a quaternary Zn-Al-Fe-Mn system. A preliminary computational thermodynamic assessment (CALPHAD) of this quaternary system in the Zn corner was performed in the present study using the prior experimental measurements conducted by the undersigned. Sixteen sets of data with multiple phase equilibria involving the liquid phase, Fe_2Al_5, δ_{Mn} and δ_{Fe} phases at 445°C, 460°C and 480°C were evaluated. An additional twenty sets of Zn bath chemistry analysis results with various Al, Fe and Mn contents at the three different temperatures were also included in the evaluation. Sub-lattice models of the aforementioned key intermetallic compounds were proposed. Their corresponding excess Gibbs energy values, expressed in Redlich-Kister polynomial functions, were optimized. Effects of Mn on galvanizing reactions were also discussed.

A-3-2 *Invited* 16:40
MICROSTRUCTURE AND TOUGHNESS OF FE-ZN INTERMETALLIC COATINGS OF GALVANNEALED STEEL SHEET

Junya Inoue
The University of Tokyo, Japan

The effect of the microstructures of Fe-Zn intermetallic compounds on their toughness was studied using newly developed method based on fracture mechanics principles, and fracture behavior of multilayered Fe-Zn intermetallic coating was further investigated to clarify the mechanism of enhanced formability of Fe-Zn intermetallic coatings. Fe-Zn intermetallic compound layers were fabricated on a low-carbon steel sheets by either hot-dipping process or Fe/Zn diffusion couple, and various microstructures were prepared by changing the process temperature and holding time. From the mono-layered samples, the toughness of each intermetallic compound was evaluated. From the multilayered samples the fracture behavior of the intermetallic compound coatings was investigated. It was clarified that the fracture toughness of Γ is far less as compared to δ_p, because of the weak grain boundaries. Whereas the weak grain boundaries of Γ were also found to deflect delamination crack effectively to steel substrate, and thus retards delamination of coating layer under large deformation and enhance coating formability.

A-3-3 17:00
SIMULATION OF OXIDATION OF SELECTED ADVANCED HIGH STRENGTH STEELS DURING ANNEALING PRIOR TO GALVANIZING

Weichen Mao[1,2], Johannes C. Brouwer[1], Wanda Melfo[3], Marga Zuijderwijk[3], Johannes Winter[3], Willem G. Sloof[1]
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The oxidation behaviour of selected Mn and Mn-Cr alloyed steels is simulated with a newly developed coupled thermodynamic-kinetic internal oxidation model. The type and amount of internal oxides as well as the alloy composition as a function of depth below the surface after annealing are predicted considering annealing temperature profiles of industrial galvanizing lines and ambient dew points. The simulations show that the Mn and Mn-Cr alloyed steels are oxidized internally at dew points of -10 and 10 °C, but externally at dew point of -30 °C. The kinetics of internal oxidation increases with temperature while the concentration

of internal oxide precipitates is independent of temperature and time. However, when annealing at a dew point of -30 °C the enrichment of oxide near surface significantly increases with temperature and time. Transformation from austenite to ferrite increases the kinetics of internal oxidation at high annealing dew points and promotes oxide enrichment at steel surface at dew point of -30 °C.

A-3-4 17:20
PHASE TRANSFORMATION IN GALVANISED COATINGS ON PRE-COATED STEEL

Anindita Chakraborty[1], Avik Mondal[1], Poojari Govardhana[2], Tapas Laha[2], ShivBrat Singh[2], Monojit Dutta[1]
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Hot dip galvanising of prior metallic coated steel sheets has gained significant importance over the last decade. The coating process is performed in two stages, e.g. deposition of a metallic layer such as iron, copper, nickel or their alloys on the pickled steel substrate followed by either continuous or batch galvanising process. The prior metallic layer is capable of reducing the bare spot defect in high strength steels by suppressing the surface segregation of alloying elements in steel during recrystallization annealing treatment. Furthermore, the galvanised coating quality can be significantly improved in terms of coating thickness, coating porosity, corrosion performance etc. for continuous as well as batch galvanised coatings. The present study deals with the microstructural evolution of coating phases for prior nickel coated steels. The effect of initial nickel coating thickness and the time of immersion during hot dipping were investigated. The dissolution behaviour of nickel in molten zinc bath and subsequent phase transformation were studied. Glow Discharge Optical Emission Spectroscopy (GDOES), cross sectional Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS) results revealed the microstructure and compositions of different phase layers. Additionally, cross sectional elemental mappings were generated using Electron Probe Micro Analyzer (EPMA) and Wavelength Dispersive Spectroscopy (WDS). The coating thickness was drastically reduced upon applying the nickel layer as compared to the bare steel. It has been found that beyond a certain thickness of prior nickel coating, Ni-Zn phases rather than the Fe-Zn phases are formed.

B-1 AHSS, IH, Alloy Plating

Date: Monday, November 13
Time: 11:10-12:40
Venue: Room B
Chairs: Thomas Moertlbauer (voestalpine Stahl GmbH, Austria)
Takeshi Watase (Kobe Steel, Ltd., Japan)

B-1-1 *Keynote* 11:10
CHALLENGES, INNOVATION AND DESIGNS IN GALVANIZING TECHNOLOGIES FOR AHSS

Michel Dubois, Brice Vanhoutte
CMI INDUSTRY Metals, Belgium

Steel grades requiring galvanizing have dramatically changed in the last 20 years going from simple CQ for construction to ultra high strength Dual Phase grades up to 1100-1220 MPa. At the same time there are different requirements for the condition of these grades such as extra soft and deep drawing qualities. These requirements have led to key modifications and improvements that are reviewed. Furnaces must accommodate new heat cycles, some with annealing temperatures over 900°C. Fast cooling to various temperatures are sometimes followed by “aging” sections. Surface oxidation must be controlled to achieve good wettability. Mg-added coatings offer the chance to lower the quenching temperatures. Improvement in strip conveying as well as temper mill surface texturing and tension levelling of new grades is also addressed.
Final words are given on the expected new products that may come soon such as thinner and wider sheet requirements for sandwiches construction, bainitic grades and medium manganese compositions.

B-1-2 *Invited* 11:40
JET VAPOUR DEPOSITION: COATINGS STEELS OF THE FUTURE

Cécile Pesci[1], Luc Diez[1], Daniel Chaleix[1], Bruno Chatelain[2], Eric Silberberg[3]
[1]ArcelorMittal Global R&D, France, [2]ARCEO, Belgium, [3]CRM Group, Belgium

Jet Vapor Deposition technology (JVD) is a very high efficiency vacuum evaporation process, fully compatible to the vacuum deposition of Zn coatings on high speed steel strips. JVD allows depositing pure zinc coatings on all kinds of steel grades, with processing and in-use product properties equal to those of Electro-Galvanized (EG) coatings. One first major advantage of JVD is its flexibility. For automotive industry, deposited thicknesses range from 5 to 10 µm. But, lower thicknesses can be reached, down to 1 µm, or different thicknesses can be deposited on each side of the steel strip. Another major advantage of JVD is to be hydrogen free. Compared to EG, no post-thermal treatment is required to degas hydrogen. Thus, as JVD allows deposition on any surface, it is the most suitable process to coat the new generation of advanced high strength steels. Lastly, JVD is a green process compared to EG.

B-1-3 12:00
GALVANIZING OF 3rd GENERATION AHSS-GRADES WITH ADVANCED FURNACE AND PRE-OXIDATION TECHNOLOGY

Lutz Kümmel, Thomas Daube, Fritz Brühl, Caesar Sasse
SMS group GmbH, Germany

Weight reduction is the main target of all carmakers, which results in a continuous development of new steel grades. Latest 3rd generation advanced high-strength steel grades (AHSS) are complex materials with special chemical compositions and multiphase microstructures. The annealing and galvanizing process of these grades is different due to the changed chemical compositions and microstructures. Therefore, these innovative steel grades place new demands on the plant technology of hot-dip galvanizing lines.
One of the new requirements is the prevention of surface faults caused by bare spots, which can occur since these materials feature a higher content of alloying elements like silicon or manganese. Prevention is possible with the special pre-oxidation technologies. The pre-oxidation technology is a proven solution for hot-dip galvanizing of high-alloyed steel grades. The strip surface is therefore deliberately oxidized and then reduced during the process. The technology is characterized by a very accurate formation of the iron oxide layer thickness. Another highlight of the system is that the major part of the injected oxygen migrates into the strip surface. Thus, contamination of the furnace atmosphere by excessively discharged oxygen is prevented.

Another important topic is a precisely controlled and very flexible heating and cooling process in the furnace. The highly efficient radiant-tube furnaces are equipped with powerful heating and cooling systems and facilities for quench and tempering. The newly developed intelligent furnace optimizes the heat treatment and production process. It smartly combines a mathematical/physical model to control the furnace and to optimize production with an online strength measurement system and a newly developed annealing microstructure model to predict material properties after the heat treatment.
This paper and presentation will feature more detailed information and ideas on the new requirements on galvanizing lines for the production of 3rd generation advanced high-strength steel grades. Furthermore, the paper presents some newly developed solutions which are already put into operation for the production of advanced high-strength automotive grades. Furthermore, it focusses on the pre-oxidation technology as well as on cooling technology and furnace control.

B-1-4 (P-15) 12:20
INDUCTIVE STRIP HEATING

Jean Lovens[1], Philippe Weber[1], Marc Anderhuber[2]
[1]Inductotherm Coating Equipment, Belgium, [2]ArcelorMittal Maizieres, France

Ampere's, Faraday's and Ohm's laws are the theoretical base of induction heating. After a reminder of these 3 physical laws, this paper will describe the three basic configurations of strip heating : Proximity, Longitudinal and Transverse flux.
In a second part, this paper will present typical examples of industrial longitudinal flux strip heaters. They show the present maturity of that technology well accepted in the worldwide steel industry to heat magnetic strip.
In a third part, a special attention will be given to the transverse flux concept adapted to non magnetic strip heating. This paper will present an innovative approach applied in an industrial 3.3 MW strip heater commissioned in 2016.

B-2 Air Knife, Quality Control

Date: Monday, November 13
Time: 14:00-16:00
Venue: Room B
Chairs: Michel Dubois (CMI Metals, Belgium)
Takao Tsujimura (Nisshin Steel Co., Ltd., Japan)

B-2-1 (P-16) *Invited* 14:00
NUMERICAL INVESTIGATION OF FLOW CHARACTERISTICS OF GALVANIZING LINE AIR KNIFE

Le Quang Phan[1], Andrew D. Johnstone[1], Buyung Kosasih[1], Wayne Renshaw[2]
[1]University of Wollongong, Australia, [2]Bluescope Steel Pty Ltd, Australia

Flow of planar air jet (air knife) impinging on flat solid surface at low jet-to-plate distance, H to jet-opening, d ratio ($H/d < 20$) is reported. Firstly, wall pressure and shear stress profiles of steady jet flow are simulated at various H/d and jet Re. Wall pressure profile and the maximum value are H/d dependent when it is greater than the critical H/d but exhibit a high degree of insensitivity when H/d is lower. The critical H is approximately of the same length of the jet potential core. Study of the unsteady behaviors such as the jet flapping mode and frequency dependency on H/d and Re shows a periodic fluctuation of the maximum wall pressure location and amplitude. This phenomenon can be explained by the anti-symmetric shedding of the vortices.

B-2-2 14:20
THE STABILISATION OF AIR KNIFE FLOWS USING AUXILIARY PLANAR JETS

Dónal Finnerty[1], Joseph McDermid[1], Frank Goodwin[2], Samir Ziada[1]
[1]McMaster University, Canada, [2]International Zinc Association, USA

This paper presents the results of a particle image velocimetry (PIV) analysis of a prototype multiple air knife design impinging upon a rigid plate. It is well established that a planar jet impinging upon a rigid plate generates large amplitude high-intensity acoustic tones due to an aeroacoustic feedback mechanism[1,2,3]. It has been shown that this acoustic tone is eliminated by auxiliary planar jets of sufficient velocity[4]. The PIV analysis is presented in this paper to show the effect of auxiliary jets on the velocity field of a planar jet impinging upon a plate. The velocity field of the planar jet without auxiliary jets shows the jet column oscillating due to the aeroacoustic feedback mechanism. With an auxiliary jet velocity of 100m/s, the acoustic tone and flapping oscillation of the jet, seen in the PIV analysis, were eliminated. The correlation between the flapping of the jet and the tonal noise indicates that auxiliary jets can be used to eliminate large amplitude noise, an industrial hygiene issue, and stabilise the oscillations found in a jet experiencing an aeroacoustic feedback mechanism. The elimination of the oscillations may have implications for increasing coating weight uniformity and will be the subject of future investigations.

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4. D. Finnerty, J. R. McDermid, S. Ziada, F. Goodwin: Proc. of AISTech, (2016), 2075.

B-2-3 (P-17) 14:40
COATING FILM EVOLUTION SUBJECT TO TIME DEPENDENT PRESSURE AND SHEAR STRESS PROFILES

Andrew Dennis Johnstone[1], Buyung Kosasih[1], Le Quang Phan[1], Andrew Dixon[2], Wayne Renshaw[2]
[1]University of Wollongong, Australia, [2]Bluescope Steel Pty Ltd, Australia

Impinging planar jets are a widely used method for removing excess drag-out coating material from steel strip and thereby to control the final thickness of the coating. A wide range of possible coating defects are known to occur for this process, many of which are suspected to have their origin in the spatio-temporal characteristics of the air jets. It is therefore of interest to improve understanding of the link between the jet behaviour and the evolution of the coating free surface. In this paper, the coating response within the effective jet wiping region and immediately downstream is investigated using a numerical model. The model includes the density and viscosity of the coating fluid and the speed of the strip as it passes through the jet impingement region. The magnitude of the pressure and shear stress distributions

acting on the coating surface along the strip are imposed as time-varying inputs.

B-2-4 (P-18) 15:00
QUALITY INTELLIGENCE PACKAGE DEDICATED TO STATE-OF-THE- ART PROCESSING LINES FOR A COMPREHENSIVE APPROACH

Benjamin Grenier, Laurie Bonhomme, Yvon Fontaine,
Stéphane Georges, Benoit Jalard, Yoichi Kai, Sébastien Maillard
Primetals Technologies France SAS, France

In order to serve the market demand, main goals for steel producers specialized in annealed and galvanized materials are to focus on new steel grades with a large move from conventional steels to high-strength steel grades, new coatings and quality improvement (mechanical properties, surface aspect …). This shall be done at the earliest stage of the production while trying to reduce at the same time operational costs with a dedicated preventive maintenance. The manufacture of basic and high-strength steels generally requires a modification of the production steps along the entire value chain. Besides the necessity to define specific entire plant parameters and machine sizing, this new generation of materials or coatings involves other matters that need to be addressed, for instance, precisely monitored upstream processes, furnace control with pre-oxidation or rapid cooling system. All of these factors have a major impact on the end-product quality.

With a continuous aim of driving improvement, Primetals Technologies has developed a metallurgical expertise service sustained by a complete plant scale solution with a global through process approach based on a large spectrum of mechatronic packages including a process expert system for just-in-time warnings and decision making, condition monitoring and surface inspection systems. Thanks to this global approach and with the support of in-house experts assisting customers in the development of advanced or new steel grades, the most demanding challenges are close at hand.

This paper presents the latest solutions developed and implemented by Primetals Technologies dedicated to modern galvanizing lines with up-to-date equipment and process, associated with specific support.

B-2-5 (P-19) 15:20
ADVANCEMENTS IN MEASURING CGL SURFACE CLEANLINESS ONLINE

Eric Almquist
TolketStarTool (TST), Star Tool & Die Works, USA

Online measurement systems for modern process lines are becoming more commonplace and necessary. A state-of-the-art surface cleanliness measurement system has been used for measuring surface contaminants including iron fines and oil residue on the moving metal product, continuously, and without contacting the metal's surface. Recently this system has demonstrated its unique capabilities to allow cleaning sections to be operated by measuring surface cleanliness: the single metric of importance for cleaning sections.
The function of the system will be presented. The benefits of having surface cleanliness data along the entire coil will be highlighted. Examples of case studies will be shared. The high-resolution data enables utilizing Statistical Process Control (SPC) for the cleaning section instead of guesswork that often entails sampling minuscule areas at the coil's extremities haphazardly and often hazardously. The system enables process control of the cleaning section by identifying and optimizing critical components of the cleaning section while also providing facts which can lead to correct decisions about choosing to idle or disable systems - including brushes - that prove redundant. Details of actual case-study data will be presented to illustrate and support the technical points.
Cleaning sections and surface cleanliness are a topic of growing importance. The more common use of radiant tube furnaces for premium quality steels requires cleaning done before entering the furnace. The growing array of AHSSs with surface wettability challenges and other more stringent requirements for quality benefit from clean surfaces. Reducing costs related to energy, consumables, line down-time, labor, safety, and other things are those which can be reduced once the surface cleanliness of the sheet is known. The paper will illustrate how some of these goals have been met or could be met with the system.

B-2-6 15:40
APPLICATION OF THE HOT-DIP ZN-AL-MG ALLOY PLATING TO THE STEEL STRUCTURES

Toshihiko Morooka
KOWA KOGYOSHO Co., LTD., Japan

It is well known that corrosion resistance improves when aluminum is added in zinc, and Zn-Al alloy coating steel sheet was already commercialized in 1970s, and recently, Zn-Al-Mg alloy coating steel sheet for further corrosion resistance improvement is commercialized. On the other hand, we did not have many examples in the plating of the steel structures because there were many technical problems. Even under such situations, we pay attention to Zn-Al-Mg alloy plating early on and we commercialized it approximately 30 years ago, and now, this plating is in use for steel structures such as a road, a railroad, a building and electric power parts, etc.

B-3 Conversion Coatings and Pre-painted Steels

Date: Monday, November 13
Time: 16:20-17:50
Venue: Room B
Chairs: David Penney (Swansea University, UK)
Shin Ueno (Nisshin Steel Co., Ltd., Japan)

B-3-1 *Keynote* 16:20
DEVELOPMENT TREND OF PRE-PAINTED STEEL SHEET IN JAPAN

Kohei Ueda
Nippon Steel & Sumitomo Metal Corporation, Japan

Pre-painted steel sheet (PSS), which is steel sheet that has been painted in advance, was used in various industrial fields. PSS has been applied in the construction field and then expanded to home appliances, such as refrigerators, washing machines, outdoor air-conditioner units and flat panel TVs. On the other hand, the trend of PSS development has shifted from improving general performance such as formability and corrosion resistance to “Ecological corrosion resistant technology”, “Additional functions” and “Pursuit of high productivity and cost reduction”.
The development of chromate-free PSS was the main target for ecological corrosion resistance technology, and various kinds of chromate-free conversion and primer

paint were developed. Research was also conducted in regards to the application of Zn-Al-Mg alloy coated steel sheet as a substrate to increase the corrosion resistance of the chromate-free PSS. The research into functional PSS to solve the problems of heat and electromagnetic waves generated in the home appliances, reduce the energy consumption of lighting equipment, solve the stain problem for outdoor equipment to control the surface contact angle has also progressed. Furthermore, the development of thin water based PSS has been advanced as a high productivity, low cost product.
This paper will introduce these recent development trends of PSS.

B-3-2 *Invited* 16:50
DEVELOPMENT OF NEXT GENERATION CHROMATE-FREE COATINGS BY NOBLE INORGANIC POLYMER
Akira Matsuzaki, Takeshi Matsuda, Rie Kaneko, Kazuaki Tsuchimoto
JFE Steel Corporation, Japan
In recent years, domestic production of electrogalvanized steel sheets has decreased due to market erosion by low-priced products and the poor sales performance of Japanese electrical appliance manufacturers. In order to overcome this situation, it was necessary to develop a high/multifunctional chromate-free coating that is capable of reducing manufacturing costs by the mass production effect of high-speed production and aggregation of small quantity varieties, reduction of submaterials and process omission by users. Trends in the expansion of chromate-free products also extend to building material applications, and the use of chromate-free products was recommended in the 2016 Public Work Specifications published by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) in Japan.
Based on the results of fundamental research on the corrosion resistance mechanism of a self-assembled monolayer (SAM), the authors conceived a complex of silicate and ultrafine silica that features high adhesion by covalent bonding with zinc and a high barrier property by three-dimensional crosslinking. For electrical appliances, our current development work includes (1) a high functionality chromate-free coating that compatibilizes corrosion resistance and electrical conductivity and (2) a multifunctional chromate-free coating with lubricity and paint adhesion, and for building materials, (3) a low-cost chromate-free coating with weather resistance.

B-3-3 17:10
THE EFFECT OF MELAMINE CONCENTRATION IN WATER-BASED POLYESTER / MELAMINE FILM ON MARKER RESISTANCE FOR PRE-PAINTED STEEL SHEETS
Akiko Muto, Kunihiko Toshin, Fumio Shibao, Kohei Ueda
Nippon Steel & Sumitomo Metal Corporation, Japan
Water-based pre-painted steel sheets (PSS) have been developed recently as a more environmentally-friendly alternative to the typical application of solvent-based coatings to PSS. However, the relation between water-based paint film structure and its performance is insufficiently understood. In order to reveal the difference between solvent-based coatings and water-based coatings, this study focused on the melamine enrichment phenomenon which is a unique technique that provides not only hardness and marker resistance but also high formability.
In this study, water-based and solvent-based polyester / melamine paint were compared and the effect of melamine on the paint stability and the melamine concentration on the film surface were investigated. The water-based polyester emulsion stably included only selected melamine formaldehyde and no catalysts. However, the melamine concentration and the stain resistance on the film surface were higher in water-based films than those in solvent-based under the same conditions.

B-3-4 17:30
DEVELOPMENT OF BLACK THIN-FILM PAINTED STEEL SHEET
Kunihiko Toshin, Fumio Shibao, Atsushi Morishita
Nippon Steel & Sumitomo Metal Corporation, Japan
A pre-painted steel sheet is widely used as the panel of an audiovisual equipment and an office automation equipment. Generally, this pre-painted steel sheet has a primer-layer and a top-layer on a galvanized steel sheet. These two layers are applied by the use of solvent-based paints.
In order to save energy and to reduce the emission of VOC, we developed the new black thin-film painted steel sheet. This steel sheet doesn't have the primer-layer and have only the top-layer on a galvanized steel sheet. The top layer of our newly developed steel sheet is thinner than that of the conventional pre-painted steel sheet and is applied through the use of water-based paint.
Our new pre-painted steel sheet is the same as the conventional pre-painted steel sheet in performance.

C-1 Metallic Coating on Advanced High-strength Steels I

Date: Monday, November 13
Time: 11:10-12:40
Venue: Room C
Chairs: Joo-Youl Huh (Korea University, Korea)
Hiroshi Irie (Kobe Steel, Ltd., Japan)

C-1-1 (P-1) *Keynote* 11:10
THE EFFECT OF ANNEALING TEMPERATURE ON THE SELECTIVE OXIDATION OF A 0.1C-6MN-2SI ADVANCED HIGH STRENGTH STEEL DURING CONTINUOUS GALVANIZING HEAT TREATMENTS
Maedeh Pourmajidian, Joseph R. McDermid
McMaster University, Canada
The effects of peak annealing temperature and annealing time on the selective oxidation and reactive wetting of a prototype medium-Mn 0.1C-6Mn-2Si third generation advanced high strength steel were investigated. Annealing heat treatments were carried out in a N_2-5vol.%H_2 –30˚C dew point process atmosphere at 800˚C and 690˚C for 120s and 600s. Surface oxide chemistries, morphologies and thickness were determined at a variety of length scales by several techniques, including SEM, XPS and TEM combined with EELS. TEM observations of the sample cross-sections revealed the formation of an internal oxide network in the subsurface grains as well as the grain boundaries. The maximum depth of the internal oxidation zone reached 5 μm in the sample annealed at 800˚C for 600s. EELS results revealed that the internal oxide network was composed of a multi-layer oxide structure with varying chemistry from the oxide core towards the outer shell. The

effect of annealing temperature on the surface structure development and its impact on reactive wetting of the substrates by a Zn-0.2wt.%Al (dissolved) galvanizing bath was also explored. In contrast to the 800˚C × 120s steel, the 690˚C × 120s substrate showed significantly superior reactive wetting, owing to the much finer morphology and widely spaced distribution of the surface oxides that were formed on this sample prior to immersion.

C-1-2 11:40
EFFECT OF ANNEALING PARAMETERS ON SELECTIVE OXIDATION AND REACTIVE WETTING OF CMNSI ADVANCED HIGH STRENGTH STEEL

Ghazal Seyed Mousavi, Joseph McDermid
McMaster University, Canada

Selective oxidation and reactive wetting of a Fe-0.1C-2Mn-1.3Si (wt%) advanced high strength steel intercritically annealed at 819°C for annealing times of 120 and 600s in a N_2-5 vol.% H_2 gas atmosphere at dew points of –50°C, – 30°C and +5°C were investigated. It was found that in the +5°C dp process atmosphere, either $MnSiO_3$ or Mn_2SiO_4 plates were formed on the surface; while Si-rich oxides were formed internally. Additionally, for the –30°C and –50°C dp atmospheres, a thick, compact Mn_2SiO_4/$MnSiO_3$ mixed oxide layer was formed on the surface. Longer annealing times resulted in the formation of either a thicker oxide layer/larger oxide particles on the surface or a larger penetration depth of oxides below the surface. Good wetting was obtained using the +5°C dp and –30°C dp process atmospheres. The relatively poor wetting observed for the –50°C dp process atmosphere was due to the increased thickness of the external oxide film.

C-1-3 12:00
FINE-SCALE MICROSTRUCTURE CHARACTERIZATION AND MECHANICAL PROPERTIES OF CGL-COMPATIBLE HEAT TREATED MEDIUM MN TRIP STEEL

Kazi Bhadhon[1], Joseph McDermid[1], Xiang Wang[1], Elizabeth McNally[1], Frank Goodwin[2]
[1]McMaster University, Canada, [2]International Zinc Association, USA

Medium Mn TRIP steels are promising third generation advanced high strength steels (3G-AHSSs) for meeting automotive weight reduction demands without compromising passenger safety. However, these steels must be compatible with the thermal processing capabilities of continuous galvanizing lines (CGLs) in order to be successfully employed in automotive applications. In that regard, a 0.2C-6Mn-1.5Si-0.5Al-0.5Cr (wt.%) medium Mn TRIP steel with a martensitic starting microstructure was annealed with CGL compatible heat treatment parameters. The effect of intercritical annealing (IA) parameters on the retained austenite volume fraction and stability was determined in this study. The retained austenite volume fraction increased significantly with increasing holding times up to 360s at 675°C IAT. However, the retained austenite volume fraction decreased significantly when intercritical holding times were greater than 360s and 60s at 675°C and 710°C, respectively, owing to chemically unstable intercritical austenite which transformed to martensite during final cooling. Tensile tests of annealed samples with greater than0.30 volume fraction retained austenite revealed an excellent combination of strength and ductility (UTS × TE ≥ 30,000 MPa%). TEM analysis of the fine-scale microstructure showed that most of the retained austenite was present as a film type morphology which is known to be chemically and mechanically stable and, therefore, promotes gradual stress-induced transformation of the retained austenite.

C-1-4 12:20
MICROSTRUCTURE AND PAHSE EVOLUTION OF GALVANIZED PRESS HARDENING STEEL

Yunkyum Kim, Joseph R. McDermid
McMaster University, Canada

The effect of the annealing time and temperature on the microstructure and the phase evolution of a galvanized press hardening steel (22MnB5) were investigated. An annealing experiment was carried out in a trailed tube furnace which can rapidly quench to room temperature. The samples were annealed at either 700 °C or 900 °C for varying times. After annealing, the microstructure of the coating layer was analyzed by SEM, XRD, and GDOES. The experimental results showed that the Γ-Fe_3Zn_{10} phase formed at the initial stages of annealing at 700 °C. The Γ-Fe_3Zn_{10} phase did not transform to α-Fe(Zn) with increased annealing time. However, at 900 °C the Γ-Fe_3Zn_{10} phase completely transformed to α-Fe(Zn) after 240 s of annealing time. The GDOES analysis showed that the Zn concentration of the coating layer decreased as the annealing time increased and the thickness of the coating layer increased as the annealing time increased. Based on these results, annealing at 900 °C for 240 s is the most optimal condition for prevention of liquid metal induced embrittlement (LMIE) problems and effective corrosion resistance during direct hot-press forming (DHPF).

C-2 Metallic Coating on Advanced High-strength Steels II

Date: Monday, November 13
Time: 14:00-15:00
Venue: Room C
Chairs: Joseph Robert McDermid (McMaster University, Canada)
Yusuke Fushiwaki (JFE Steel Corporation, Japan)

C-2-1 *Invited* 14:00
SELECTIVE OXIDATION OF HIGH ALUMINIUM LOW DENSITY STEEL

Xinyan Jin[1,2], Yingxiu Xie[1,2], Hua Wang[3]
[1]Baosteel Research Institute, China, [2]State Key Laboratory of Development and Application Technology of Automotive Steels, China, [3]Shanghai University, China

High aluminium low density steels have been actively studied due to its potential use as lightweight steels for automotive applications. However, with increasing aluminium content, the selective oxidation behaviour of aluminium might ruin the galvanizability or phosphatability of the steel. In order to understand the effects of annealing parameters such as annealing temperature, holding time and dew point on the selective oxidation of Al, annealing experiments were conducted on low density steel with 4% Al addition. The depth profiles of Fe, Al, Mn and O of the annealed samples along a 3 μm depth from the surface were measured by GDOES, the surface morphologies were demonstrated by FESEM equipped with EDS and the high resolution cross sections were prepared by FIB and characterized by TEM. It is found that the dew point of the annealing atmosphere has a great effect on the selective oxidation of Al and the surface

morphologies of the steel. With dew point increasing, the external oxidation of Al transfers into internal oxidation. Moreover, an attractive surface morphology which is totally different from other Mn and/or Si strengthening advanced high strength steel is found. A layer of nodular iron is formed on the outermost surface followed by layers of internal Al, Mn oxides and recrystallized ferrite. It is also found that the nodular iron grains grow up with annealing temperature and holding time increasing, leading to a higher coverage on the surface.
The theoretical calculation of the internal oxides volume of different alloy elements indicates that the outermost nodular iron layer is caused by the overflow of iron from the subsurface because of the volume expansion of the alumina. It is expected that such a surface morphology will significantly improve the galvanizability and phosphatability of high aluminium low density steel.

C-2-2 *Invited* 14:20
RESEARCH ON THE MICROSTRUCTURE, MECHANICAL PROPERTIES AND SELECTIVE OXIDATION OF C-MN-SI-AL STEEL
Yun Han[1,2], Jiali Cao[3], Shuang Kuang[1,2], Guangrui Jiang[1,2], Chunqian Xie[1,2], Guanghui Liu[1,2]
[1]Shougang Research Institute of Technology, China, [2]Beijing key Laboratory of Green Recyclable Process for Iron & steel Production Technology, China, [3]State Grid Xinyuan Company LTD., China
A typical C-Mn-Si-Al steel was designed and galvanizing process parameters on the microstructure and mechanical properties were investigated. Moreover, the C-Mn-Si-Al steel was annealed under different dew point during the heating section which was simulated by a hot dip galvanized simulator. The microstructures and selective oxidation behaviours on external surface of the steel were examined by optical microscopy (OM), electron back-scattered diffraction (EBSD), transmission electron microscopy (TEM), X–rays diffraction (XRD), Glow Discharge Optical Emission Spectroscopy (GDOES). It was found that, the C-Mn-Si-Al steel microstructures consist of ferrite and martensite phase which is similar to the typical dual phase steel character. However, the further EBSD and XRD results show that there is also some retained austenite evenly distributed in the matrix, the volume fraction of which is about 5%. The tensile test of the C-Mn-Si-Al steel was conducted on a universal materials tester and compared to the same level dual phase steel. The results show that the C-Mn-Si-Al steel exhibits similar strength but obviously better elongation compared to the DP590 steel. Furthermore, the mechanical properties of the C-Mn-Si-Al steel have minor fluctuation as the process temperature varying. All the elongations of the steel experienced different processes exceed 30%. In addition, the dew points during the heating section at 700℃ were chosen as -60℃, -30℃ and -10℃. It shows that the enrichment of aluminium elements within the surface will increase as the dew point decreasing from -10℃ to -60℃. However, the enrichment of silicon and manganese elements within the external surface is obvious suppressed. It implies that the lower dew point may play important role to improve the wettability of the C-Mn-Si-Al steel.

C-2-3 14:40
PERFORMANCE OF MULTI-LAYER PVD COATINGS CONTAINING ZN AND ZN-MG FOR AUTOMOTIVE APPLICATIONS
Ruud Johannes Westerwaal, Arnoud de Vooys, Jörgen van de Langkruis, Peter Beentjes, Edzo Zoestbergen
Tata Steel, The Netherlands
The majority of the steel strip sold by us to the automotive market is coated with a Zn or ZnAlMg coating for corrosion protection. Such coatings are most often deposited using a hot dip galvanising (HDG) or electro plating (EZ) process. However, these processes suffer from de-wetting (HDG) and hydrogen embrittlement (EZ). Therefore we work on the development of a novel Physical Vapour Deposition (PVD) technology for the deposition of coatings onto HSS. Recently, multi-layer coatings consisting of a ZnMg-Zn dual layer and a Zn-ZnMg-Zn triple layer have been developed with optimized properties. Key results on corrosion resistance are presented, demonstrating the flexibility of this coating technology. The outstanding performance of these coatings with respect to perforation and cosmetic corrosion resistance is comparable to and even exceeding those of state-of-the-art coatings like galvannealed (GA) and galvanised (GI) and can compete with more recent coatings such as ZnAlMg (HDG).

C-3 Metallic Coating on Advanced High-strength Steels III

Date: Monday, November 13
Time: 15:20-17:10
Venue: Room C
Chairs: Thomas Koll (Salzgitter Mannesmann Forschung GmbH, Germany)
Taizo Matsuda (Nisshin Steel Co., Ltd., Japan)

C-3-1 *Keynote* 16:00
TREND OF ADVANCED HIGH STRENGTH STEELS FOR AUTOMOTIVE
Hiroshi Irie, Kuniyasu Araga
Kobe Steel Ltd., Japan
Zn coated steel sheet is applied to enhance car body durability, and hot dip galvanizing and galvannealing steel became main coating type. Recently, the regulation level for car performance of ‘safety improvement for collision’ and ‘reduction of CO_2 emission’ is strengthened year by year. In order to light weighting car body by thinning steel sheet for both purposes, it is necessary to apply high tensile steel to car body. To enhance tensile strength of steel, strengthening element such as Si or Mn is added to the the steel. However, these elements are precipitated as oxide to the steel sheet surface during annealing , and the Zn coatability is deteriorated. Recently, in order to respond the necessity for high tensile steel of automotive, investigation for improvement of coatability of high tensile steel has been widely carried out. At this time, I will introduce the trend of this coatability improvement study.

C-3-2 16:30
EFFECT OF Si/Mn RATIO ON GALVANNEALING BEHAVIOR OF Si ADDED STEEL
Mai Miyata, Yusuke Fushiwaki, Yoshitsugu Suzuki, Yasunobu Nagataki
JFE Steel Corporation, Japan

The influence of the Si/Mn ratio of the galvannealing behavior of 1.5wt%Si added steel was investigated in both the annealing process and the oxidation-reduction process. The reactivity of galvannealing became higher with a decreasing Si/Mn ratio. Two kinds of Si oxide formed on the steel surface after annealing. The amount of SiO_2 decreased while Mn_2SiO_4 increased with a decreasing Si/Mn raio. Mn_2SiO_4 is believed to have a lower ability to inhibit atomic diffusion than SiO_2. Therefore, reactivity increased at a lower Si/Mn ratio. The same tendency was observed in both the annealing process and the oxidation-reduction process. However, the reactivity of galvannealing was higher in the oxidation-reduction process, in which smaller amount of Si oxide existed on the steel surface after annealing. These results indicate that both the quantity and the kind of Si oxide affect the galvannealing reaction.

C-3-3 16:50
INFLUENCE OF CR ADDITION ON SELECTIVE OXIDATION BEHAVIOUR OF MN ADDED HIGH-STRENGTH STEEL SHEET

Yusuke Fushiwaki, Takashi Kawano, Yasunobu Nagataki
JFE Steel Corporation, Japan

The present study focused on the influence of Cr addition on selective surface oxidation which determines Zn wettability on cold-rolled sheet steel containing 0-1.0 mass%Cr-1.5 mass%Mn. Wettability was investigated by measuring the contact angle of molten Zn containing 0.14 mass%Al on the steel. The main results obtained are as follows. The contact angle tended to decrease as the amount of Cr addition increased. However, the amount of selective surface oxidation of Mn did not change greatly even when Cr additon increased. Moreover, whereas the selective surface oxide was MnO without Cr addition, it was $MnCr_2O_4$, which is known as Cr-Mn spinel, with Cr addition. Therefore, it is suggested that molten Zn wettability should be controlled by the formation of Cr-Mn spinel, which can react with Al in the molten Zn more easily than MnO, so that the contact angle of molten Zn decreases as the amount of Cr increases.

C-3-4 (P-2) 17:10
EFFECTS OF ANNEALING TEMPERATURE AND DEW POINT ON KINETICS OF Mn EXTERNAL OXIDATION

Yusuke Okumura, Minoru Tanaka, Yusuke Fushiwaki, Yasunobu Nagataki
JFE Steel Corporation, Japan

Because the selective oxidation of Mn in steel during recrystallization annealing causes coating defects of hot-dip galvanized steel, basic research on the kinetics of selective oxidation is important. In this study, the effects of the annealing temperature and dew point on the kinetics of Mn external oxidation were investigated experimentally, and the Mn external oxidation rate was estimated based on a diffusion equation and thermodynamic equilibrium. It was found that Mn oxidation is a diffusion limited process, as in other reports. The Mn oxidation rate increased with increasing temperature and showed a peak, and the Mn oxidation rate became dramatically slower at higher temperatures. This peak value of the Mn oxidation rate depended on the dew point, and the peak value decreased at lower dew points. It is thought that the Mn oxidation rate becomes slower at high temperature because the gradient of the Mn concentration around the steel surface becomes small at high temperature near equiliblium.

C-3-5 17:30
WETTABILITY AND REACTIVITY OF ZN-AL-MG ALLOYS ON ADVANCED HIGH-STRENGTH STEELS

Joo-Youl Huh[1], Min-Je Hwang[1], Seung-Woo Shim[1], Tae-Chul Kim[2], Jong-Sang Kim[2]
[1]Korea University, Korea, [2]POSCO, Korea

A sessile drop method was used to study the wetting characteristics of individual surface oxides, MnO and amorphous (*a*-) SiO_2, by molten Zn-Al-Mg alloys as a function of the Al and Mg contents in the alloys. The sessile drop tests were carried out at 460 °C by measuring the variations in contact angle (θ_c) for 20 s for alloys containing 0.2–2.5 wt.% Al and 0–3.0 wt.% Mg. For all alloys, the MnO-covered steel substrate exhibited reactive wetting whereas the *a*-SiO_2-covered steel exhibited nonreactive and nonwetting ($\theta_c > 90°$) behavior. The wettability of MnO-covered steel substrates was significantly improved by increasing Mg content but was reduced by increasing Al content. Although the reactions of the Al and Mg in molten alloys with the surface *a*-SiO_2- were slow, both the Al and Mg additions lowered θ_c. The present results suggested that the wettability of advanced high-strength steel (AHSS) sheets, for which the surface oxide layer consists of a mixture of MnO and SiO_2, with Zn-Al-Mg alloys could be improved by increasing Mg content and minimizing Al content.

D-1 Automotive Applications I

Date: Monday, November 13
Time: 11:10-12:40
Venue: Room D
Chairs: Jennifer Schulz (thyssenkrupp Steel Europe AG, Germany)
Shinichi Koga (Nisshin Steel Co., Ltd., Japan)

D-1-1 *Keynote* 11:10
EXPECTATION OF STEEL INDUSTRY FOR VEHICLE LIGHT WEIGHTING

Yoshimasa Ureshino
Toyota Motor Corporation, Japan

In order to reduce electric vehicle weight, light weighting technology is so important. In material engineering areas, there is in particular a mission for providing new value by "light weighting". Although usage of resin based materials including the CFRP and the nonferrous metal for light weighting is spreading, HSS usage is so important in future. However, corrosion performance for part is one of major concern for using HSS.

D-1-2 *Invited* 11:40
COATING PROPERTY COMPARISON OF COMMERCIAL GA NB-TI-IF AND GA TI-IF PRODUCTS PRODUCED UNDER A SIMILAR HOT-DIP GALVANNEALING CONDITION

Chann Cheng, Venu Krishnardula
ArcelorMittal USA Global R&D, USA

Ten Ti-IF and ten Nb-Ti-IF galvannealed coils produced for the same commercial automotive exposed application were studied for their coating chemistries, structures and powdering properties. The result shows Ti-IF steel has a slightly wider Fe% range in the GA coating and has slightly more zeta phase at the coating surface than Nb-Ti-IF steel. Although the difference in coating structure between the two substrates is subtle, Double Olsen test result shows GA Nb-Ti-IF steel has a slightly better powdering resistance than GA Ti-IF steel while all 20 products are well within

the acceptable powdering range. In this study, the benefits of using an induction furnace to properly galvanneal Ti-IF steel is explained by previous hot-dip simulator results. The basic difference at the early stage of galvannealing (the breakdown of the inhibition layer and the initial outburst structure of the coating) between Ti-IF and Nb-Ti-IF steels is investigated.

D-1-3 12:00

DEVELOPMENT OF ELECTRO GALVANIZED AHSS WITH TENSILE STRENGTH RANGING FROM 1200 TO 1500MPA FOR AUTOMOTIVE APPLICATION WITH NO RISK OF DELAYED FRACTURE

Cedric Georges[1], Bernard Colinet[1], Thierry Sturel[2], Christian Allely[2], Vincent Lhoist[3], Dominique Cornette[2]
[1]CRM Group, Belgium, [2]ArcelorMittal R&D Automotive Products, France, [3]ArcelorMittal, Belgium

Advanced high strength steels (AHSS) with Dual Phase (DP) or Martensitic (MS) microstructures, presenting 1180 to 1500MPa of tensile strength are integrated in the modern car bodies by a large way. During the electro-galvanizing process (EG), diffusible hydrogen can be introduced into such high strength steels. In case of hydrogen excess and presence of very high stresses, they can be sensitive to the delayed fracture phenomena. In this article, the critical diffusible hydrogen of the material has been quantified and an adaptation of the industrial process route has been realized in order to ensure very low final hydrogen contents even in the case of detrimental EG conditions. It is finally verified that, despite the use of a very severe test, the industrial material is fully safe regarding the delayed fracture risk.

D-1-4 12:20

EFFECT OF SELECTIVE OXIDATION ON GALVANIZABILITY OF SI, MN ADDED HIGH STRENGTH HOT-ROLLED STEEL AT LOW ANNEALING TEMPERATURE

Masaki Koba, Yusuke Fushiwaki, Yasunobu Nagataki
JFE Steel Corporation, Japan

Galvanizability and the selective oxidation behavior of 0.7%Si-1.2%Mn added hot-rolled steel annealed at 600-800℃ were investigated by comparing with those of cold-rolled steel. Above 700℃, selectively oxidized Si and Mn on the hot-rolled steel surface deteriorated the galvanizability. On the other hand, at the temperature below 700℃, thin oxide layer of Fe existed on the hot-rolled steel surface deteriorated the galvanizability. This thin oxide layer was reduced by Si and Mn diffused from steel substrate. In the case of cold-rolled steel, same selective oxidation behavior and reduction mechanism of Fe oxide were confirmed. However, the galvanizability of cold-rolled steel at low temperature was better than that of hot-rolled steel. This can be explained by the faster diffusion rates of Si, Mn in cold-rolled steel than in hot-rolled steel that the reduction of Fe oxide on the surface is prompted on the cold-rolled steel.

D-2 Automotive Applications II

Date: Monday, November 13
Time: 14:00-15:50
Venue: Room D
Chairs: Martin Huisert (Tata Steel Europe, The Nederlands)
Kiyokazu Ishizuka (Nippon Steel & Sumitomo Metal Corporation, Japan)

D-2-1 *Keynote* 14:00

DEVELOPMENT OF AHSS AND APPLICATION TECHNOLOGY FOR AUTOMOTIVE USE IN HYUNDAI STEEL

Man-Been Moon
Hyundai Steel Company, Korea

Amidst regulations on CO_2 emission today, the automotive industry strives to reduce car body weight to increase fuel efficiency while focusing on high strength steel to meet strict safety regulations.
Steel makers came up with two-tracks to seek solutions for changing market needs. The first approach is to develop new steel grades tailored to the requirements of each auto-body part for automotive use, including the third generation steel sheets equipped with improved strength and forming characteristics. The second approach is to develop application technologies to employ new materials. It consists of new technologies to enhance weldability, formability and characteristics of hydrogen delayed fracture, solving issues regarding joining and corrosion of dissimilar materials for application of nonferrous materials such as aluminum and CFRP (Carbon Fiber Reinforced Plastic). In this paper, the trends of automotive steel and development status of relevant technology in Hyundai Steel will be introduced.

D-2-2 *Invited* 14:30

NEW POTENTIALS FOR Zn-Mg-Al HOT-DIP GALVANIZED COATINGS IN AUTOMOTIVE APPLICATIONS

Jennifer Schulz, Anastasia Schüßler, Georg Parma, Adrian Paton, Andreas Birkenstock
thyssenkrupp Steel Europe AG, Germany

Thanks to high-quality galvanized steel sheets, corrosion in the body area is outstandingly manageable today. The available surface textures of hot-dip and electro-galvanized products fulfill even the highest demands on the surface of visible body components. Therefore, new zinc-magnesium-aluminum (ZM) coatings will not only find their way into the vehicles due to their superior corrosion protection potential, but above all by a significant improvement in their processing properties.
ZM offers lower friction and superior forming properties with reduced adhesive wear and a high corrosion protection, especially in the case of stone chipping, cutting edges and scoring, allows a reduction in the coating weight compared to standard GI.
The automotive industry has the possibility to use ZM coatings in all relevant fields of application: ZM coatings protect internal parts and visible outer parts with a high-quality surface - suitable, e. g., for fillerless paint systems.

D-2-3 (P-8) 14:50
INDUSTRY 4.0 IN COATING PROCESSES ENABLED BY PROACTIVE QUALITY ASSURANCE
Helga Evers, Hans Peintinger
QuinLogic GmbH, Germany
Smart factory, high flexibility, short time to market in an industrial scale are the key words of Industry 4.0. Digitalization and growing quality requirements for high-end products are at the same time an enormous challenge, which is often in competition with efficiency targets and market driven cost-cutting measures.This paper describes the implementation experience of ExpertShell system and the achieved benefits of an innovative new Industry 4.0 technology. Major players like TATA, ArcelorMittal, USS Posco, AK Steel and Nucor have implemented this solution already.
It opens the chance for a new way of using all the available experience inside a mill to improve the workflow and increase efficiency.
This technology helps in principle all production lines in all grades but has the highest impact in challenging grades like ultra-high strength specialty steel and especially in automotive applications in CGL, CALGL and EGL lines.
The new solution has an embedded automatic improvement cycle, which makes sure that modifications and adaptations to new market requirements can be taken care of instantly. Speed of adaptation as well as reliability of the delivered quality will be the differentiator in the upcoming years. Interestingly the investment in proactive quality assurance not only improves competitive position in quality, but has proven return of invests figures below one year.

D-2-4 15:10
MAXIMUM YIELD IN AUTOMOTIVE PROCESSES THROUGH REAL-TIME MONITORING OF DROSS AND SPANGLE
Steffen Burkhardt, Michael Hoenen
ISRA Vision Parsytec, Germany
Galvanized material plays an important role for the quality of exposed parts of cars and vehicles. As the required surface quality is increasing constantly, the need for reliable quality control and decision support is increasing likewise. Real-time process surveillance is an ideal support in decision making and production of such parts, as it offers direct reaction to occurrences during processing through immediate alarms. Using state-of-the-art optical surface inspection systems, producers of galvanized parts are enabled to detect even small defects embedded in the galvanized structure. An important defect is dross occurring in the zinc pot, especially when setting up the line for producing a new item. Dross and spangle, the second most quality influencing defect, should both be permanently monitored for reliable quality assurance. This paper presents new approaches of real-time monitoring of dross and spangle appearances for online production improvement. The technology is completed by additional alarming functions, which can be set to indicate specific defect patterns and defect densities. All results can also be applied for final coil releasing based on an application and customer dependent rule set. This advanced optical surface inspection system is the most reliable way to maximize yield by enlarging high quality campaigns in flat steel galvanizing and simultaneously prevent customer claims.

D-2-5 15:30
STATIC IMMERSION TESTING OF LASER CLAD COATINGS FOR JOURNAL BEARING APPLICATIONS
Rhys Faulkner[1,2], Samuel L. Evans[1], Alastair Clarke[1], David Penney[2], Nicholas Collins[3]
[1]Cardiff University, UK, [2]Swansea University, UK, [3]Llanwern Steel Works, UK
Two Co alloy coatings (CoCrWC and CoMoSi) and two Fe based alloy coatings (D2 tool steel and FeCrNiBSi) were laser clad on to a SS316L substrate creating samples of 26.5mm diameter which were statically immersed in molten Zn with 0.35%Al for a period of 672hrs with samples of each alloy coating being removed weekly and characterized in terms of performance. All samples were seen to react with ZnAl, primarily in the Co solid solution phases for Co based alloys and the FeCrNiSi phase in the FeCrNiBSi alloy. Reaction layers grew perpendicular to sample surfaces and were measured and ranked relative to each alloy. CoMoSi alloy was seen to form significantly smaller reaction layers than the other three alloys, with mean reaction layer depth growing to 15µm, compared to 60µm to 80µm for the remaining three alloy coatings. Roughness measurement provided a method of surface characterization and showed that CoMoSi alloy coating performed the best. Examples of large scale material debris detaching from the sample surface was present in the Co based samples.

D-3 Automotive Applications III

Date: Monday, November 13
Time: 16:10-17:30
Venue: Room D
Chairs: Chann Cheng (ArcelorMittal USA, USA)
Yasunobu Nagataki (JFE Steel Corporation, Japan)

D-3-1 *Invited* 17:30
AUTOMOTIVE ANTI-CORROSION SPECIFICATION TRANSITION DUE TO ENVIRONMENT SURROUNDING CHANGE
Hideaki Yaegashi
Nissan Motor Co., Ltd., Japan
Automobile has made a big progress in many aspects to deal with improving convenience of customers, environmental change in the market, regulations for substance of concern, and so on. Anti-corrosion specifications and materials for automobiles have been no exception. No corrosion on automobiles was attractive quality about 30 years ago, but it is must-be quality now. The evolution of anti-corrosion technology about zinc phosphate, electro deposition coating and zinc or zinc alloy coated steel mainly made it possible.
In this lecture, three main topics will be covered. The 1st one is anti-corrosion technology history based on the above mentioned anti-corrosion material for Body-In-White (BIW). The 2nd one is current quality issue in the market. And the last one is latest anti-corrosion technology breakthrough for the light weight of automobiles.

D-3-2 16:30
LONG-TERM OBSERVATIONS OF POST-GALVANIZING OIL LAYER
Martin Huisert, Rutger Stottelaar, Albert Westendorp, Joost Hartsink
Tata Steel Europe, The Netherlands

In this work the inline measurement of the oil layer thickness on Hot Dip Galvanized (HDG) material is studied. Customers require a homogeneous oil layer thickness for their processing of Hot Dip Galvanized steel. The oil is electrostatically applied in small droplets on the strip, but the inline measurement of the oil layer thickness requires a closed film to measure the amount of oil accurately. Therefore oil distribution rolls are used to transform the droplets into a closed film. This study shows that the film formation, and thus the oil layer thickness measurement, depends on a number of parameters, such as line speed and the status of the oil distribution rolls.
Standard software shows the measurement of the oil layer thickness of a single coil. However, it would be useful for technologists to see the history of the oil distribution of a couple of days or weeks. Tata Steel developed a monitor to see this distribution combined with information on the oil type and oil flow. In this way trends of the oiling process can be observed, analyzed and improved.

D-3-3 16:50
ENHANCING THE LUBRICITY OF AUTOMOTIVE STEELS USING CARBOXYLIC ACID COATINGS

Donald Hill[1], Peter Holliman[1], James McGettrick[1], Justin Searle[1], Marco Appelman[2], Pranesh Chatterjee[2], Trystan M. Watson[1], David Worsley[1]
[1]Swansea University, UK, [2]TATA Research & Development, The Netherlands

Herein we report a novel approach for controlling the lubricity of galvanized steel for sheet metal forming processes using films formed from lauric (C12), stearic (C18) or perfluorooctanoic (C8) acid. These are deposited onto either pre-cast TiO_2 coatings on galvanized steel or directly onto the zinc coating. Assessment of the films' tribological properties revealed that the coefficient of friction (μ) of the galvanized steel studied dropped by more than 65% after deposition of the C12 and C18 films, from 0.309 to less than 0.11, whereas the C8 film reduced the μ by about 35% to 0.195. In line with the reduced friction, confocal microscopy reveals that there is significantly less wear on surfaces functionalized with the carboxylic acids. X-ray photoelectron spectroscopy (XPS) showed that the films are formed from multilayers of carboxylic acids, whilst infrared (IR) spectroscopy revealed that this material is largely physisorbed, with some chemisorbed carboxylates also present.

D-3-4 17:10
EFFECT OF STARTING MICROSTRUCTURE AND INTERCRITICAL ANNEALING PARAMETERS ON THE MECHANICAL PROPERTY DEVELOPMENT OF A MEDIUM-MN THIRD-GENERATION ADVANCED HIGH STRENGTH STEEL

Daniella M. Pallisco[1], Joseph R. McDermid[1], Elizabeth A. McNally[1], Frank E. Goodwin[2]
[1]McMaster University, Canada, [2]International Zinc Association, USA

Third generation advanced high strength steels (3G AHSS) are relatively cost-effective alloys with superior combinations of high strength and ductility that make them promising candidate materials for vehicle light-weighting. Medium-Mn TRIP-assisted steels are of particular interest due to the compatibility of their processing routes with the continuous galvanizing line, which provides a cost-effective means of corrosion protection necessary for the application of these steels in the automotive industry. The present work investigates the mechanical property development of a prototype 0.15C-5.6Mn-1.9Al-1.1Si (wt.%) 3G AHSS resulting from heat treatments compatible with the continuous galvanizing process. The ultimate tensile strength, total elongation, and work hardening behavior of the samples in uniaxial tension was shown to be a strong function of starting microstructure and intercritical annealing conditions. Samples with significant fractions of retained austenite displayed a two-stage deformation regime, resulting in higher ultimate tensile strengths but less total elongation. Three intercritical annealing cycles resulted in achieving the target mechanical property envelope for 3G AHSS.

Poster Sessions

Date: Monday, November 13
Time: 18:00-19:00
Venue: Poster Room

P-1 (C-1-1)
THE EFFECT OF ANNEALING TEMPERATURE ON THE SELECTIVE OXIDATION OF A 0.1C-6MN-2SI ADVANCED HIGH STRENGTH STEEL DURING CONTINUOUS GALVANIZING HEAT TREATMENTS

Maedeh Pourmajidian, Joseph R. McDermid
McMaster University, Canada

The effects of peak annealing temperature and annealing time on the selective oxidation and reactive wetting of a prototype medium-Mn 0.1C-6Mn-2Si third generation advanced high strength steel were investigated. Annealing heat treatments were carried out in a N_2-5vol.%H_2 –30˚C dew point process atmosphere at 800˚C and 690˚C for 120s and 600s. Surface oxide chemistries, morphologies and thickness were determined at a variety of length scales by several techniques, including SEM, XPS and TEM combined with EELS. TEM observations of the sample cross-sections revealed the formation of an internal oxide network in the subsurface grains as well as the grain boundaries. The maximum depth of the internal oxidation zone reached 5 μm in the sample annealed at 800˚C for 600s. EELS results revealed that the internal oxide network was composed of a multi-layer oxide structure with varying chemistry from the oxide core towards the outer shell. The effect of annealing temperature on the surface structure development and its impact on reactive wetting of the substrates by a Zn-0.2wt.%Al (dissolved) galvanizing bath was also explored. In contrast to the 800˚C × 120s steel, the 690˚C × 120s substrate showed significantly superior reactive wetting, owing to the much finer morphology and widely spaced distribution of the surface oxides that were formed on this sample prior to immersion.

P-2 (C-3-4)
EFFECTS OF ANNEALING TEMPERATURE AND DEW POINT ON KINETICS OF Mn EXTERNAL OXIDATION

Yusuke Okumura, Minoru Tanaka, Yusuke Fushiwaki, Yasunobu Nagataki
JFE Steel Corporation, Japan

Because the selective oxidation of Mn in steel during recrystallization annealing causes coating defects of hot-dip galvanized steel, basic research on the kinetics of

selective oxidation is important. In this study, the effects of the annealing temperature and dew point on the kinetics of Mn external oxidation were investigated experimentally, and the Mn external oxidation rate was estimated based on a diffusion equation and thermodynamic equilibrium. It was found that Mn oxidation is a diffusion limited process, as in other reports. The Mn oxidation rate increased with increasing temperature and showed a peak, and the Mn oxidation rate became dramatically slower at higher temperatures. This peak value of the Mn oxidation rate depended on the dew point, and the peak value decreased at lower dew points. It is thought that the Mn oxidation rate becomes slower at high temperature because the gradient of the Mn concentration around the steel surface becomes small at high temperature near equiliblium.

P-3 (C-5-6)
INFLUENCE OF THE ANTICORROSIVE PIGMENT ON THE CUT EDGE CORROSION OF CHROMATE-FREE PRE-PAINTED STEEL SHEETS IN RAIN WATER

Yasuaki Kawamura, Hiroyasu Furukawa,
Masamitsu Matsumoto, Kohei Ueda
Nippon Steel & Sumitomo Metal Corporation, Japan

Studies on the corrosion resistance for pre-painted steel sheets (PSS) have mainly focused on the long-term corrosion until now; however, the occurrence of red rust in the short term on the cut edge of PSS by accumulated rain water has not yet been investigated. Therefore, we performed the dipping test of chromate-free and chromate PSS in ion exchanged water and reproduced the red rust occurrence on the PSS.

The anticorrosive pigment contained in the PSS dissolved in the water, but the dissolution velocity of chromate-free pigment was slower than that of chromate pigment. Therefore, the chromate-free pigment could not fully dissolve in the rain water. As a result, the sacrificial protection of zinc at the cut edge of chromate-free PSS was prevented and there was an early occurrence of red rust. This study enabled us to solve this problem with highly water-soluble pigment.

P-4 (C-5-4)
ANALYSIS OF CORROSION BEHAVIOR OF IRON AND ZINC IN VARIOUS ATMOSPHERIC ENVIRONMENTS USING ELECTRICAL RESISTACE TECHNIQUE

Masataka Omoda, Daisuke Mizuno, Nobuyuki Ishikawa
JFE Steel Corporation, Japan

Until recently, it has been very difficult to estimate in detail corrosion behavior variations of Fe and Zn during the test periods. For this challenge, in-situ corrosion monitoring technique is useful. Therefore, in-situ change of corrosion loss has been monitored by using an electrical resistance sensor, of which corrosion loss of sensor made by evaluated material can be detected as a change of electrical resistance. In this study, in-situ corrosion monitoring using electrical resistance sensors of Fe and Zn was conducted in various atmospheric environments. And then, by comparing with each environmental factor, the impact of environmental factors on corrosion behavior of Fe and Zn was investigated. In addition, corrosion monitoring by this sensor was conducted under accelerated corrosion test, ISO16539 Method B. From the comparison of corrosion behavior in a day, it was confirmed that ISO16539 method B reproduces corrosion behavior in atmospheric environments.

P-5 (C-4-3)
INVESTIGATION ON CORROSION BEHAVIOR OF PRIMARY AL PHASE IN ZN-11%AL-3%MG-0.2%SI COATING

Tetsuya Toba, Shinichi Yamaguchi, Masamitsu Matsumoto
Nippon Steel & Sumitomo Metal Corporation, Japan

The corrosion behavior of the primary Al phase in Zn-11mass%Al-3mass%Mg-0.2mass%Si coating was investigated using Al-Zn solid solution alloys with the same composition of the primary Al phase. The immersed potentials of Al-Zn solid solution alloys were more negative than those of Zn and $MgZn_2$, the other phase in the coating. After cyclic corrosion tests on the alloys, zinc aluminum carbonate hydroxide, $Zn_6Al_2(CO_3)(OH)_{16}\cdot 4H_2O$, was detected as a corrosion product. From these results, one of the reasons for the high corrosion resistance of Zn-11mass%Al-3mass%Mg-0.2mass%Si coating is that the primary Al phase corroded selectively and $Zn_6Al_2(CO_3)(OH)_{16}\cdot 4H_2O$ formed on the coating in the early stage of corrosion.

P-6 (C-4-6)
CORROSION RESISTANCE MECHANISM OF HOT-DIP ZN-6%AL-3%MG ALLOY COATED STEEL SHEET IN CORROSION TEST IN WATER FILM FORMATION STATE

Masaaki Uranaka, Yasunori Hattori
Nisshin Steel, Co., Ltd., Japan

We prepared test specimens with steel substrate exposed by partially removing the coating layer, and subjected to a corrosion test with a water film of 5% NaCl solution applied to the surface. It was confirmed that any of coating layer exhibited protective corrosion prevention in the early stage of corrosion. On the other hand, as the test time got longer, occurrence of red rust in steel substrate exposure was suppressed in a hot-dip Zn-6%Al-3%Mg alloy coated steel sheet ("Zn-Al-Mg") than Galvannealed steel sheet (GA) and Galvanized steel sheet (GI). Upon investigating specimens conducted corrosion test using equipment analysis, dense Zinc corrosion products containing Mg were formed on steel substrate exposure of a Zn-Al-Mg, and the formation of ZnO was suppressed. Moreover, when the cathodic polarization curves of the portion where the corrosion products were formed at the steel substrate exposure were measured by electrochemical measurements, the effect of suppressing reduction reactions of dissolved oxygen were not observed in GA and GI, but reduction reactions of dissolved oxygen were suppressed in Zn-Al-Mg. From this result, it was considered that elution of the coating layer is suppressed in Zn-Al-Mg, and the effect of protecting steel substrate exposure was maintained for a long time compared to GA and GI.

P-7
EVALUATION OF HYDROGEN EMBRITTLEMENT IN ELETRO- GALVANIZED ADVANCED HIGH STRENGTH STEEL

Il-Jeong Park, Jin Ho Jung
POSCO, Korea

Effects of electro-galvanizing process and Zn coating layers formed by electro-galvanizing on hydrogen embrittlement (HE) was investigated using electro-galvanized advanced high strength steel (AHSS) through slow tensile tests

and thermal desorption analysis. Although, hydrogen is accumulated in surface of steel and slightly absorbed to the steel during the electro-galvanizing, it does not lead to HE in AHSS. Meanwhile, HE occurred in electro-galvanized AHSS after hydrogen charging and the hydrogen concentration of these specimen was approximately 5 times higher than that of hydrogen uncharged specimen. This means that the Zn layer formed by electro-galvanizing is not effective in preventing permeation of hydrogen to specimen. The objective of the present study was to investigate the causes for HE in electro-galvanized 7Mn steel using both hydrogen-charged and -uncharged specimens.

P-8 (D-2-3)
INDUSTRY 4.0 IN COATING PROCESSES ENABLED BY PROACTIVE QUALITY ASSURANCE

Helga Evers, Hans Peintinger
QuinLogic GmbH, Germany

Smart factory, high flexibility, short time to market in an industrial scale are the key words of Industry 4.0. Digitalization and growing quality requirements for high-end products are at the same time an enormous challenge, which is often in competition with efficiency targets and market driven cost-cutting measures.This paper describes the implementation experience of ExpertShell system and the achieved benefits of an innovative new Industry 4.0 technology. Major players like TATA, ArcelorMittal, USS Posco, AK Steel and Nucor have implemented this solution already.

It opens the chance for a new way of using all the available experience inside a mill to improve the workflow and increase efficiency.

This technology helps in principle all production lines in all grades but has the highest impact in challenging grades like ultra-high strength specialty steel and especially in automotive applications in CGL, CALGL and EGL lines.

The new solution has an embedded automatic improvement cycle, which makes sure that modifications and adaptations to new market requirements can be taken care of instantly. Speed of adaptation as well as reliability of the delivered quality will be the differentiator in the upcoming years. Interestingly the investment in proactive quality assurance not only improves competitive position in quality, but has proven return of invests figures below one year.

P-9
A STUDY OF SIMULATION ON WET NITROGEN GAS FLOW IN SNOUT FOR CONTROLLING Zn ASH

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Within snout, evaporation of Zn from plating bath surface is a significant source which can cause surface defects during continuous galvanizing process. In order to enhance snout cleanliness, Zn vapor, evaporated from the plating bath surface, needs to be controlled because it causes deterioration of coating quality by forming Zn ash which is a compound of Zn and oxygen. Therefore, techniques for reducing Zn ash to control the temperature of plating bath and supply of additional ambient gas such as wet nitrogen gas are important. However, as wet nitrogen gas is injected into plating bath surface, it is difficult to distribute it evenly through pipe. In this paper, we focus on finding optimized conditions through the computational fluid dynamics simulation of the wet nitrogen gas flow.

P-10 (D-6-6)
THE SELF-CALIBRATING POT CHEMISTRY LIBS SENSOR

Alexandre Nadeau, Jean-David Grenon, Marc Choquet
Tecnar Automation Ltée, Canada

In today's challenging economics for steelmaking, the need for enhanced efficiency and better quality is more than ever a daily reality. Among others, pot chemistry and pot level are two key parameters that need precision. The last 10 years has seen a laser based technology making its place in the world of pot chemistry control. Now with nearly thirty sites globally operating a 24/7 LIBS sensor, Tecnar is proud to introduce the next generation of its now established technology. The aim of the new product is to remove the need for lab analysis, usually required to calibrate the first generation instruments, thus giving full autonomy to the process personnel. Furthermore, the new generation sensor delivers a pot level measurement that is unaffected by skimming activities or dross accumulation at the surface. In this paper, we present the scientific and industrial performances of the calibration feature based on solid standards. The results show a relative standard deviation below 2%. Furthermore, thanks to the laser's micro-sampling capabilities, the soluble contents can be measured directly on the solidified pot sample, without the need to a calculus based on Fe-Al content and pot temperature.

P-11 (D-7-1)
OPTIMISATION OF AHSS ANNEALING CYCLES BY ON-LINE CONTROL OF STRIP SURFACE EMISSIVITY AND TENSILE-STRUCTURE PROPERTIES

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This paper presents the results of the development of an approach using advanced online devices to improve the overall HDG process control in terms of strip temperature, tensile properties and product microstructure. The furnace consists of high performance direct flame burners and radiant tubes fed by natural gas to achieve the desired metallurgical properties for the automotive product mix. Online strip emissivity measurement is fundamental in order to produce a variety of steel grades from interstitial free to advanced high strength steels with different C and Mn contents and different surface conditions. To comply the demand of consistency of structure-properties it was implemented a new mathematical model to skin pass mill aiming to online monitoring the tensile properties and microstructural features of the AHSS strip. This model can give important indications for a metallurgically based definition of the HDG process parameters.

The online measured yield stress as a function of the applied skin pass strain allowed calculating the MA fraction by means of the theory of Ashby. The proposed method could represent a new solution to define the optimized processing conditions to achieve the target microstructure for improved mechanical properties and forming-ability properties of dual-phase steels. Laboratory tensile tests and metallographic investigations confirmed a good agreement with the online structure-properties characteristics calculated with the mathematical model.

The analysis of online measured strip emissivity and online mechanical properties resulted the key strategy to guarantee the targeted strip quality, properties and low global energy

consumption.

P-12 (B-7-1)
CLARIFICATION OF AIR KNIFE STREAK GENERATION CONDITIONS

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In the continuous galvanizing line (CGL), adhesion of a spray of molten zinc, or so-called splash to the surface of the air knives causes longitudinal streaks on the galvanized steel strip. Air knife streak is one of the critical defects of strip surface appearance. This paper presents a clarification of the conditions for generation of air knife streaks based on experiments with a laboratory wiping simulator and a CFD analysis. Although adhesion of splash to the front edge or the upper part of the air knife had an insignificant effect on surface quality, blocking of the slit gap greatly affected the generation of air knife streaks. The CFD analysis revealed that blocking of the slit gap led to a reduction of the impingement pressure of the wiping gas. Thus, the reduction of the impingement pressure by blocking of the slit gap was clearly the main cause of air knife streaks.

P-13 (B-7-4)
INTEGRATED SOLUTION OF ELECTROMAGNETIC STRIP STABILIZATION AND AIR KNIVES: FIRST INSTALLATIONS, EXPERIENCES AND RESULTS

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The strip vibration damping results and the increased added value to be achieved through the use of an electromagnetic strip stabilization system depend significantly on the optimum arrangement of the strip stabilization system in relation to the air knife system. The general rule is: the better the electromagnetic strip stabilization system is integrated into the air knife arrangement and the closer the strip stabilization system is located to the level of the air knife lips (i.e. the actual point of technology), the better the results for vibration damping and crossbow reduction are to be expected. Vice versa the best coating results and a uniform coating layer of the zinc layer defined by the air knives also depend on the optimum arrangement and performance of the electromagnetic strip stabilizer.

In 2016 EMG Automation and DUMA-BANDZINK developed a fully integrated strip stabilizer / air knife solution based on EMG's electromagnetic strip stabilizer and the advanced air knife technology of DUMA-BANDZINK: the "integrated solution".

This combination of the two high end technological solutions allows highest and most accurate zinc coating results, the creation of optimum conditions for a closed loop control circuit and an enhanced control of the overall coating process. The design of the "integrated solution" is optimized for free view of the running strip, easy maintenance as well as for lip cleaning issues and leads in addition to a significant noise reduction. The proximity of the electromagnetic strip stabilization system to the air knife lip enables the user to draw direct conclusions with regard to the strip position and shape between the air knife lips, thereby enabling corrections to be made to the position of the air knife without any delay.
Due to the exact knowledge of the strip position in two dimensions, the strip shape, the strip behavior and the direct mechanical (and electronically) coupling of the air knife arrangement with the strip stabilizer, a new quality of parameters is achieved for optimum air knife control. The fully integrated design promises not only best damping and coating results, but provides also an optimized system handling for the operators in case of any production line works. Above all the "integrated solution" allows the potential users to increase throughput and to produce coated strips with improved surface characteristics.

This paper will mainly concentrate on realized results and experiences of the first installations of the integrated solution. Additionally the technological framework conditions for the integrated system and the system design will be introduced.

P-14 (B-7-5)
IMPACT OF SNOUT HEAT INSULATION ON THE HNX FLOW

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The current and claimed efficient practice against Zn dust is to heat insulate the snout supposedly because Zn cannot condensate on walls and so fall on the strip. That explanation is unfortunately very unsatisfactory because the HNX temperature in the snout is always lower than the zinc condensation temperature
The present work has the objective to analyze the HNX flow in the snout by CFD modeling using a simplified geometry. The purpose is to make a "differential study" considering various level of heat insulation as well as bottom water injection.
The key finding is that the buoyancy phenomena induced by the temperature difference between the walls, the snout shoe and the strip is the driving force of the flow. The strip has a much lower impact due to its relative low Reynolds number compared to the Grassof one. The lower the heat insulation and the higher the HNX circulation in the snout is. This could be the true reason why a good insulation is beneficial against the Zn dust defects.

P-15 (B-1-4)
INDUCTIVE STRIP HEATING

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Ampere's, Faraday's and Ohm's laws are the theoretical base of induction heating. After a reminder of these 3 physical laws, this paper will describe the three basic configurations of strip heating : Proximity, Longitudinal and Transverse flux.
In a second part, this paper will present typical examples of industrial longitudinal flux strip heaters. They show the present maturity of that technology well accepted in the worldwide steel industry to heat magnetic strip.
In a third part, a special attention will be given to the transverse flux concept adapted to non magnetic strip heating. This paper will present an innovative approach applied in an industrial 3.3 MW strip heater commissioned in 2016.

P-16 (B-2-1)
NUMERICAL INVESTIGATION OF FLOW CHARACTERISTICS OF GALVANIZING LINE AIR KNIFE

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Flow of planar air jet (air knife) impinging on flat solid surface at low jet-to-plate distance, *H* to jet-opening, *d* ratio (*H/d* < 20) is reported. Firstly, wall pressure and shear stress profiles of steady jet flow are simulated at various *H/d* and jet *Re*. Wall pressure profile and the maximum value are *H/d* dependent when it is greater than the critical *H/d* but exhibit a high degree of insensitivity when *H/d* is lower. The critical *H* is approximately of the same length of the jet potential core. Study of the unsteady behaviors such as the jet flapping mode and frequency dependency on *H/d* and *Re* shows a periodic fluctuation of the maximum wall pressure location and amplitude. This phenomenon can be explained by the anti-symmetric shedding of the vortices.

P-17 (B-2-3)
COATING FILM EVOLUTION SUBJECT TO TIME DEPENDENT PRESSURE AND SHEAR STRESS PROFILES

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Impinging planar jets are a widely used method for removing excess drag-out coating material from steel strip and thereby to control the final thickness of the coating. A wide range of possible coating defects are known to occur for this process, many of which are suspected to have their origin in the spatio-temporal characteristics of the air jets. It is therefore of interest to improve understanding of the link between the jet behaviour and the evolution of the coating free surface. In this paper, the coating response within the effective jet wiping region and immediately downstream is investigated using a numerical model. The model includes the density and viscosity of the coating fluid and the speed of the strip as it passes through the jet impingement region. The magnitude of the pressure and shear stress distributions acting on the coating surface along the strip are imposed as time-varying inputs.

P-18 (B-2-4)
QUALITY INTELLIGENCE PACKAGE DEDICATED TO STATE-OF-THE- ART PROCESSING LINES FOR A COMPREHENSIVE APPROACH

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Primetals Technologies France SAS, France

In order to serve the market demand, main goals for steel producers specialized in annealed and galvanized materials are to focus on new steel grades with a large move from conventional steels to high-strength steel grades, new coatings and quality improvement (mechanical properties, surface aspect …). This shall be done at the earliest stage of the production while trying to reduce at the same time operational costs with a dedicated preventive maintenance. The manufacture of basic and high-strength steels generally requires a modification of the production steps along the entire value chain. Besides the necessity to define specific entire plant parameters and machine sizing, this new generation of materials or coatings involves other matters that need to be addressed, for instance, precisely monitored upstream processes, furnace control with pre-oxidation or rapid cooling system. All of these factors have a major impact on the end-product quality.

With a continuous aim of driving improvement, Primetals Technologies has developed a metallurgical expertise service sustained by a complete plant scale solution with a global through process approach based on a large spectrum of mechatronic packages including a process expert system for just-in-time warnings and decision making, condition monitoring and surface inspection systems. Thanks to this global approach and with the support of in-house experts assisting customers in the development of advanced or new steel grades, the most demanding challenges are close at hand.

This paper presents the latest solutions developed and implemented by Primetals Technologies dedicated to modern galvanizing lines with up-to-date equipment and process, associated with specific support.

P-19 (B-2-5)
ADVANCEMENTS IN MEASURING CGL SURFACE CLEANLINESS ONLINE

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TolketStarTool (TST), Star Tool & Die Works, USA

Online measurement systems for modern process lines are becoming more commonplace and necessary. A state-of-the-art surface cleanliness measurement system has been used for measuring surface contaminants including iron fines and oil residue on the moving metal product, continuously, and without contacting the metal's surface. Recently this system has demonstrated its unique capabilities to allow cleaning sections to be operated by measuring surface cleanliness: the single metric of importance for cleaning sections.
The function of the system will be presented. The benefits of having surface cleanliness data along the entire coil will be highlighted. Examples of case studies will be shared. The high-resolution data enables utilizing Statistical Process Control (SPC) for the cleaning section instead of guesswork that often entails sampling minuscule areas at the coil's extremities haphazardly and often hazardously. The system enables process control of the cleaning section by identifying and optimizing critical components of the cleaning section while also providing facts which can lead to correct decisions about choosing to idle or disable systems - including brushes - that prove redundant. Details of actual case-study data will be presented to illustrate and support the technical points.
Cleaning sections and surface cleanliness are a topic of growing importance. The more common use of radiant tube furnaces for premium quality steels requires cleaning done before entering the furnace. The growing array of AHSSs with surface wettability challenges and other more stringent requirements for quality benefit from clean surfaces. Reducing costs related to energy, consumables, line down-time, labor, safety, and other things are those which can be reduced once the surface cleanliness of the sheet is known. The paper will illustrate how some of these goals have been met or could be met with the system.

P-20 (B-6-2)
THE EFFECT OF FE-ZN INTERMETALLIC COMPOUNDS ON LIQUID ZN- ASSISTED EMBRITTLEMENT OF GALVANIZED TWIP STEEL

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TWIP steels are known to be an attractive candidate for automotive application owing to their superior strength and ductility. However, the application has been restricted by the cracks which are generated by Liquid Metal Embrittlement (LME), because the substrate alloy gets exposed to liquid Zn.

The present study attempts to suppress LME cracks in a TWIP steel by controlling Fe-Zn intermetallic compounds which have higher melting points in comparison with pure Zn. Hot tensile tests are conducted with different heating rates to verify their effect on LME. The heating rate alters the microstructures at the coating/substrate interface. Consequently, the embrittlement becomes severe with higher heating rate at 700 °C. Furthermore, Resistance Spot Welding (RSW) was carried out for the TWIP steel specimens which are coated with different Fe-Zn intermetallics. The number and length of the LME cracks depend on the major intermetallic in the coating, which suggested RSW can be improved by the formation of the Fe-Zn intermetallic compounds.

P-21
MICROSCOPIC ANALYSIS STUDY ON SLIDING MECHANISM BETWEEN GALVANNEALED STEEL AND DIE SURFACES DURING FLAT SLIDING TEST

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Wataru Tanimoto[2], Yuji Yamasaki[1], Kazuhiko Higai[1],
Hideo Kijima[1]
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We have investigated the surfaces of a galvannealed steel sheet (GA) and a die after use for a flat sliding test using various micro-beam analysis techniques in order to clarify the sliding mechanism. Low-voltage scanning electron microscopy (LV-SEM) observations and 3-dimensional SEM (3D-SEM) analysis revealed the shape and composition of the adhesive materials on the die surfaces. The adhesive materials are (1) Al oxide – Fe-Zn alloy composite tightly bonded to ridges of the die surface and (2) Fe-Zn alloys located in the hollows of the die surface. The former material is viewed as built-up edge-like adhesive layers on the die surface. The formation of this material differs according to the position of die surface along to the sliding direction. Our results revealed that these differences are a result of Al transferred from GA surface. The Fe-Zn alloy was also detected on the die surface by X-ray diffraction (XRD), but the diffraction peaks were different from those of Fe-Zn alloys on the original GA surface. A grazing incident XRD (GI-XRD) also revealed that similar XRD peaks appeared on the GA surface after the sliding test. These results suggest that the GA surface were deformed and partially transferred to the die surface during the sliding test.

P-22 (D-5-2)
WHITE SPOT DEFECT ON HIGH-TENSILE STRENGTH GALVANNEALED STEEL SHEET

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Production of high-tensile strength GA which use base steel with high Mn content, there is a case that white spot defect occurs on the coating surface. The occurrence mechanism of this defect is estimated as follows from above results. Mn oxide precipitated on steel surface during annealing is deposited and grows up on the hearth roll surface locally. The Mn oxide on the hearth roll surface is transferred on steel surface during annealing. Transferred Mn oxide inhibits the formation of Fe-Al layer on the steel surface in the coating bath. Because of the absence of the Fe-Al layer, Zn-Fe alloying reaction progresses on that portion in the coating bath. The locally grown Zn-Fe alloy inhibits the wiping of zinc, and coating layer thicken partially. As a result, Fe content in the coating layer decreases, and that portion exhibits white spot appearance defect.

P-23 (C-6-4)
RELATIONSHIP BETWEEN SUBSTRATE CRYSTAL ORIENTATIONS AND DISTRIBUTION OF INITIAL ELECTRODEPOSITION

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The effect of substrate crystal orientation on the initial distribution of electrodeposit in Zn and Ni plating with a deposit of 0.1g/m^2 or less was investigated by using chemically polished polycrystalline low carbon Al-killed steel sheets. It was identified that distributions of Zn and Ni were conformed to the substrate crystalline grain sizes. However, the trend of the initial distribution was different between Zn and Ni. Zn deposits was affected by the consistency between the Zn(002) and α-Fe orientation. On the other hand, the Ni deposits had a distribution depending on the face density of α-Fe. It is thought that this was caused by displaced Ni plating. Therefore, we confirmed by using Fe plating on Ni substrate which is without displaced deposition. As a result, initial distribution of Fe on the Ni was affected by the consistency between the deposited Fe and substrate Ni orientation same as relationship between Zn and α-Fe.

P-24
AN ENVIRONMENT-FRIENDLY CONVERSION COATING FOR HOT-DIP GALVANIZING FORMULATED WITH VANADATE(IV) SOLUTION

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The vanadate (IV) (species with tetravalent vanadium) conversion treatment requires use of peroxoborate functioning as a accelerators in aqueous metavanadate-based solutions. The V(IV) conversion coating is investigated through potentiodynamic measurement and X-ray photoelectron spectroscopy. The V(IV) conversion coating is composed of hydroxide, phosphate, and oxide, containing V(IV) and a small amount of V(III). The poor crystallinity of V(III) hydroxide particles acts as germ nucleuses that facilitate the coating formation. The V(IV) species imparts excellent corrosion protection for substrates owing to passivation action. The corrosion inhibition of coatings functions mainly by the suppression of oxygen reduction reactions. However, it should not be ignored that Al-containing intermetallic compounds acting as local anodes also affect the corrosion inhibition.

P-25 (A-5-1)
NOVEL ZINC-NANOCONTAINER COMPOSITE COATINGS FOR INTELLIGENT CORROSION PROTECTION

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Currently the established way for achieving enhanced active corrosion protection by release of inhibitors is to apply organic coatings containing pigments that can leach these active agents. The drawback of these coating systems is the uncontrollable leaching of inhibitor into the environment leading to pollution and a shortened corrosion protection lifespan, as the release also occurs when the inhibitors are not needed. The aim therefore has to be to develop novel coating system where the release is triggered case sensitively only by corrosion. Storing inhibitors and self-healing agents loaded into nano-containers inside the zinc coating is the most ideal solution: the storage insight the zinc coating ensures safe long-term storage and release absolutely only when corrosion occurs. In this paper an overview will be given about how such zinc composite coatings can be prepared and what new possibilities for corrosion protection and self-healing might be achieved.

P-26
MICROSTRUCTURES AND TEXTURES OF THE PHASES CONSTITUTING HOT-DIP Zn-Al-Mg COATINGS ON A SHEET STEEL

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The phases constituting hot-dip Zn-Al-Mg alloy coatings with different Al contents on an extra deep drawing quality sheet steel were investigated in terms of the development of microstructures and microtextures. In the Zn-2.5 wt.% Al-3 wt.% Mg coating, the crystallization of the primary Zn single phase was followed by pseudo-eutectic reaction forming a mixture of eutectic (Zn) and $MgZn_2$ phases, and then the remaining liquid solidified into a ternary eutectic structure consisting of (Zn), $MgZn_2$ and Al phases. In the Zn-6 wt.% Al-3 wt.% Mg coating, due to increase in Al content, the Al alloy phase appeared to nucleate first with developing a large scale of dendritic growth. The eutectic structures consisting of the (Zn) and $MgZn_2$ phases were observed at the inter-dendritic region. The remaining liquid finally solidified to conduct a hexagonal shape of the eutectic structure consisting of (Zn) and Mg_2Zn_{11} phases. Cracking phenomena taking place during bending of the Zn-Al-Mg coatings have been discussed on the basis of these experimental observations in the phases in relation to their material parameters.

P-27
MICROSCALE DEFORMATION OF THE Γ AND δ_{1P} PHASES IN THE FE-ZN SYSTEM

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Deformation modes of the intermetallic phases in the hot-dipped galvannealed steel, the Γ and δ_{1p} phases, have been investigated via compression tests of single-crystal micropillar specimens machined by the focused ion beam method. The {110}<111> slip system has been confirmed to operate by slip trace analyses in the cubic Γ phase and the (0001) $<11\bar{2}0>$ slip system has been observed in the hexagonal δ_{1p} phase.

P-28
THE FILM FORMING MECHANISM OF CHROMIUM FREE PASSIVATION PROCESS IN THE TANNIC ACID SYSTEM FOR HOT DIP GALVANIZING COATING

Zhefeng Xu, Zhiwang Zheng, Haoqing Zheng, Quan Xu
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In this paper, tannic acid, fluorine titanate and silane coupling agent passivation solution were used to prepare hot dip galvanized steel sheet passivation coating. And then the mechanism of film formation was studied. The microstructure, surface composition, layer by layer element distribution and molecular structure of galvanized steel sheet passivation coating were revealed in scanning electron microscopy, X ray photoelectron spectroscopy, glow discharge atomic emission spectrometry and infrared spectrometry, respectively. The results show that: in one hand, using the silane coupling agent would produce many sol-gel particles in the passivation solution. On the other hand, tannic acid would produce spatial mesh structure. Therefore, passivation solution would generate a smooth, uniform and compact galvanized steel sheet passivation coating or membrane.

P-29
INFLUENCE OF ZINC PURITY ON FORMATION OF ZnO NANOFIBER FILMS BY ANODIZING OF ZINC

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Hokkaido University, Japan

For possible application of anodizing technique to surface treatments of galvanized steels, zinc sheets with different purities were anodized in $KHCO_3$ aqueous electrolyte. The nanowire films with a wire diameter of 200 nm were formed regardless of the purity of zinc, but the adhesion of the nanowire films to the zinc substrate was high enough only when high purity 99.99% zinc was used. The nanowires formed on the 99.5% pure zinc containing 0.3 mass% copper were readily detached from the substrate. Copper enrichment occurred in the metal immediately beneath the anodic film during anodizing, leading to the oxygen gas generation. The reduced adhesion of the nanowire films on the copper-containing zinc may be associated with the gas generation.

P-30 (A-6-2)
THE EFFECT OF ADDITIVES ON ZINC ELECTLODEPOSITION ON THE STEEL PLATE

Akinobu Kobayashi, Takashi Futaba, Yasuto Goto
Nippon Steel & Sumitomo Metal Corporation, Japan

From the viewpoint of electric charge, the effect of additives on Zn electrodeposition on steel were investigated. Quaternary ammonium salt (QAS) and polyethylene glycol (PEG) were selected as the cation and non-ion additive. Zn was electrodeposited with the bath including additives on the steel. As a result, QAS and PEG were found to effect the overpotential of Zn electroplating and the orientation indexes of Zn (002) were also changed to those of Zn (100) and Zn (110).

Moreover, a pre-adsorption method was applied for investigation of the additive. As a result, the orientation of Zn was affected by QAS at the initial stage of progress of electroplating. This means that the character of the initial layer between the steel and the plating could be changed from the other part of plating with pre-adsorption.

P-31 (A-6-3)
EFFECT OF OXIDATION ON EMISSIVITY FOR DP780 AND DP980 STEELS

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Temperature control during heat treatment of AHSS steels is critical for obtaining the desired mechanical properties, but accurate pyrometry requires detailed knowledge of the spectral emissivity of the steel. The present work explores the relationship between spectral emissivity and the surface state of two types of cold-rolled dual-phase steels, DP780 and DP980, along with the consequential impact on pyrometrically-inferred temperatures. Results show that the spectral emissivity of DP780 is more influenced by the heat treatment cycle than that of DP980. SEM observations and GDEOS measurements show that the oxide coverage and thickness are smaller for DP980 when compared to DP780. These measurements indicate that low wavelength spectral emissivity increases with oxide thickness and coverage.

P-31 (A-6-4)
EFFECT OF TEMPERATURE DEVIATION DURING INTERCRITICAL ANNEALING OF HSLA AND DP980 STEELS

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[1]Ecole Polytechnique de Montreal, Canada, [2]University of Waterloo, Canada

The microstructure and mechanical properties of galvanized advanced high-strength steels (AHSS) such as DP980 are known to be more sensitive to variations in intercritical annealing temperature compared to high strength low alloy (HSLA) steels. The objective of this research is to define the temperature range that will ensure that DP980 steels have strength and elongation properties conforming to specification. Results confirm that the mechanical properties of DP980 are strongly affected by deviations in intercritical annealing temperature of ±50 K. The yield strength of DP980 annealed at 50 K below nominal temperature exceeds the minimum ASTM A1089 requirement of 550 MPa only by 5 MPa. In the case of DP980 annealed 50 K above the nominal temperature. The properties of HSLA grade 50 were comparatively much less sensitive to annealing temperature. These results suggest that intercritical annealing temperature excursions must be maintained well below ±50 K considering the other process uncertainties, which motivates development of improved pyrometry techniques for closed-loop temperature control.

Plenary Lectures

Date: Tuesday, November 14
Time: 8:30-9:50
Venue: Room A
Chairs: Hiroki Habazaki (Hokkaido University, Japan)

Plenary Lecture 3 8:30
SUSTAINABLE PRODUCTION AND TECHNOLOGY CHALLENGES FOR GALVANIZED STEEL SHEETS

Doo-Jin Paik[1], Moon-Hi Hong[2]
[1]POSCO, Korea, [2]POSCO C&C, Korea

Hot-dip galvannealed (GA), galvanized (GI) and aluminized steel sheets have been increased in production, mainly for automobiles, home appliances and building materials in Korea. Also #7 CGL, as an exclusive production line for advanced high strength steel(AHSS), in Gwangyang steel works has been completed in April, 2017 and POSCO's ready to produce various AHSS, especially, including the high manganese twinning induced plasticity (TWIP) steel. In GA steel sheets, it is very important to design the chemical composition of steel substrate in the viewpoint to achieve the balance between reducing the surface oxidation and securing the mechanical properties. In addition, steel making, hot-rolling, cold-rolling and galvannealing processes have to be also carefully controlled. The adhesive-strength between GI coating and steel substrate with a different spangle size has been examined. It is known that the cooling-rate affects not only spangle size and dendrite morphology but also mechanical properties related to the crystallographic orientation. We developed an aluminum coating with magnesium addition using stainless steel substrate instead of conventional steel substrate for automotive exhaust system and Al-Si-Mg ternary alloys were investigated in terms of corrosion resistance mechanism. Thus, in the present paper, the results of recent technological development at POSCO's hot-dipped GA, GI and Al steel sheets will be introduced.

Plenary Lecture 4 9:10
DEVELOPMENT AND PERSPECT OF ZINC AND ZINC-ALLOY COATED STEEL SHEETS IN CHINA

Qifu Zhang, Sheming Jiang
China Iron & Steel Research Institute Group, China

With Chinese economic expansion and consumption structure update, the galvanizing industry in China went through rapid growth. And now China has the largest production output in the world due to steadily increasing demands of construction, home appliances, and automobile industry and so on. This paper gives overviews of development and application of zinc and zinc alloy coated steel sheets in China in recent years, and briefly introduces present condition of continuous galvanizing lines (CGLs). Moreover, the paper highlights recent progress in galvanized advanced high strength steels (AHSS), and galvanized 3rd generation automobile steels, including Q&P steel, medium-manganese steel and so on. Developments of Zn-Al-Mg coatings, functional coatings and environmentally friendly post-treatments are also described. The paper finally discusses the development trend of zinc and zinc-alloy coated steel sheet in China.

A-4 Corrosion Behavior

Date: Tuesday, November 14
Time: 10:10-12:20
Venue: Room A
Chairs: Dominique Thierry (French Corrosion Institute, France)
Hideki Katayama (National Institute for Materials Science, Japan)

A-4-1 *Keynote* 10:10
FUNDAMENTAL ASPECTS OF CORROSION OF PRESS HARDENED GALVANIZED STEEL

Achim Walter Hassel
Johannes Kepler University Linz, Austria

Press hardened galvanized steel is an innovative product that is produced from hot dip galvanized steel with a subsequent austenitisation and quenching steps. The process causes an interdiffusion of iron and zinc resulting in a conversion of the zinc alloy coating into a coating that consist of Zn saturated α-iron and Γ-FeZn. The corrosion protection of this coating in cyclic corrosion tests is around 5 times more efficient due to the formation of complex and relatively insoluble layer of corrosion products consisting of akaganeite, hydrozincite and simonkolleite. Chances and challenges of the identification of these corrosion products are discussed. The higher nobility of the mixed phase coating as compared to the pure zinc alloy can be quantified and is sufficient for an effective corrosion protection.

A-4-2 *Invited* 10:40
GALVANIC CORROSION OF A ZINC-STEEL COUPLE IMMERSED IN AQUEOUS $MGCL_2$ SOLUTION

Eiji Tada, Atsushi Nishikata
Tokyo Institute of Technology, Japan

Galvanic corrosion behavior of a zinc-steel couple was investigated in $MgCl_2$ solutions of various concentrations. Two types of galvanic couples of zinc and steel were prepared to measure open circuit potential (OCP) and galvanic current during immersion in the solutions. It was found that OCPs during the immersion depended on $MgCl_2$ concentration and they shifted to more negative values with increasing $MgCl_2$ concentration. It was also found from the results of galvanic current that dissolution rate of zinc increased with increasing $MgCl_2$ concentration. These results indicated that cathodic reduction reaction taking place on steel was enhanced with increasing $MgCl_2$ concentration.

A-4-3 *Invited* 11:00
REAL-TIME MICROELECTROCHEMICAL OBSERVATIONS OF INITIATION AND VERY EARLY STAGE OF CORROSION ON STEELS

Izumi Muto, Yu Sugawara, Nobuyoshi Hara
Tohoku University, Japan

A detail of the microelectrochemical system for *in situ* high-resolution optical microscopy was reviewed. For Type 304 stainless steel (Fe-18Cr-8Ni), it was directly observed that the metastable and stable pits were initiated at MnS inclusion/steel boundaries in NaCl solutions. The corrosion morphology in the early stage of pitting on AISI 1045 ferrite-pearlite steel (Fe-0.45C) was observed in boric-borate buffer solutions with NaCl at pH 8.0. The pits initiated by micro-scale polarization were in the pearlite only and not in primary ferrite. The initial pits were polygonal or rod-like in

shape, and the growth direction of the pits was found to be the same as that of the pearlite lamellae. Under galvanostatic anodic polarization, the dissolution behavior of 55%Al-Zn coated steel was also observed in NaCl solutions. The Zn-rich phases were clearly confirmed to corrode at lower potentials than the dissolution potential region of the Al-rich matrix phases.

A-4-4 11:20
ATMOSPHERIC CORROSION BEHAVIOR OF GALVANIZED STEEL SHEET IN ASIA

Tadashi Shinohara[1], Le Thi Hong Lien[2],
Amnuaysak Chianpairot[3], Ekkarut Viyanit[3]
[1]National Institute for Materials Science, Japan, [2]Vietnamese Academy of Science and Technology (VAST), Vietnam, [3]National Metal and Materials Technology Center (MTEC), Thailand

The exposure test results for galvanized steel sheet at 16 sites in Japan are reported. The exposed surface of coupons were exposed to skyward and groundward. The corrosion rate, CR, of galvanized steel sheet, CR[Zn], increases with increasing temperature, and it was less than 1/10 of CR of carbon steel, CR[CS]. The CR[Zn] value increases with increasing airborne salinity, S, and the dependence of CR[Zn] on S is stronger for groundward-exposure than for skyward-exposure, because the deposited sea salt on the surface exposed to groundward was not washed away by rain. The measured corrosion rates were higher than the estimated values with the advocated formula by ISO. These results show that in the Asian region there is a risk that the corrosion rate will be underestimated if the ISO-formula is used. Thus it was confirmed that an estimation formula suited to the Asian region is needed.

A-4-5 11:40
THE INFLUENCE OF THE COMPOSITION OF Zn, Mg CORROSION PRODUCTS ON CORRSION PROTECTION

Mamoru Saito, Takehiro Takahashi, Kiyokazu Ishizuka
Nippon Steel & Sumitomo Metal Corporation, Japan

In this study, mass loss of steel sheets and Zn sheets that coated by zinc oxide and magnesium oxide were estimated under CCT condition in order to elucidate the corrosion protection by corrosion products. As a result, magnesium oxide inhibited corrosion of steel sheet due to barrier function and passivation of steel with pH rising, and it also inhibited corrosion of Zn sheet due to barrier function. Zinc oxide inhibited corrosion of steel sheet due to passivation of steel with pH rising, but it promoted corrosion of Zn sheet due to high water retentivity.

A-4-6 12:00
CROSS SECTIONAL ELEMENTAL MAPPING OF UNDER FILM CORROSION OF GALVANIZED STEEL SHEETS BY CONFOCAL XRF ANALYSIS

Koji Akioka[1], Takashi Doi[1], Ryota Yagi[2], Tsuyoshi Matsuno[3], Kouichi Tsuji[3]
[1]Nippon Steel & Sumitomo Metal Corporation, Japan, [2]Nippon Steel & Sumikin Technology Corporation, Japan, [3]Osaka City University, Japan

For understanding the under-film corrosion of the painted steel sheet, the behaviors of elements in the solid–liquid interface are important. X-ray fluorescence spectrometry (XRF) is thought to be an effective analysis technique because element distribution information can be measured non-destructively. Moreover, the micro-XRF technique using the confocal optical system enables non-destructive observation of the test specimen cross-sections. This time, the process of under-film corrosion of painted galvannealed steel sheet was investigated by confocal micro-XRF. To utilize the merit of the non-destructive analysis, the cross-sectional elemental maps of the same field of view were observed every 120 h. The cross-sectional elemental maps obtained by the XRF non-destructive method were compared to the cross-sectional scanning electron microscopy/energy dispersive X-ray spectrometer (SEM/EDS) images obtained by a destructive method.

A-5 Microstructure, Physical Properties I

Date: Tuesday, November 14
Time: 13:40-15:30
Venue: Room A
Chairs: Myriam Brochu (Ecole Polytechnique de Montreal, Canada)
Norihiko L. Okamoto (Institute for Materials Research, Tohoku University, Japan)

A-5-1 (P-25) *Keynote* 13:40
NOVEL ZINC-NANOCONTAINER COMPOSITE COATINGS FOR INTELLIGENT CORROSION PROTECTION

Michael Rohwerder, The Hai Tran
Max-Planck-Institut für Eisenforschung GmbH, Germany

Currently the established way for achieving enhanced active corrosion protection by release of inhibitors is to apply organic coatings containing pigments that can leach these active agents. The drawback of these coating systems is the uncontrollable leaching of inhibitor into the environment leading to pollution and a shortened corrosion protection lifespan, as the release also occurs when the inhibitors are not needed. The aim therefore has to be to develop novel coating system where the release is triggered case sensitively only by corrosion. Storing inhibitors and self-healing agents loaded into nano-containers inside the zinc coating is the most ideal solution: the storage insight the zinc coating ensures safe long-term storage and release absolutely only when corrosion occurs. In this paper an overview will be given about how such zinc composite coatings can be prepared and what new possibilities for corrosion protection and self-healing might be achieved.

A-5-2 *Invited* 14:10
SOLID Fe/LIQID Zn INTERFACIAL REACTION OF HOT-DIP GALVANIZED Fe-Si ALLOY SHEETS

Naoki Takata, Kunihisa Hayano, Asuka Suzuki,
Makoto Kobashi
Nagoya University, Japan

In order to understand the effect of solute Si (in the steel sheet) on the interfacial reaction between liquid Zn and solid Fe (α-Fe phase) in the hot-dip galvanized steels, a change in the interfacial microstructure between Zn coating and Fe substrate in Fe–Si alloy sheets hot-dipped in Zn melt with dipping time at 460ºC was examined. The chemical compositions of the studied alloys were Fe–0 Si (pure Fe) and 1 Si (wt.%). In pure Fe sheet, the Fe–Zn intermetallic layers form at the interface between solid Fe and liquid Zn at an early stage of dipping and subsequently grow to approximately 60 μm in thickness after 600 s. In Fe–1Si alloy, the thickness of Zn coating substantially increases to beyond 500 μm after 600 s. In contrast, the thickness of

the Fe–Si alloy sheet in the dipped sample continuously decreases till 60 s and then is reduced significantly after 600 s. The thickness loss in the later stage of dipping is more significant in the Fe-Si alloy with higher Si content. These results indicate a significant Fe dissolution into liquid Zn could occur at the later stage of dipping the Fe–Si alloy in Zn melt, which is distinguished from the interfacial reaction between pure Fe and liquid Zn. The unique interfacial reaction observed in Fe–Si alloys is discussed in terms of thermodynamic calculation of the Fe–Zn–Si ternary system.

A-5-3 14:30
EFFECT OF STEEL SUBSTRATE ALUMINUM ON GALVANNEALING KINETICS OF DUAL PHASE STEELS

Venu Gopal Krishnardula, Chann Chen Cheng
ArcelorMittal Global R&D, USA

Galvannealed coatings contain various Fe-Zn phases such as gamma, delta and zeta phases. These phases play a crucial role during press forming for automotive applications and hence, a balanced combination of these phases is desired for good stamping performance. These Fe-Zn phases are formed as a result of inter-diffusion between iron and zinc during the hot dip and galvannealing treatment. The kinetics of this reaction between iron and zinc are dependent on the incoming steel surface chemistry in addition to the zinc bath chemistry and galvannealing heat treatment conditions. In this study, the authors studied the effect of steel substrate aluminum content on galvannealing kinetics. Two dual phase steels (0.04- 0.10 wt.% C, 2.0 wt.% Mn + Cr) containing no Al and 0.5 wt.% Al were produced in an industrial continuous galvanizing line in the same production campaign. Both steels were galvannealed at various temperatures. Al containing steel exhibited faster galvannealing kinetics than the steel without Al. The paper presents the experiments and discusses the results in terms of the coating microstructure, composition and adhesion behavior.

A-5-4 14:50
IN-SITU OBSERVATION OF THE CRYSTALLIZATION AND GROWTH BEHAVIOR OF Fe_2Al_5 INTERMETALLIC COMPOUND ("TOP DROSS") IN THE MOLTEN ZINC USING X-RAY TRANSMISSION IMAGING METHOD

Sho Katsura[1], Noriaki Nakatsuka[1], Toshiki Sato[1], Hideyuki Yasuda[2]
[1]Kobe Steel, Ltd., Japan, [2]Kyoto University, Japan

In-situ X-ray transmission imaging experiments were performed to the simulated molten zinc baths of CGL in order to clarify the nucleation and growth behavior of Fe_2Al_5 solid intermetallic compounds called "top dross". Zinc alloy ingot containing a small amount of Fe and Al (0.29 mass% Al and 0.07 mass% Fe) was melted in a high vacuum atmosphere and cooled by various rates. The *in-situ* X-ray transmission observations were performed during the cooling process. The nucleation and growth behavior of Fe_2Al_5 particles can be observed directly. The nucleation behavior is strongly affected by cooling rate, as cooling rate gets faster, the average particle size gets smaller and the number of particles increases. It is suggested that we have a possibility to control their size or number of dross particles by controlling bath temperature. Their nucleation behavior also suggests that they need a certain amount of Al, Fe supersaturation or supercooling in order to nucleate new dross particles in the bath. The required supercooling temperature was calculated. *In-situ* X-ray imaging method can be a promising technique to understand the nucleation or growth behavior of dross particles generated in CGL baths.

A-5-5 15:10
KINETICS OF REACTIVE DIFFUSION BETWEEN LIQUID Zn AND SOLID Ni

Minho O, Shuhei Murakami, Masanori Kajihara
Tokyo Institute of Technology, Japan

The kinetics of the reactive diffusion between liquid Zn and solid Ni was experimentally examined using Ni/Zn diffusion couples. The diffusion couples were prepared by an isothermal bonding technique and then immediately annealed in the temperature range of T = 803–863 K for various times up to 7.2 ks (2 h). During annealing, an intermetallic layer of the γ phase is formed at the original Ni/Zn interface in the diffusion couple. The mean thickness of the intermetallic layer is proportional to a power function of the annealing time. The exponent n of the power function takes values of 0.51–0.60 under the present annealing conditions. When growth of an intermetallic layer with uniform thickness is controlled by volume diffusion, n is equivalent to 0.5. Since n is rather close to 0.5, volume diffusion is the predominant rate-controlling process of the layer growth.

A-6 Microstructure, Physical Properties II

Date: Tuesday, November 14
Time: 15:50-17:30
Venue: Room A
Chairs: Marie-Laurence Giorgi (CentraleSupelec, France)
Naoki Takata (Nagoya University, Japan)

A-6-1 *Invited* 15:50
PLASTIC DEFORMATION AND FRACTURE BEHAVIOR OF SINGLE CRYSTALS OF THE INTERMETALLIC COMPOUNDS IN THE FE-ZN SYSTEM

Norihiko L. Okamoto[1,2], Yukichika Hashizume[1], Shota Michishita[1], Haruyuki Inui[1]
[1]Kyoto University, Japan, [2]Now at Tohoku University, Japan

Micropillar compression and microbeam bending testing of single-crystals of the Γ phase have been conducted. The Γ phase exhibits significant plastic deformability in the single-crystal form during micropillar compression. The operative slip system in the Γ phase is determined to be {110}<111>. The Γ phase fractured in a brittle manner during microbeam bending. The fracture toughness of the Γ phase estimated by the microbeam bending testing is considerably small compared to that for 6H-SiC.

A-6-2 (P-30) 16:10
THE EFFECT OF ADDITIVES ON ZINC ELECTLODEPOSITION ON THE STEEL PLATE

Akinobu Kobayashi, Takashi Futaba, Yasuto Goto
Nippon Steel & Sumitomo Metal Corporation, Japan

From the viewpoint of electric charge, the effect of additives on Zn electrodeposition on steel were investigated. Quaternary ammonium salt (QAS) and polyethylene glycol (PEG) were selected as the cation and non-ion additive. Zn was electrodeposited with the bath including additives on the steel. As a result, QAS and PEG were found to effect the overpotential of Zn electroplating and the orientation

indexes of Zn (002) were also changed to those of Zn (100) and Zn (110).
Moreover, a pre-adsorption method was applied for investigation of the additive. As a result, the orientation of Zn was affected by QAS at the initial stage of progress of electroplating. This means that the character of the initial layer between the steel and the plating could be changed from the other part of plating with pre-adsorption.

A-6-3 (P-31) 16:30
EFFECT OF OXIDATION ON EMISSIVITY FOR DP780 AND DP980 STEELS
Quentin Somveille[1], Paul Mosser[1], Myriam Brochu[1], Kyle Daun[2]
[1]Ecole Polytechnique de Montreal, Canada, [2]University of Waterloo, Canada
Temperature control during heat treatment of AHSS steels is critical for obtaining the desired mechanical properties, but accurate pyrometry requires detailed knowledge of the spectral emissivity of the steel. The present work explores the relationship between spectral emissivity and the surface state of two types of cold-rolled dual-phase steels, DP780 and DP980, along with the consequential impact on pyrometrically-inferred temperatures. Results show that the spectral emissivity of DP780 is more influenced by the heat treatment cycle than that of DP980. SEM observations and GDEOS measurements show that the oxide coverage and thickness are smaller for DP980 when compared to DP780. These measurements indicate that low wavelength spectral emissivity increases with oxide thickness and coverage.

A-6-4 (P-31) 16:50
EFFECT OF TEMPERATURE DEVIATION DURING INTERCRITICAL ANNEALING OF HSLA AND DP980 STEELS
Paul Mosser[1], Quentin Somveille[1], Kyle Daun[2], Myriam Brochu[1]
[1]Ecole Polytechnique de Montreal, Canada, [2]University of Waterloo, Canada
The microstructure and mechanical properties of galvanized advanced high-strength steels (AHSS) such as DP980 are known to be more sensitive to variations in intercritical annealing temperature compared to high strength low alloy (HSLA) steels. The objective of this research is to define the temperature range that will ensure that DP980 steels have strength and elongation properties conforming to specification. Results confirm that the mechanical properties of DP980 are strongly affected by deviations in intercritical annealing temperature of ±50 K. The yield strength of DP980 annealed at 50 K below nominal temperature exceeds the minimum ASTM A1089 requirement of 550 MPa only by 5 MPa. In the case of DP980 annealed 50 K above the nominal temperature. The properties of HSLA grade 50 were comparatively much less sensitive to annealing temperature. These results suggest that intercritical annealing temperature excursions must be maintained well below ±50 K considering the other process uncertainties, which motivates development of improved pyrometry techniques for closed-loop temperature control.

A-6-5 17:10
ANALYSIS OF ZN FLOW INSIDE THE SINK ROLL GROOVES
Michel Dubois
CMI Metals, Belgium
The liquid flow inside the various groove shapes is investigated by CFD (Computed Fluid dynamics) while modeling only the area around the roll surface. This methodology is required due to the big difference in scale between the total pot volume and the groove dimension. It is shown that the liquid velocity in the channel formed by the roll and the strip is slightly higher than the roll velocity. Whereas the flow is quite low, it due to a combination of the high pressure at roll entry and depression at exit. Situation is very different in the "open channel" area and is similar to a classical boundary layer.
The effect of the groove design as well as line speed are clearly shown. This explains why a groove pattern and size must depend on line speed as well as strip tension since a too high pressure versus the roll-strip contact force will lead to a lubricant situation and roll stoppage.
The results on particle trapping are quite difficult to interpret. The effect of line speed appears negligible. It is mostly at the exit that the particle hit the strip and at the entry that the hits are the lowest. The effect of the groove design exists but seems quite low.

B-4 Selective Oxidation

Date: Tuesday, November 14
Time: 10:10-12:00
Venue: Room B
Chairs: Eduardo A. Silva (United States Steel Corporation, USA)
Shoichiro Taira (JFE Steel Corporation, Japan)

B-4-1 *Keynote* 10:10
EFFECT OF DEW POINTS DURING HEATING ON SELECTIVE OXIDATION OF C-MN-SI-AL STEELS
Guangrui Jiang[1,2], Guosen Zhu[3], Haiquan Wang[1,2,4], Dongying Qiu[1]
[1]Shougang Technology Research Institute, China, [2]Beijing key Laboratory of Green Recyclable Process for Iron & steel Production Technology, China, [3]Jingtang Irion and Steel Co. Ltd., China, [4]China Iron and Steel Research Institute Group (CISRI), China
Advanced high strength steel (AHSS) contains a large amount of alloying elements, such as Si, Mn, Al, Cr and so on, which could be selective oxidized on the external surface of the steel and terribly deteriorate ability of hot-dip galvanizing. In order to improve galvanizability of AHSS, some methods have been studied for a long time, including annealing with high dew point, two step procedure consisting of an oxidation followed by a reduction, deposition of a layer of metal prior to annealing and addition of surface active elements to the steel. However, less attention has been paid on the dew point during heating. In this study, the effect of dew points during heating on the selective oxidation of a C-Mn-Si-Al steel was studied on a Hot-Dip Process Simulator (HDPS). During heating and soaking, the dew point was different. External surface of as-annealed steel samples were characterized by using SEM (scanning electron microscopy), EDS (energy dispersive spectrometer). Alloying element profiles were detected by GDOES (low discharge optical emission spectroscopy). As heating with a dew point of -10 ºC, little oxides could

be found on the external surface. As the dew point during heating decreased to -50 ºC, much more oxides composed with manganese and aluminum could be observed on the external surface. Moreover, high dew point temperature during heating extremely suppress enrichment of alloying elements to the external surface.

B-4-2 *Invited* 10:40
THE GROWTH BEHAVIOR OF THE INTERNAL OXIDATION LAYER OF AHSS AT ANNEALING PROCESS IN THE HIGH DEW POINT ATMOSPHERE

Ryosuke Otomo, Mikako Takeda, Hiroshi Irie
Kobe Steel, Ltd., Japan

The growth behaviors of internal oxide layer in the steel containing Si are discussed to control GA surface quality of AHSS. This study focusses on clarifying the controlling factor of internal oxide layer's growth rate in the process of heat treatment like annealing.
The result shows that the controlling factor of the growth rate of internal oxide layer is different in conditions, at 0 degrees Celscius of dew point, the solid diffusion in the steel sheet controls the growth rate , but under -10 degrees Celcius, the supply of oxygen atoms to the steel surface controls it. And in the phase the growth rate is controlled by atmosphere, the oxygen spent for internal oxides is estimated supplied mainly by water vapor molecules.

B-4-3 11:00
SELECTIVE OXIDATION OF Fe-Mn (1 wt.%) BINARY ALLOY

Nathalie Ruscassier, Li Gong, Mehdi Ayouz, Thomas Reiss, Paul Haghi-Ashtiani, Marie-Laurence Giorgi
Université Paris-Saclay, France

The present study focused on the oxide particles formed on Fe-Mn (1 wt.%) alloy during annealing. The samples were heated to 800°C and kept at this temperature for 60 s in N_2 / H_2 (5 vol.%) with a dew point of -40°C. The annealed samples were then observed by scanning electron microscopy. Image analysis was performed to obtain the size and surface density of the oxides. Thin cross-sections were analyzed by Energy Dispersive Spectroscopy in a Transmission Electron Microscope to determine the particles' composition. The influence of the ferrite grain orientation on the oxide particles' shape was studied by Electron Back Scattered Diffraction. The annealed Fe-Mn surfaces were covered by MnO single crystals whose shape depended on the underlying ferrite grain orientation. The equilibrium MnO crystal shape in contact with Fe(100), Fe(110) and Fe(111) was calculated by Wulffmaker. The calculated shapes were in good agreement with the experimental results.

B-4-4 11:20
CORROSION PROPERTIES OF HOT DIP ZINC GALVANIZED COATINGS ON 22MnB5 PRESS HARDENED STEELS

Caitlin Dever, Joseph Kish, Joseph McDermid
McMaster University, Canada

Concern for vehicle light-weighting has led to the development of new steels. One improvement is the press hardened steels (PHS), predominantly the 22MnB5 grade, which are galvanized to provide cathodic corrosion protection. These steels undergo direct hot press forming (DHPF), which presents challenges for galvanized Zn-coatings. Specifically, liquid metal embrittlement (LME) and a narrow processing window for providing a cathodically protective zinc coating have inhibited the use of PHS in vehicle design. The electrochemical properties of Zn-coated PHS annealed for varying times at 900°C were assessed to determine if these coatings can provide cathodic protection to the underlying substrate. The current findings detail the compositional window found to avoid LME and provide cathodically protective coatings for 22MnB5.

B-4-5 11:40
SIMULATING PHYSICAL VAPOUR DEPOSITION ON STEEL SUBSTRATE USING THE DIRECT SIMULATION MONTE CARLO (DSMC) METHOD

Samuel Minshell[1], James Paolo Carlos[1], Will Newton[1], Edzo Zoestbergen[2], Colin Commandeur[2], David Penney[1], Nicholas P. Lavery[1]
[1]Swansea University, UK, [2]Tata Steel R&D, The Netherlands

Physical Vapour Deposition (PVD) is being developed as a coating process for steel substrates and is undertaken in high vacuum conditions to minimise contaminants mixing with the zinc vapour. The low-pressure conditions in the vacuum chamber, equates to large Knudsen numbers for the flow, due to this, continuum CFD methods tend to become invalid. For dilute or rarefied gases, the Direct Simulation Monte Carlo (DSMC) method is the prevalent method to analyse such flow conditions.
A DSMC solver called dsmcFOAM from an open-source software is used. Existing research from K. Hencken uses dsmcFOAM to investigate copper vapour condensation in a vacuum interrupter[1)]. Current research at Swansea University benchmarks and adapts the modelling steps taken in work by K. Hencken, to simulate zinc vapour deposition onto a moving steel substrate. Preliminary simulations show that the species are colliding and impinging on the steel substrate and shows that the vacuum locks limits evacuation in the chamber.

REFERENCE
1) Hencken K. Investigation of Metallic Vapor Condensation in a Vacuum Interrupter using dsmcFOAM DSMC Introduction. 9th OpenFOAM® Work. 2014;

B-5 Hot Stamping of Coated Steels

Date: Tuesday, November 14
Time: 13:40-15:00
Venue: Room B
Chairs: Cedric Georges (CRM Group, Belgium)
Koji Akioka (Nippon Steel & Sumitomo Metal Corporation, Japan)

B-5-1 *Keynote* 13:40
COATINGS DEDICATED TO PRESS HARDENED STEELS FOR AUTOMOTIVE APPLICATIONS

Pascal Drillet
ArcelorMittal Global R&D, France

The Press Hardened Steels (PHS) are very well placed in the light-weighting race in which automotive manufacturers are engaged, due to the unique advantage to perform parts with very high mechanical properties at high temperatures enabling the production of complex geometries and especially the elimination of post-forming spring-back.
In this frame the pre-coating solution is the key of PHS success, confirmed by an increasing demand of the

Automotive market. The final in-use properties like corrosion resistance and spot welding are in fact fully dependent on the chosen coating and its microstructure after the austenitization step. This paper deals with the behavior of the Al-Si and Zn based coatings during austenitization, including their interactions with the Hot Stamping tools. The Al-Si shows the widest process window and this pre-coated solution, accepted by most of the car makers, is the best-in-class in perforating corrosion resistance: it exhibits a very efficient barrier effect created by the Al-Si coating corrosion products, leading to a very limited attack of the steel substrate.
Nevertheless, this Al-Si remains sensitive to the red rusting from the surface of the coating, especially in areas with a too thin E-coat or areas where E-coat is locally eliminated (like stone chipping for instance). Zn based coatings can give an appropriate answer on that point, but the process-window is much narrower than observed on Al-Si. In the aim to keep a large process window an Al-Si improved solution has been developed in lab and validated through several industrial trials. This new coating, based on a Zn-flash deposition after the aluminizing step, is described and the improvements of paint adhesion and cosmetic corrosion are illustrated by lab results. Satisfying paint-ability and corrosion performance are kept in a wide process-window.
The challenge in the development of coatings dedicated to PHS is to satisfy the main requests of the final customers by keeping a solution working in a large industrial range of production for the Hot Stamper.

B-5-2 *Keynote* 14:10
CORROSION PERFORMANCES AND MICROSTRUCTURES OF VARIOUS COATED STEELS AFTER HOT STAMPING PROCESS (LITERATURE REVIEW)
Jun Maki
Nippon Steel & Sumitomo Metal Corporation, Japan
The hot stamping process, which is used to produce 1470 MPa class high strength automotive parts, is being applied to meet the demand for lighter, safer, more robust vehicle bodies. In the hot stamping process, coating plays two main roles: control of both the oxidization and the decarburization of the steel surface in the heating process, and improvement of corrosion resistance of parts. Aluminized steel sheet and galvanized steel sheet are currently used in the hot stamping process. In this paper, the corrosion performances and coating microstructure of coated steel sheets are reviewed. Galvanized steel, which has been widely used for corrosion resistance of vehicle body steel, now has various process restrictions in view of Liquid Metal Embrittlement (LME). For aluminized steel, although the process restrictions are limited, it is more susceptible to red rust than galvanized steel and so requires attention in application. In recent years, findings on new coatings such as Zn-Al-Mg-based coating have been reported. This paper summarizes the existing knowledge on changes of the coating layer microstructure in the heating process and the corrosion characteristics of these various coated steels.

B-5-3 14:40
ADVANCED ALSI COATING WITH IMPROVED HYDROGEN PERFOMANCE AFTER PRESS HARDENING
Manuela Ruthenberg, Janko Banik, Grit Reimann,
Martin Norden, Frank Friedel
thyssenkrupp Steel Europe, Germany
In recent years the press hardening process has gained great significance in terms of providing crash relevant and structural automobile parts. Regarding metallic coatings for press hardening, the aluminum-silicon coating (also known as AlSi or AS) is the measure of all things. In this paper a further development of the AlSi-coating with an improved performance will be presented addressing the issue of hydrogen dissociation.
As is well known, the standard AlSi-coating still faces a challenge relating to the high oxygen affinity and the associated formation of dissociated hydrogen. During the annealing step in the press hardening process, hydrogen is absorbed and diffuses into the steel. This paper presents a solution to the challenge of reducing the formation of dissociated hydrogen by an enhanced aluminum-silicon coating and industrial production results at continuous galvanizing line #1 (CGL#1).

B-6 Forming and Joining Technologies

Date: Tuesday, November 14
Time: 15:40-17:10
Venue: Room B
Chairs: Pascal Drillet (ArcelorMittal Global R&D, France)
Jun Maki (Nippon Steel & Sumitomo Metal Corporation, Japan)

B-6-1 *Keynote* 15:40
PAST AND CURRENT TRENDS IN RESEARCH ON PRESS FORMING OF ZINC-BASED COATED SHEET STEELS FOR AUTOMOTIVE USE
Yuji Yamasaki
JFE Steel Corporation, Japan
The past and present trends in research on frictional properties and coating failures in press forming of zinc-based coated steel sheets in the automobile industry are reviewed. Many zinc-based coated sheet steels with improved corrosion resistance, press formability, weldability and paintability have been developed. The frictional properties of various coated sheet steels have been investigated as they relate to press formability. The failure behaviors of the coatings of zinc-based coated sheet steels during press forming are another key issue because failure of the coatings can cause cosmetic deficiencies and deterioration in corrosion resistance. The application of zinc-based coated advanced high strength steel (AHSS) sheets to automotive parts has increased since around 2000. The higher contact pressure between the coatings and tools can result in adhesion abrasion and galling in press forming of AHSS.

B-6-2 (P-20) *Invited* 16:10
THE EFFECT OF FE-ZN INTERMETALLIC COMPOUNDS ON LIQUID ZN- ASSISTED EMBRITTLEMENT OF GALVANIZED TWIP STEEL
Doyub Kim[1], Seokhyun Hong[1], Jee-Hyun Kang[1],
Du-Youl Choi[2], Sung-Joon Kim[1]
[1]POSTECH, Korea, [2]POSCO, Korea
TWIP steels are known to be an attractive candidate for

automotive application owing to their superior strength and ductility. However, the application has been restricted by the cracks which are generated by Liquid Metal Embrittlement (LME), because the substrate alloy gets exposed to liquid Zn.
The present study attempts to suppress LME cracks in a TWIP steel by controlling Fe-Zn intermetallic compounds which have higher melting points in comparison with pure Zn. Hot tensile tests are conducted with different heating rates to verify their effect on LME. The heating rate alters the microstructures at the coating/substrate interface. Consequently, the embrittlement becomes severe with higher heating rate at 700 °C. Furthermore, Resistance Spot Welding (RSW) was carried out for the TWIP steel specimens which are coated with different Fe-Zn intermetallics. The number and length of the LME cracks depend on the major intermetallic in the coating, which suggested RSW can be improved by the formation of the Fe-Zn intermetallic compounds.

B-6-3 16:30
FORMABILITY OF 800MPa GRADE HOT-DIP GALVANIZED STEEL SHEET
Renbo Song[1], Kai Zhang[1], Yi Gao[2]
[1]University of Science and Technology Beijing, China, [2]TKAS (Chongqing) Auto Steel Company Limited, China
Hot-dip galvanized steel sheets have already been widely used in the automotive industry, electrical appliance industry and construction industry for their better corrosion resistance. With the development of steel materials and the need for higher performance of galvanized steel, it is urgent to carry out research on the formability of 800MPa or even higher grade hot-dip galvanized steel sheets. In this paper, forming limit diagram (FLD) test was carried out and the forming limit curve (FLC) was fitted. The ultimate strain in the plane strain state of the experimental hot-dip galvanized steel sheet (FLD_0) is 0.28. The industrial production should be maintained under the FLC in order to prevent fracture. During the FLD test, the zinc layer is subjected to micro-mechanical failure. The zinc coating is generally thinner and the risk of substrate exposed to the external environment increases because of wear, pulverization, shedding and crack of the zinc layer.

B-6-4 16:50
FRICTIONAL BEHAVIOR AND PRESS FORMABILITY OF SURFACE MODIFIED HOT-DIP GALVANIZED STEEL SHEETS
Katsuya Hoshino, Shinichi Furuya, Yuki Ogihara, Eiji Iizuka, Kazutoshi Hanada, Masayasu Nagoshi, Hiroshi Matsuda, Yuji Yamasaki
JFE Steel Corporation, Japan
The frictional behavior and press formability of hot-dip galvanized steel sheets (HDG) to which surface modification technology was applied were investigated. Surface modified HDG and conventional HDG based on mild steel sheets with various mechanical properties were prepared as test specimens. The friction coefficients were measured by a flat sliding test, and press formability was evaluated by both a stretch forming test and a deep drawing test. As results, it was found that the surface modified HDG show a lower friction coefficient and higher press formability than the conventional HDG. This suggested that the surface modification technology can be applied to HDG, and surface modified HDG is a promising material for improving and stabilizing the press formability of HDG for automotive use.

C-4 Corrosion I

Date: Tuesday, November 14
Time: 10:10-12:20
Venue: Room C
Chairs: Bo Rendahl (Swerea KIMAB, Sweden)
Masamitsu Matsumoto (Nippon Steel & Sumitomo Metal Corporation, Japan)

C-4-1 *Keynote* 10:10
AUTOMOTIVE CORROSION AND CORROSION EVALUATION METHODS FOR COATED STEEL SHEETS
Daisuke Mizuno
JFE Steel Corporation, Japan
There have been numerous studies on zinc and zinc alloy coated steel sheets since corrosion problems were widely recognized in automotive industry in the 1970s. In general, corrosion resistance of coated steels is evaluated by using accelerated corrosion tests in laboratories for shortening the developing period. However, the reproducibility of laboratory tests to corrosion in service is always controversial issue. In this paper, corrosion of coated steel sheets in automobiles was studied by analyzing corroded vehicles collected in the US, Europe and Asia. Corrosion behaviors of coated steels in snow-belt and tropical regions were clarified. Accelerated corrosion tests were conducted to compare with corrosion behavior in actual vehicles. Correlation of corrosion between actual vehicles and laboratory tests were assessed by using the index which is determined as the corrosion rate ratio of steel and zinc. There is a possibility that the index provides optimum design of accelerated corrosion tests and adequate evaluation of zinc alloy coatings. Influence of specimen configuration was also investigated.

C-4-2 *Invited* 10:40
CORROSION PERFORMANCE OF COIL COATED STEEL: MODEL BUILDINGS VERSUS STANDARDIZED PANELS
Nathalie LeBozec, Dominique Thierry
French Corrosion Institute, France
The acceptance of new prepainted materials to be introduced to the market is often based on results of weathering tests at outdoor sites that are carried out in Europe according to EN 13523-19 and 13523-21 standards using panels of up to 30x20 cm with variable radius bends, overlaps, rivets, screws and artificial defects. Degradation of coil coated materials is a complex process depending on the panel orientation, deposition of corrosive contaminants, UV irradiation, time of wetness, temperature, coating properties, metallic coating, pretreatment, anticorrosive pigment formulated in primer etc. In real buildings, many different conditions can be met in terms of water condensation, temperature cycling, deposition, accumulation and removal of contaminants and geometry. Although the effect of some of these parameters on corrosion of coil coated materials is known, there are many unclear aspects yet.
Model buildings including roofs of various angles and facades with or without shelters were constructed at two locations one inland and the other in a coastal area. Coil coated materials that were used to build the huts were also exposed at 5 and 90° as per EN 13523-19 in order to compare

their kinetics and mode of degradations upon exposure conditions. Selected locations on the model buildings were also characterized as regards to micro-climate (temperature, relative humidity, air pollutants), accumulated corrosive pollutants and corrosion rate of zinc and carbon steel coupons and further compared to conventional exposure at 5 and 90°angle.

C-4-3 (P-5) 11:00
INVESTIGATION ON CORROSION BEHAVIOR OF PRIMARY AL PHASE IN ZN-11%AL-3%MG-0.2%SI COATING

Tetsuya Toba, Shinichi Yamaguchi, Masamitsu Matsumoto
Nippon Steel & Sumitomo Metal Corporation, Japan

The corrosion behavior of the primary Al phase in Zn-11mass%Al-3mass%Mg-0.2mass%Si coating was investigated using Al-Zn solid solution alloys with the same composition of the primary Al phase. The immersed potentials of Al-Zn solid solution alloys were more negative than those of Zn and $MgZn_2$, the other phase in the coating. After cyclic corrosion tests on the alloys, zinc aluminum carbonate hydroxide, $Zn_6Al_2(CO_3)(OH)_{16}•4H_2O$, was detected as a corrosion product. From these results, one of the reasons for the high corrosion resistance of Zn-11mass%Al-3mass%Mg-0.2mass%Si coating is that the primary Al phase corroded selectively and $Zn_6Al_2(CO_3)(OH)_{16}•4H_2O$ formed on the coating in the early stage of corrosion.

C-4-4 11:20
ON THE ROLE OF MICROSTRUCTURE IN CORROSION PERFORMANCE OF ZN-AL AND ZN-AL-MG

Tomáš Prošek[1,2], Dominique Thierry[1], Joacim Hagström[3], Jan Stoulil[2], Ondřej Chocholatý[4]
[1]Institut de la Corrosion / French Corrosion Institute, France, [2]University of Chemistry and Technology Prague, Czech Republic, [3]Swerea KIMAB AB, Sweden, [4]University of West Bohemia, Czech Republic

Zn-5Al and Zn-3Al-2Mg model alloys were cast and heat treated in order to obtain specimens with distinct microstructures and identical chemical compositions. The microstructure was characterized to identify composition, size and distribution of present phases. Mass loss of samples with different microstructures and identical chemical compositions subjected to a cyclic corrosion test differed by a factor of up to two. In most cases, finer structures were more corrosion resistant but other factors apparently also played a role. The results suggest that even microstructures of commercial line coatings can possibly be tailored in order to maximize their corrosion resistance. Electrochemical measurements on model $MgZn_2$, $Mg2Zn_{11}$, η-Zn and α-Al (68 wt.% Al, 32 wt.% Zn) phases prepared by casting showed that Mg-rich phases were more electronegative than zinc matrix. They formed anodic locations and dissolved preferentially. The α-Al phase was nobler than zinc in acidic and neutral electrolytes but activated after alkalization of cathodic sites. The better corrosion stability of the alloys with finer microstructures is believed to be linked to a rapid blocking of cathodic sites due to better availability of ions required for precipitation of protective corrosion products and a more uniform pH and potential distribution over the surface.

C-4-5 11:40
ATMOSPHERIC CORROSION BEHAVIORS OF HOT-DIP ZN-6%AL-3%MG COIL COATED STEEL SHEET

Takao Tsujimura, Masaaki Uchiyama, Yasunori Hattori
Nisshin Steel Co., Ltd., Japan

In this study, we investigated corrosion behaviors of Zn-6%Al-3%Mg coil-coated steel sheets (Zn-Al-Mg) exposed outdoor environments at several sites in China. As a result, the amount of corrosion loss of Zn-Al-Mg at each site was large in the order of Guangzhou, Wuhan, and Beijing. This order is accords with the order of characteristic values of environments, temperature, amount of rain-fall, and moisture at each site. We found that the corrosion product on the surface of Zn-Al-Mg exposed at Guangzhou included more amount of Sulphur than Okinawa by XMA. It was considered that SO_2 in air is one of the important promotion factor of corrosion for Zn-Al-Mg as same as GI. Zn-Al-Mg turned out to be performed excellent corrosion resistance in comparison with GI at an environment with higher SO_2 in air.

C-4-6 (P-6) 12:00
CORROSION RESISTANCE MECHANISM OF HOT-DIP ZN-6%AL-3%MG ALLOY COATED STEEL SHEET IN CORROSION TEST IN WATER FILM FORMATION STATE

Masaaki Uranaka, Yasunori Hattori
Nisshin Steel Co., Ltd., Japan

We prepared test specimens with steel substrate exposed by partially removing the coating layer, and subjected to a corrosion test with a water film of 5% NaCl solution applied to the surface. It was confirmed that any of coating layer exhibited protective corrosion prevention in the early stage of corrosion. On the other hand, as the test time got longer, occurrence of red rust in steel substrate exposure was suppressed in a hot-dip Zn-6%Al-3%Mg alloy coated steel sheet (“Zn-Al-Mg”) than Galvannealed steel sheet (GA) and Galvanized steel sheet (GI). Upon investigating specimens conducted corrosion test using equipment analysis, dense Zinc corrosion products containing Mg were formed on steel substrate exposure of a Zn-Al-Mg, and the formation of ZnO was suppressed. Moreover, when the cathodic polarization curves of the portion where the corrosion products were formed at the steel substrate exposure were measured by electrochemical measurements, the effect of suppressing reduction reactions of dissolved oxygen were not observed in GA and GI, but reduction reactions of dissolved oxygen were suppressed in Zn-Al-Mg. From this result, it was considered that elution of the coating layer is suppressed in Zn-Al-Mg, and the effect of protecting steel substrate exposure was maintained for a long time compared to GA and GI.

C-5 Corrosion II

Date: Tuesday, November 14
Time: 13:40-15:40
Venue: Room C
Chairs: Nathalie LeBozec (French Corrosion Institute, France)
Tomas Prosek (University of Chemistry and Technology Prague, Czech Republic)

C-5-1 *Invited* 13:40
EDGE CORROSION BEHAVIOUR OF COATED STEEL SHEET

Masamitsu Matsumoto
Nippon Steel & Sumitomo Metal Corporation, Japan

Coated steel sheets have superior corrosion resistance, formability, weldability and various performances. Therefore, they are used as component materials for automobiles, buildings and home appliances. The coated steel sheets are generally approved by judgment from the results of prescribed corrosion tests. The results, however, are often different from those of the exposure tests in the environments that the coated steel sheets are actually used. It is important that the causes of the differences are clarified. In this paper, the edge corrosion of 55mass%Al-Zn alloy coated steel sheet is focused. On the coated steel sheet, it was recognized that red rust occurred from shear cut edge was spread in early stage. In order to clarify the causes of red rust spread in early stage, the effects of NaCl, $MgCl_2$ and artificial seawater, those of continuous wetting and wet-and-dry are investigated. The specimens were the steel sheets with actual shear cut edge and the samples simulated the shear cut edge. The specimens and the corrosion products were evaluated by electrochemical methods were analyzed by SEM/EDS, XRD and FTIR. Furthermore, the corrosion phenomenon was verified by the numerical analysis methods that consider the electrochemical reactions, chemical reactions, solubility products etc. In the results, in case of NaCl, the corrosion of the coating near shear cut edge is accelerated by the galvanic action that the steel on the edge is cathodic and the coating near the edge is anodic. In case of $MgCl_2$ and artificial seawater, the corrosion products with less electric conductivity and less solubility cover the steel on the edge and depressed the galvanic action, and then the corrosion of the coating near shear cut edge was depressed and delayed.

C-5-2 14:00
CORROSION BEHAVIOUR OF PRIOR NICKEL COATED GALVANISED STEELS

Kuntal Sarkar, Avik Mondal, Anindita Chakraborty, Nitu Rani, Monojit Dutta
Tata Steel, India

Corrosion performance of hot dip galvanised coatings can be enhanced by incorporating other elements in the coating. Introduction of other elements within zinc bath or prior layer deposition on steel substrate are recent processes being investigated. In the present work, the corrosion performance of prior nickel coated galvanised coating is examined and compared with conventional galvanised coatings. The prior nickel coated galvanised coating comprises of different Ni-Zn phases, e.g., nickel rich solid solution, Ni-Zn gamma and Ni-Zn delta phases; whereas the conventional galvanised coating contains zinc and Fe-Zn intermetallic layer(s) only. The corrosion performance was studied using potentiodynamic polarization tests; time dependent Electrochemical Impedance Spectroscopy (EIS) along with Scanning Electron Microscopy (SEM) to reveal the morphology of corrosion products for both types of samples. The potentiodynamic polarization test results revealed that both coatings are sacrificial in nature with comparable E_{corr} and I_{corr} values. This is probably due to the presence of sacrificial overlay zinc layer at the top surface of both the coatings. However, the impedance of the prior nickel coated galvanised steel increased with time due to stable oxide layer formation of the underneath Ni-Zn phases. On the contrary, the impedance for conventional galvanised steel increased initially due to the formation of oxide layer which is followed by continuous decrease in impedance with time. Such lowering of impedance value can be attributed to the instability of the oxide layer. The SEM images of corroded samples revealed that the corrosion products were globular in nature for conventionally galvanised samples whereas globular, flake and needle like structures were observed for prior nickel coated galvanised samples.

C-5-3 14:20
CORROSION BEHAVIOR AND MECHANISM OF 1000MPa GRADE HOT-DIP GALVANIZED STEEL SHEET

Kai Zhang[1], Renbo Song[1], Yi Gao[2]
[1]University of Science and Technology Beijing, China, [2]TKAS (Chongqing) Auto Steel Company Limited, China

This paper is anticipated to study the corrosion behavior and mechanism of 1000MPa grade hot-dip galvanized steel in 3.5% NaCl solution simulated marine atmosphere environment after neutral salt spray tests of different time. Subsequent weight loss measurement and electrochemical measurements were applied. The results demonstrated that at the initial period of neutral salt spray (NSS), zinc coating was severely corroded, and corrosion rate increased to $0.236 g/m^2 \cdot h$; after that, uniform and protective corrosion products formed on the surface; gradually, the dissolution of that layer exposed the steel matrix to serious corrosion.

C-5-4 (P-4) 14:40
ANALYSIS OF CORROSION BEHAVIOR OF IRON AND ZINC IN VARIOUS ATMOSPHERIC ENVIRONMENTS USING ELECTRICAL RESISTACE TECHNIQUE

Masataka Omoda, Daisuke Mizuno, Nobuyuki Ishikawa
JFE Steel Corporation, Japan

Until recently, it has been very difficult to estimate in detail corrosion behavior variations of Fe and Zn during the test periods. For this challenge, in-situ corrosion monitoring technique is useful. Therefore, in-situ change of corrosion loss has been monitored by using an electrical resistance sensor, of which corrosion loss of sensor made by evaluated material can be detected as a change of electrical resistance. In this study, in-situ corrosion monitoring using electrical resistance sensors of Fe and Zn was conducted in various atmospheric environments. And then, by comparing with each environmental factor, the impact of environmental factors on corrosion behavior of Fe and Zn was investigated. In addition, corrosion monitoring by this sensor was conducted under accelerated corrosion test, ISO16539 Method B. From the comparison of corrosion behavior in a day, it was confirmed that ISO16539 method B reproduces corrosion behavior in atmospheric environments.

C-5-5 15:00

CORROSION MODELLING TOOL AND HIGH THROUGHPUT APPROACH FACILITATES SMART METALLIC COATING DESIGN

Krista Van den Bergh[1], Joost De Strycker[1], Christian Allely[2], Olga Dolgikh[3], Hans Simillion[3], Svetlana Lamaka[4,5], Alexander Bastos[6], Bart Van Den Bossche[7], Johan Deconinck[3]
[1]ArcelorMittal Global R&D Gent, Belgium, [2]ArcelorMittal Global R&D Maizières-les Metz, France, [3]Vrije Universiteit Brussel (VUB), Belgium, [4]Instituto Superior Técnico, Universidade de Lisboa, Portugal, [5]Institute of Materials Research, Germany, [6]DEMaC / CICECO, Universidade de Aveiro, Portugal, [7]Elsyca N.V., Belgium

Corrosion mechanisms of Zn-based galvanized steel are studied rather thoroughly. However, for economically and environmental reasons, the tendency in the current developments of metallic coatings is to switch to the Al-based coatings with (minor) addition of zinc and/or magnesium. Metallic coating development takes a long time and is expensive because of the long-term corrosion testing in both lab and outdoor conditions.

Simulation-assisted engineering could lead to significant acceleration and cost-reduction of the development of new coatings. The modelling of atmospheric corrosion of steel protected by aluminium-based alloys, applied by hot dip processing is studied (RFSR-CT-2011-00015). Based on the analysis of corrosion products found at different locations at the cut-edge, a map of corrosion products distribution was made. Results from simulations showed a very similar trend. This has led to a fundamental understanding and quantification of the corrosion processes taking place.

C-5-6 (P-3) 15:20

INFLUENCE OF THE ANTICORROSIVE PIGMENT ON THE CUT EDGE CORROSION OF CHROMATE-FREE PRE-PAINTED STEEL SHEETS IN RAIN WATER

Yasuaki Kawamura, Hiroyasu Furukawa,
Masamitsu Matsumoto, Kohei Ueda
Nippon Steel & Sumitomo Metal Corporation, Japan

Studies on the corrosion resistance for pre-painted steel sheets (PSS) have mainly focused on the long-term corrosion until now; however, the occurrence of red rust in the short term on the cut edge of PSS by accumulated rain water has not yet been investigated. Therefore, we performed the dipping test of chromate-free and chromate PSS in ion exchanged water and reproduced the red rust occurrence on the PSS.

The anticorrosive pigment contained in the PSS dissolved in the water, but the dissolution velocity of chromate-free pigment was slower than that of chromate pigment. Therefore, the chromate-free pigment could not fully dissolve in the rain water. As a result, the sacrificial protection of zinc at the cut edge of chromate-free PSS was prevented and there was an early occurrence of red rust. This study enabled us to solve this problem with highly water-soluble pigment.

C-6 Interfacial Reaction

Date: Tuesday, November 14
Time: 16:00-17:30
Venue: Room C
Chairs: Bruno Charles De Cooman (POSTECH, Korea)
Ryosuke Kainuma (Tohoku University, Japan)

C-6-1 *Keynote* 16:00

ACHIEVEMENTS OF HOT-DIP GALVANIZING CONSORTIUMS IN JAPAN

Hiroshi Takebayashi[1],
Hot-Dip Galvanizing Consortium in Japan[2]
[1]Nippon Steel & Sumitomo Metal Corporation, Japan, [2]The Iron and Steel Institute of Japan, Japan

Hot-dip galvanized steels are used for automobiles, construction, and electric appliances because of their good anti-corrosion. In particular, galvannealed (GA) steel-sheets that have Zn–Fe intermetallic compounds (IMCs) for coating layers are widely used for automobiles in Japan. The origins of the good properties, for example formability, in the GA steel-sheets have been studied by many researchers, and a lot of mechanisms to explain them have been proposed. However, there are many discrepancies in the previous reports, which are also sometimes different from the behavior seen in the industrial operation.

In the background, a series of consortiums, organized by the Iron and Steel Institute of Japan, started in 1998 and are still running. In these consortiums, so far, a lot of innovative and epoch-making results—such as the new Zn–Fe binary phase diagram, more accurate Zn-Fe IMC crystal structures, micro-pillar deformation study, phase transformation under high pressure, fracture toughness of a coating layer, and in-situ microscopic observation of coating deformation—were obtained by using some advanced methods and approaches. Some topics pertaining to those innovative results will be introduced in this presentation.

C-6-2 16:30

THE EFFECT OF THE CRYSTAL ORIENTATION OF STEEL SUBSTRATE ON THE GROWTH OF A FE-AL INHIBITION LAYER IN HOT-DIP GALVANNEALING

Kosuke Ota, Takashige Mori, Toyomitsu Nakamura, Jun Maki
Nippon Steel & Sumitomo Metal Corporation, Japan

In a hot-dip galvannealing bath, a Fe-Al inhibition layer is formed on the surface of steel grains, and the effect of crystal orientation of steel grains on the growth of the Fe-Al inhibition layer is not clear. In this study, the relation between crystal orientation of steel grains and the growth of the Fe-Al inhibition layer was investigated using electron backscatter diffraction (EBSD) and energy dispersive X-ray spectroscopy (EDS). As a result, crystal orientations of steel grains were, in the descending order of the amount of Fe-Al inhibition layer, {211}, {111}, {101}, and {001}. In addition, the relation between the crystal orientation of steel grains and Fe-Al inhibition layer showed that a low misfit rate (i.e., the difference of the position of the Fe atom between Fe-Al inhibition layer and steel grains) tended to cause a high amount of Fe-Al inhibition layer. Consequently, it is suggested that the growth rate of the Fe-Al inhibition layer is determined mainly through misfit rate.

C-6-3 16:50

STUDY OF THE INHIBITION LAYER FORMED IN A GA BATH ON A TRIP MN-AL STEEL

Andreea Paunoiu[1,2], Jean-Michel Mataigne[1], Florence Bertrand[1], David Zapico Álvarez[1], Jonas Staudte[1], Marie-Laurence Giorgi[2]

[1]ArcelorMittal Global R&D, France, [2] Université Paris-Saclay, France

The nature of the inhibition layer formed on an industrially galvanized TRIP Mn-Al substrate was investigated. The Zn bath contained low Al content (0.122 wt.%) as generally used before GalvAnnealing (GA) treatment. Prior to hot-dipping, the steel was recrystallized in a gas atmosphere with different oxygen potentials (Dew Point - *DP*), -40 and -5°C. The morphology and the nature of selective oxides at the steel surface changed from Al-Mn-O film in low *DP* annealing conditions to MnO nodules in high *DP*. In-depth characterization of the inhibition layer revealed that it is biphasic, namely $Fe_2Al_5Zn_x$ and δ, regardless the *DP* of annealing atmosphere. The $Fe_2Al_5Zn_x$ layer is discontinuous with δ on top. The selective oxides formed during recrystallization annealing were found to be embedded in the inhibition layer. A mechanism accounting for the formation of the inhibition layer in GA bath in presence of selective oxides is proposed in this paper. It will also be pointed out that the nature of the inhibition layer does not depend on the substrate.

C-6-4 (P-23) 17:10

RELATIONSHIP BETWEEN SUBSTRATE CRYSTAL ORIENTATIONS AND DISTRIBUTION OF INITIAL ELECTRODEPOSITION

Takashi Futaba, Akinobu Kobayashi, Yasuto Goto

Nippon Steel & Sumitomo Metal Corporation, Japan

The effect of substrate crystal orientation on the initial distribution of electrodeposit in Zn and Ni plating with a deposit of 0.1g/m^2 or less was investigated by using chemically polished polycrystalline low carbon Al-killed steel sheets. It was identified that distributions of Zn and Ni were conformed to the substrate crystalline grain sizes. However, the trend of the initial distribution was different between Zn and Ni. Zn deposits was affected by the consistency between the Zn(002) and α-Fe orientation. On the other hand, the Ni deposits had a distribution depending on the face density of α-Fe. It is thought that this was caused by displaced Ni plating. Therefore, we confirmed by using Fe plating on Ni substrate which is without displaced deposition. As a result, initial distribution of Fe on the Ni was affected by the consistency between the deposited Fe and substrate Ni orientation same as relationship between Zn and α-Fe.

D-4 Structural Analysis and Property

Date: Tuesday, November 14
Time: 10:10-12:20
Venue: Room D
Chairs: Doojin Paik (Gwangyang Steel Works, POSCO, Korea)
Hiroshi Takebayashi (Nippon Steel & Sumitomo Metal Corporation, Japan)

D-4-1 *Keynote* 10:10

ZINC LIQUID METAL EMBRITTLEMENT OF ADVANCED HIGH STRENGTH STEEL

B.C. De Cooman, Woosung Jung, Kyoung Rae Jo, Dimas Hand Sulistiyo, Lawrence Cho

Pohang University of Science and Technology, Korea

Liquid metal embrittlement (LME) is the structural transgranular or intergranular decohesion of a metal or an alloy by the rapid percolation of another liquid metal or alloy into its microstructure along the grain boundaries of the polycrystalline material, or along sub-grain boundaries in a single crystal of the material. In the presence of tensile stresses the presence of the liquid film results in grain boundary decohesion. As the grain boundary is replaced by a liquid-like film, brittle fracture occurs due to the rapid intergranular propagation of one or more fracture cracks formed in the liquid metal-penetrated region. When the sensitivity of a materials combination to LME is tested in laboratory conditions, *i.e.* by carrying out a tensile test in conditions in which the embrittling metal or alloy is in the liquid state, a pronounced decrease in both the fracture strength and the amount of plastic deformation prior to fracture is observed. A technologically important case of LME occurs for Zn-coated Twinning-induced plasticity (TWIP) steel, and press hardening steel (PHS). Both resistance spot welding and die-quenching are critical processing steps during which Zn-LME is observed. The microstructure of PHS consists of ferrite and pearlite prior to the hot stamping process. In the direct hot stamping process, the PHS sheet is heated at 1073-1123K (900-950ºC) for 3-10 minutes and the microstructure is fully austenitized. The steel sheet is simultaneously press-formed and quenched in water-cooled dies to obtain a high strength, fully martensitic microstructure. Zn-coated PHS often fractures due to Zn-LME cracking in the early stage of the press hardening, *i.e.* during the press forming at high temperature. As the Zn-coated PHS is deformed at high temperature, brittle intergranular fracture occurs as Zn diffuses along the austenite grain boundaries. The present contribution focusses on the analysis of the mechanism of LMIE in high strength steel grades such as PHS and propose solutions to achieve a LME-free behavior.

D-4-2 *Invited* 10:40

THE GLUE STUD TEST – AN INNOVATIVE MEANS FOR ASSESSING ZINC COATING ADHESION

Thomas Koll, Tobias Böddeker, Wilko Flügge

Salzgitter Mannesmann Forschung GmbH, Germany

The adhesion of hot-dip coatings during forming at the customer is assessed online at the production line to release the produced material and – if necessary – to take counteractions at the line to ensure good coating adhesion. Various methods are being used like bending tests, roll forming tests, cupping tests or impact tests. So far there is no online test specially designed to predict coating performance in the unwanted situation of a car crash. We are developing

a fast procedure to also test the coating adhesion in a crash situation. This procedure will combine a ball impact with the peeling effect of a glued on stud with the aim to be fast enough to be carried out during daily production. The glue stud test introduced in this paper involves the following actions: To glue a solid stud onto the zinc coated sheet, to perform the impact test at the position of the stud, this includes lifting the stud off the coating during forming the cup, to assess the underside of the stud. The target to cure the glue inductively for fast testing has not been reached yet.

D-4-3 11:00
A STUDY INTO THE PRE-DEPOSITION OF NICKEL COATINGS AND THEIR EFFECT ON INTERMETALLIC FORMATION IN HOT DIP GALVANISING

Lewis Berry[1], John Demmel[1], Craig Phillips[2], David Penney[1]
[1]Swansea University, UK, [2]Tata Steel Strip Products, UK

The use of aluminium in galvanising coating baths is a long standing industrial practice to minimise the formation of brittle FeZn intermetallics within the galvanised coating, but also results in the formation of intermetallic dross and cobalt aluminides. These insoluble precipitates reduce product quality and submerged pot hardware lifetime, respectively. This paper seeks to explore alternatives to Al addition within the galvanising bath, through the predeposition of a nickel interfacial layer. Pre-deposition of the nickel intermetallic through electrochemical means increases corrosion performance of the galvanised system but also results in the formation of brittle intermetallics which reduces press performance. The energy intensive nature of this process makes electrodeposition an unsuitable technique for industrial application. Thermal degradation of Ni based coating to form a NiFe intermetallic is explored as a possible alternative to the addition of Al to the melt.

D-4-4 11:20
MICROSTRUCTURAL INVESTIGATION OF A HOT-DIP Zn-10%Al ALLOY COATING USING THE SEM-EBSD TECHNIQUE

Takuya Mitsunobu, Kohei Tokuda
Nippon Steel & Sumitomo Metal Corporation, Japan

The microstructure of a hot-dip Zn–10%Al alloy coating layer was investigated using the SEM-EBSD technique. The solidification microstructure of the coating is featured by dendrites and eutectic structures. The microstructural morphology in dendrites showed a complicated two-phase structure of α^{dend}-Al and η^{dend}-Zn phases. The eutectic structure comprised matrix η^{eutec}-Zn and isolated α^{eutec}-Al phases. EBSD results revealed that the microstructure in dendrites was divided into two parts from a crystallographic viewpoint; crystal orientation distribution of η^{dend}-Zn phases tends to be different between the inside and outside parts of dendrites. In the inside part, η^{dend}-Zn and α^{dend}-Al phases show a crystal orientation relationship, described as $\{111\}_{fcc}$ // $(0001)_{hcp}$, also called the Shoji–Nishiyama relationship. However, in the outside part, η^{dend}-Zn phases tend to have the same crystal orientations as the neighbor η^{eutec}-Zn matrix. This indicated that η^{dend}-Zn in the outside part of dendrites nucleated epitaxially on the neighbor η^{eutec}-Zn matrix.

D-4-5 11:40
APPLICATION OF CROSS SECTION POLISHING FOR PRODUCT DEVELOPMENT OF GALVANNEALED

Thomas Mörtlbauer, Johann Strutzenberger, Gerhard Angeli, Johanna Pöhmer, Raffaela Sagl
voestalpine Stahl GmbH, Austria

The Cross Section Polishing (CSP) method and its application to process optimization for galvanized product at voestalpine have already been presented in the past[1)]. Meanwhile, this method has also been successfully used to analyze galvannealed coatings. For this type of coating is has been proven to be useful when sputtering a prepared cross section with Ar+-ions for a short time. Thanks to different sputtering behavior of various zinc-iron phases this leads to a so-called “contrast enhancement”, i.e. a highlighting of different phases. Thus, microstructure of a galvannealed layer can be visualized in the SEM with unprecedented lateral resolution. It is even possible to clearly identify individual crystals of a thin layer of Γ-Zn-Fe. Compared to chemical etching of mechanically polished cross sections it is now possible to visualize microstructure of coating and underlying steel simultaneously. Also, it is possible to perform surface-sensitive analytics such as Auger Electron Spectroscopy (AES). Compared to TEM or FIB preparations a large area of up to 2 mm in width can be prepared in one step and specimen preparation is considerably faster and more reliable.

This method therefore allows to link macroscopic product properties (e.g. powdering, flaking, surface defects) to microscopic aspects of the galvannealed layer and the outermost layer of the underlying steel sheet.

Within this paper two examples will be given how this method can be applied for galvannealed coatings:

1. Severe powdering/flaking in the production of IF-steels was analyzed. By cross section polishing it was possible to identify the interface between steel and Γ-Zn-Fe as the weakest link where delamination starts and crack propagation occurs. Thanks to the high quality of the cross sections numerous nanoparticles – most probably of oxidic nature – could be detected in the Γ-Zn-Fe layer. From this it was concluded that the insufficient coating adherence was connected to uncontrolled oxidation in the annealing furnace of the line.
2. A severe case of streaky defect on GA-coated steel has been analyzed using cross section polishing. It was found that the defect – visible due to higher density of craters in the defect area – is linked to uneven Zn-Fe reaction kinetics in microscopic dimension. When using “contrast enhancement” it was possible to study such outburst-phenomenon at grain boundaries with remarkable detail.

REFERENCE
1) G. Angeli, R. Sagl, A. Jarosik, J. Strutzenberger, T. Mörtlbauer, C. Riener and A. Schönauer: Galvatech 2015 Proceedings, AIST, Warrendale, PA, (2015), 356.

D-4-6 12:00
STUDY ON CHANGES OF PHYSICAL PROPERTIES AS VARIOUS COATING COMPONENTS ON SURFACE OF GALVANIZED STEEL COIL

Min-yeong Jeong, Yeong-rok Park, Yong-soo Jeong, Hyeong-jin Kim
Hyundai Steel Company, Korea

There are many kinds of coating materials and methods

for industrial use. Among those, coil coating process using applicator roll is the most effective one for mass production. The speed of manufacture is over 120 meters per minute and the coated surface has uniform quality than spray, dipping, casting coating methods and etc. Many types of coating materials are using for coil coating, and most of these are organic or organic/inorganic hybrid materials. These materials are composed of various raw materials such as polymer binders, additives, pigments, and solvents. Each of these materials has specific properties. Therefore, physical properties of coil coated galvanized steel can be changed by sort of used raw materials and composition of those.

Coil coating materials are classified by the type of polymer binders such as polyester (PE), silicon-polyester (SiPE), polyvinylidene fluoride (PVDF), epoxy, acrylates, polyurethane (PU), waterborne polyurethane (WPU) and etc. Polymer types can be selected as required major properties for application of products. And additives (such as anticorrosive agent, wax, levelling agent, optical dulling agent) can be used for improvement of specific properties as occasion demands. Among these kinds of materials, polymer binder can affect physical properties more than additives.

In the case of polymer binders, WPUs have actively studied in recent because of lower toxicity than others due to using water as solvent. In this study, we synthesized WPU polymer binders having different chemical structures and molecular weights, and various compositions. After synthesis, we determined changes of physical properties by the factors. To compare the polymer properties, Synthesized WPUs were analyzed and tested with some equipment such as Dynamic light scattering (DLS), fourier transform infrared spectroscopy (FT-IR), nuclear magnetic resonance spectra ($_1$H -NMR), Gel permission chromatography (GPC), universal testing machine (UTM) and etc.

D-5 Wettability and Surface Quality

Date: Tuesday, November 14
Time: 13:40-15:10
Venue: Room D
Chairs: Guangrui Jiang (Shougang Technology Research Institute, China)
Toyomitsu Nakamura (Nippon Steel & Sumitomo Metal Corporation, Japan)

D-5-1 *Keynote* 13:40
DYNAMIC WETTING IN HOT DIP GALVANIZING

Jean-Michel Mataigne
ArcelorMittal, Global R&D, France

In hot dip galvanizing, wetting is always dynamic as the strip has to go through the molten zinc bath at a certain speed. Static wetting, or wetting at low speed, can be studied using the sessile droplet technique for instance, or the Wilhelmy plate method, but dynamic wetting in molten metal is not easy to simulate at the laboratory scale. Here, a phenomenological model of dynamic wetting is proposed that comes from a dimensions analysis. It allows a prediction of the dynamic meniscus shape at immersion that would require to be verified experimentally. Because of the regular speed in hot dip galvanizing and because of the high density and low viscosity of liquid zinc, inertia dominates both viscosity and capillary forces when looking at the amount of zinc involved in a static meniscus. The goal of the dimension analysis is to define the amount of liquid that can be involved in a wetting meniscus, i.e. such that the capillary force dominates inertia. Such analysis suggests modeling the dynamic meniscus shape as the combination of an ascending meniscus, able to climb up along the strip surface against its movement, the extension of which being of the order of 30 µm, and an inertia meniscus, bent downwards, the extension of which being of the order of a few millimeters. This approach might look somewhat artificial, but its value lies in the fact that it allows understanding many industrial wetting defects features. The bare spot defect genesis is described and its particular asymmetric form after wiping is explained. Other particular features created by wetting defects between liquid zinc and steel at immersion are illustrated, like the entrapping of oxide films floating on the liquid seal in the snout, related to instabilities of the meniscus shape, and the possible evolution of hydrogen, escaping from the steel before coating solidification, giving rise to symmetric bare spots. Possible steel roughness effects on the dynamic of the triple line are illustrated and the existence of a precursor film allowing the movement of the triple line is highlighted. A dimensions analysis is also proposed to asses possible effects of strip vibrations on the meniscus stability.

D-5-2 (P-22) 14:10
WHITE SPOT DEFECT ON HIGH-TENSILE STRENGTH GALVANNEALED STEEL SHEET

Tomohide Konishi, Hiroshi Irie
Kobe Steel, Ltd., Japan

Production of high-tensile strength GA which use base steel with high Mn content, there is a case that white spot defect occurs on the coating surface. The occurrence mechanism of this defect is estimated as follows from above results. Mn oxide precipitated on steel surface during annealing is deposited and grows up on the hearth roll surface locally. The Mn oxide on the hearth roll surface is transferred on steel surface during annealing. Transferred Mn oxide inhibits the formation of Fe-Al layer on the steel surface in the coating bath. Because of the absence of the Fe-Al layer, Zn-Fe alloying reaction progresses on that portion in the coating bath. The locally grown Zn-Fe alloy inhibits the wiping of zinc, and coating layer thicken partially. As a result, Fe content in the coating layer decreases, and that portion exhibits white spot appearance defect.

D-5-3 14:30
EFFECTS OF STEEL SUBSTRATES ON NONUNIFORMITY OF THE COATING SURFACES DURING GALVANNEALING REACTION

Doo-Jin Paik[1], Chung-Won Kim[1], Hyeon-Seok Hwang[1], Je-Woong Lee[1], Deok-Gu Kang[1], Si-Youl Choun[1], Moon-Hi Hong[2]
[1]POSCO, Korea, [2]POSCO C&C, Korea

Interstitial free mild steels and phosphorous added BH steels for automotive were galvannealed and investigated nonuniformity of the coating surfaces at various conditions of the substrates ferrite grain sizes of 18.2, 24.4 and 65.2µm in steel A and 9.5, 11.0 and 16.5µm in steel B. Nonuniformity of the galvanneal coating surfaces was increased as ferrite grain sizes increased. In addition, annealed surfaces of steel B containing more oxygen, manganese and phosphorous amplified nonuniformity of the galvanneal coating surfaces with combining the effects of ferrite grain sizes. Also, nonuniformity of the galvanneal coating surfaces were affected by the galvannealing conditions of galvanneal heating rates, galvannealing temperatures and speeds.

D-5-4 14:50

STUDY OF A SURFACE DEFECT ON GALVANNEALED SHEET

Avik Mondal, Shoham Agnihotry, Anindita Chakraborty, Arup Kumar Halder, Puspanjali Mohanta, Soumilya Nayak, Amrendra Kumar, Rajesh Pias, Monojit Dutta
Tata Steel, India

The surface finish of these galvannealed coated steels is of prime importance. However, different types of defect may generate due to the various difficulties of the coating process. Pin-prick defect or indentation mark on the galvannealed steel is one of the major defects observed on the galvannealed steels. In the present study, Pin–prick defect has been investigated in detail. Samples were analysed using Scanning Electron Microscope (SEM) and Confocal Laser Scanning Microscope (CLSM). The relation between the defect morphology was thoroughly analysed. The defect was found on both the surface of the steel strip. It had a depth around 30 to 40 μm depending upon the steel. The defect was found on the steel strip surface. The defect was observed for both GA and GI coated steel strip. It has been found that the defect maintain an orientation relationship with the rolling direction and the position on the strip. Many simulated experiments were performed to understand the effect of different sections of the line on the defect formation such as skin pass roll, Top roll, GA furnace, Zn bath, snout and annealing furnace.

D-6 Electrogalvanizing and Dross Control

Date: Tuesday, November 14
Time: 15:30-17:30
Venue: Room D
Chairs: Josef Faderl (voestalpine Stahl GmbH, Austria)
Tomohide Konishi (Kobe Steel, Ltd., Japan)

D-6-1 *Invited* 15:30

ELECTRODEPOSITION OF Zn-V_2O_4 and Zn-Al_2O_3 COMPOSITES FROM SOLUTIONS WITHOUT DISPERSED PARTICLES

Hiroaki Nakano[1], Satoshi Oue[1], Shigeo Kobayashi[2], Hisaaki Fukushima[1]
[1]Kyushu University, Japan, [2]Kyushu Sangyo University, Japan

The electrodeposition of Zn-metal oxide composites under galvanostatic conditions from agitated sulfate solutions was investigated. The solution only contained the appropriate ion species without dispersed particles. Although V oxide could be codeposited with Zn in an additive-free solution, the codeposition of other oxides did not succeed without using an additive to suppress the Zn deposition, which shows that the codeposition behavior of metal oxides is different depending on the type of oxide. The content of oxides in the deposits increased under electrolysis conditions that increased the pH near the cathode. The codeposition mechanism of oxides of V and Al ions, whose critical pH for hydrolysis are lower than that for Zn ions, is different from that of oxides of Mg ions, whose critical pH for hydrolysis are higher than that for Zn ions. The corrosion resistance of the deposited Zn was improved by the codeposition of each oxide.

D-6-2 15:50

PASSIVATION AND CORROSION BEHAVIOR OF HASTELLOY CONDUCTOR ROLLS IN ELECTROGALVANIZING LINE

Ryo Sasaki, Sho Katsura, Mikako Takeda
Kobe Steel, Ltd., Japan

Conductor Rolls (CDR) on a continuous electrogalvanizing line are used to supply electron to the steel strips. The CDRs sometimes corrode in electrogalvanizing bath and some problems are caused. In past years, it was found that the CDR corrosion is related to the Fe impurities. However, it is not clear why Hastelloy corrodes in a cathodic polarized environment nor is it clear how Fe contributes to its corrosion. On investigation, no corrosion was observed in the bath, either with or without Fe impurities. Corrosion occurred only due to the pulse-cathodic electrolysis simulating rotation of CDR. It is estimated that formation and breaking of the passivation layer is repeated in short time cycles by pulse-cathodic electrolysis in the Fe impurities containing bath, and this seems to be a cause of Hastelloy CDR corrosion.

D-6-3 16:10

STUDYING THE EFFECTS OF NITRIDING SURFACE HEAT TREATMENT ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF VARIOUS COBALT-CHROMIUMM ALLOYS

Luis J.Escott[1], David J. Penney[1], Amit Das[1], Dean Thomas[2]
[1]Swansea University, UK, [2]Weartech International Ltd, UK

Cobalt alloys used for molten zinc applications on galvanising lines experience concentrated levels of degradation due to harsh working conditions. The lines are regularly stopped to replace bearing components resulting in significant production losses. Concentrated degradation has been linked with the formation of intermetallic phases that occur from bearing material and bath reactivity. The effects of nitriding several CoCr alloys was studied in an attempt to improve bearing performance. Nitriding was varied between 10 to 20 hours and temperatures of 450℃ to 550℃. Static dip corrosion tests of treated and untreated samples were carried out in a 0.35%Al-Zn alloy for 168 hours to observe changes in chemical resistance.
Results show all studied alloys experienced levels of nitrogen diffusion reaching a maximum of 12μm. This resulted in increases in material hardness of up to 25% and was found to improve the alloys resistance to chemical attack.

D-6-4 16:30

EFFECT OF AHSS ON DROSS FORMATION AND ZN POT MANAGEMENT AT ARCELORMITTAL DOFASCO #5CGL

Weimin Zhong, Rob Dziuba, Talha Rizvi
ArcelorMittal Dofasco, Canada

In this study, the Laser Induced Breakdown Spectroscopy (LIBS) was used to monitor the variation of dross formation in the Zn pot, and the ingot model was used to monitor the top dross formation (i.e. top skimming) and the Al consumption during production of the advanced high strength steels (AHSS). The results showed that running AHSS (up to a 70 hour campaign) had no observed effect on formation of top dross (top skimming) and the dross level in the Zn pot. Whereas, more Al (~15%) was consumed by running the AHSS in a GI pot, and less Al (~5% less) was consumed in a GA pot. Mechanisms for explaining the difference

are proposed. Al consumption during the AHSS runs was adjusted accordingly in the ingot model to improve the pot Al control capability.

D-6-5 16:50

NOVEL OPERATING PHILOSOPHY FOR PRODUCING SURFACE CRITICAL GALVANNEALED AND GALVANIZED AUTOMOTIVE STEELS

Rajesh Pais, Mohseen Kadarbhai, Soham Agnihotri, Anil Pujari, Vinay Mahashabde
Tata Steel Limited, India

Hot dip galvanized (GI) and galvannealed (GA) steels are being used increasingly in various automobile applications ranging from internal to exposed panels. Tremendous increase in coated products' demand in the past decade is seen due to their enhanced product performance. Tata Steel India's Continuous Galvanizing Line#2 has undergone continuous improvements in processes and operations aligning to higher demands. Challenges involved in processing GA and GI from single line are highlighted with GA-skewed product-mix (3GA:1GI). Present paper documents a novel operation philosophy of producing surface critical automotive panels in GA and GI in this tricky product-mix dictated by Indian automakers. This philosophy helps in making desired surface quality free of dross entrapments while enabling product quality prediction over campaign. Based on precise calculations of bath iron and bottom dross in baths, scheduling rules were reformed resulting in optimum utilization of zinc baths, creating more opportunities for producing critical GA and GI.

D-6-6 (P-10) 17:10

THE SELF-CALIBRATING POT CHEMISTRY LIBS SENSOR

Alexandre Nadeau, Jean-David Grenon, Marc Choquet
Tecnar Automation Ltée, Canada

In today's challenging economics for steelmaking, the need for enhanced efficiency and better quality is more than ever a daily reality. Among others, pot chemistry and pot level are two key parameters that need precision. The last 10 years has seen a laser based technology making its place in the world of pot chemistry control. Now with nearly thirty sites globally operating a 24/7 LIBS sensor, Tecnar is proud to introduce the next generation of its now established technology. The aim of the new product is to remove the need for lab analysis, usually required to calibrate the first generation instruments, thus giving full autonomy to the process personnel. Furthermore, the new generation sensor delivers a pot level measurement that is unaffected by skimming activities or dross accumulation at the surface. In this paper, we present the scientific and industrial performances of the calibration feature based on solid standards. The results show a relative standard deviation below 2%. Furthermore, thanks to the laser's micro-sampling capabilities, the soluble contents can be measured directly on the solidified pot sample, without the need to a calculus based on Fe-Al content and pot temperature.

Plenary Lectures

Date: Wednesday, November 15
Time: 9:00-10:20
Venue: Room A
Chairs: Moon-Hi Hong (POSCO, Korea)

Plenary Lecture 5 9:00
APPLICATION OF CONTINUOUS GALVANIZED STEEL IN EUROPE: DRIVING FORCES AND GAME CHANGER

Josef Faderl
voestalpine Stahl GmbH, Austria

Major driving forces and game changer for the application of galvanized steel in Europe in the last five decades are presented in this paper. Challenging technological and product developments in the field of continuous galvanizing were the consequence. In a common view driving forces are mainly based on customer demands and legal constraints. But implementation of galvanized steel products or materials in general is not straight forward and often linked to material tests or changes in test procedures (mechanical properties, corrosion), introduction of other materials (aluminum, aluminized PHS, plastics) and changes in application technology. Interactions are sometimes complex. Last but not least individual persons (key persons from the customers) often play an important role. Possible impacts on the future application of galvanized steel in Europe - based on the retrospective view, actual challenges and future (mega) trends - will be put up for discussion.

Plenary Lecture 6 9:40
CURRENT TOPICS AND PRIORITIES IN FORMING AND JOINING OF ADVANCED GALVANIZED SHEET STEELS

Frank E. Goodwin[1], Eduardo A. Silva[2]
[1]International Zinc Association, USA, [2]United States Steel Corporation, USA

The forming and joining behaviors of galvanized sheet steels are integral to their usefulness during processing and end-use performance. Historically, the ease and speed of forming and joining operations of these steels has been a major cost advantage over competitive materials and in many cases has enhanced performance, for example the use of work hardening and texture control during forming. Continuously increasing requirements for higher levels of mechanical properties with thinner sections has led to the adoption of hot press forming, for which the use of a zinc-based coating is highly desirable to provided needed galvanic protection. A better understanding of the nature of galvanneal (GA) coatings and post-treatments has helped to improve forming performance of GA-coated sheet steels. Zinc-magnesium-aluminum hot-dipped coatings show forming advantages over galvanize (GI). An understanding of factors influencing edge fracture in multi-phase steels has led to improvements in forming behavior of these steels. Increased austenite contents in advanced steels can be associated with loss of ductility in resistance spot welded nuggets. Strategies are used to minimize effects of liquid metal assisted cracking (LMAC) during joining of zinc-coated ultra-high strengths steels. Laser processing, both fusion welding and brazing, are now used to join advanced steel grades, both in tailored blank production and vehicle assembly and have been studied to improve joint consistency and performance.

A-7 Microstructure, Physical Properties III

Date: Wednesday, November 15
Time: 10:40-12:10
Venue: Room A
Chairs: Haruyuki Inui (Kyoto University, Japan)
Takashi Kawano (JFE Steel Corporation, Japan)

A-7-1 *Keynote* 10:40
WETTING ASSESSMENT USING THE DISPENSED DROP METHOD IN THE FIELD OF HOT-DIP GALVANIZING

Marie-Laurence Giorgi[1], Alexey Koltsov[2]
[1]Université Paris-Saclay, France, [2]ArcelorMittal Global R&D, France

In hot-dip galvanizing, the steel strip is annealed in an atmosphere of N_2 and H_2, containing only traces of water. One of the main purposes of this heat treatment is to reduce the iron oxides present at the steel surface, in order to improve the wettability by liquid zinc. At the same time, the less-noble alloying elements (Mn, Si, P, Cr, Al) of the steel segregate to the surface and preferentially oxidize. The steel surface is then composed of metallic iron (wetted by liquid zinc) and oxide particles or films (non-wetted by liquid zinc).
The main features of wetting are first presented (surface energy, triple line, contact angle) together with simple models to estimate the equilibrium contact angle (Young's, Wenzel's and Cassie's models). Two examples of studies performed by means of the dispensed drop technique in the field of hot-dip galvanizing will then be presented: the forced wetting of a partly oxidized steel by liquid Zn - Al and the final contact angle of a liquid Zn - Al droplet on iron / silica heterogeneous surfaces.

A-7-2 11:10
ZINC PENETRATION INDUCED DEGRADATION OF AUSTENITIC STAINLESS STEEL POT EQUIPMENT

Nega Setargew, Daniel Parker
BlueScope Innovation Labs, Australia

Zinc diffusion-induced degradation of AISI 316LN austenitic stainless steel pot equipment used in 55%Al-Zn and Zn-11%Al-3%Mg coating metal baths is described. SEM/EDS analyses results showed that the diffused zinc reacts with nickel from the austenite matrix and results in the formation of Ni-Zn intermetallic compounds. The Ni-Zn intermetallic phase and the nickel depleted zones form a periodic and alternating layered structure and a mechanism for its formation is proposed. The role of cavities and interconnected porosity in zinc vapour diffusion-induced degradation and formation of Ni-Zn intermediate phases is also discussed. The formation of Ni-Zn intermediate phases and the depletion of nickel in the austenite matrix results in the precipitation of σ-phase and α-ferrite in the nickel depleted regions of the matrix. This reaction will lead to increased susceptibility to intergranular cracking and accelerated corrosion in the coating bath. Zinc-induced precipitation of σ-phase in AISI 316L is a new finding with important implications for the performance of austenitic stainless steels in zinc containing metal coating baths.

A-7-3 11:30
BEHAVIOR OF WATERBORNE PAINT IN MULTILAYER COATING

Toru Eguchi, Yasuo Hirano, Tetsuya Yamamoto, Hiroo Shige
Kobe Steel, Ltd., Japan

Generally, electrogalvanized steel sheets for electrical appliances are covered by about 1 μm-thick chromate-free coating which is formed by waterborne paint. The steel sheets are required to furnish various characteristics including corrosion resistance, anti-fingerprint, workability, conductivity, etc. according to applications. We consider that a multilayer coating can offer a greater flexibility in the design of these characteristics. However, it's difficult to form a uniform multilayer coating because a resin-based underlying coating repels waterborne paint. To solve this problem, the effect of viscosity and surface tension of waterborne paint on the structure of multilayer coating was investigated.

A-7-4 11:50
EFFECT OF ADDED MAGNESIUM ON THE COATING PROPERTIES OF GALVANIZED STEEL SHEETS

Moon-Hi Hong[1], Kyung-Kwan Park[1], Deok-Gu Kang[2], Doo-Jin Paik[2], Hyeon-Seok Hwang[2]
[1]POSCO C&C, Korea, [2]POSCO, Korea

The effect of a small amount of added Mg on the microstructure, Fe-Al inhibition layer, corrosion resistance and welding properties of hot-dip galvanized and galvannealed steel sheets has been investigated. Both the microstructure and distribution of Mg were measured by scanning electron microscopy, transmission electron microscopy, glow discharge spectrometer and electron probe micro analyzer. A thin Mg layer was in-homogeneously precipitated between the Zn-coating and Al inhibition layer. During the annealing process around 470-510ºC, the Mg layer was completely diffused into the inside and/or extreme surface of the Zn coating. The corrosion resistance of galvannealed steel sheets was significantly improved by adding a small amount of Mg into the zinc pot. Fe content, the formation of the Fe-Al inhibition layer and weldability were also influenced by the added Mg.

B-7 Air Knife

Date: Wednesday, November 15
Time: 10:40-12:20
Venue: Room B
Chairs: Thomas Daube (SMS group GmbH, Germany)
Li Wang (Baosteel R&D Center for automotive sheet steels, China)

B-7-1 (P-12) 10:40
CLARIFICATION OF AIR KNIFE STREAK GENERATION CONDITIONS

Yu Ito, Soshi Yoshimoto, Hideyuki Takahashi, Kazuhisa Kabeya
JFE Steel Corporation, Japan

In the continuous galvanizing line (CGL), adhesion of a spray of molten zinc, or so-called splash to the surface of the air knives causes longitudinal streaks on the galvanized steel strip. Air knife streak is one of the critical defects of strip surface appearance. This paper presents a clarification of the conditions for generation of air knife streaks based on experiments with a laboratory wiping simulator and a CFD analysis. Although adhesion of splash to the front edge or the upper part of the air knife had an insignificant effect on surface quality, blocking of the slit gap greatly affected the generation of air knife streaks. The CFD analysis revealed that blocking of the slit gap led to a reduction of the impingement pressure of the wiping gas. Thus, the reduction of the impingement pressure by blocking of the slit gap was clearly the main cause of air knife streaks.

B-7-2 11:00
SKIN FRICTION MEASUREMENTS ON A LOW MACH NUMBER EXTERNALLY-EXCITED AIR KNIFE MODEL

Adam Ritcey[1], Joesph McDermid[1], Frank Goodwin[2], Samir Ziada[1]
[1]McMaster University, Canada, [2]International Zinc Association, USA

Air-knives employed in continuous hot-dip galvanizing can become self-excited due to upstream feedback mechanisms facilitated by the presence of the impingement plate. These fluid resonant conditions are known to produce strong jet column oscillations and large vortex structures in the shear layers. The current, and ongoing, study involves designing a lower Mach number air-knife model that exhibits acoustically forced jet column oscillations and large vortex structures in the jet flow, while investigating the skin friction at the impingement plate.

B-7-3 11:20
COATING THICKNESS REDUCTION VIA MULTIPLE SLOT AIR-KNIVES

Ali Yahyaee Soufiani[1], Joseph R. McDermid[1], Andrew N. Hrymak[2], Frank E. Goodwin[3]
[1]McMaster University, Canada, [2]University of Western Ontario, Canada, [3]International Zinc Association, USA

Gas jet wiping via an air-knife is an effective hydrodynamic method for controlling the zinc coating thickness on a moving steel substrate in the continuous galvanizing line (CGL) process. The current generation of single slot air knives used in CGLs are becoming increasingly limited with respect to their ability to produce low coating weights at the higher line speed desired for relatively thin sheet products.
In this contribution, a novel multiple slot air-knife configuration was investigated numerically as an alternative for the conventional single slot jet air-knife. In particular, the sensitivity of the coating weight to the pressure and shear stress profiles was investigated to determine if there are operating regions for coating thickness that are robust with respect to air knife process variable changes.
Based on the results of the numerical models, a modified geometry for the multiple slot air knives was designed and the effects of process variables, such as: main jet Reynolds number (Re_m), auxiliary jet Reynolds number (Re_a) and ratio of jet slot opening to wall distance on the final coating thickness. It was found that by setting the Reynolds number of the auxiliary jets as a fraction of the main jet Reynolds number, the multiple slot air-knife design can produce lighter coating weights compared to a conventional single slot jet, particularly for higher strip velocities and z/d ratios.

B-7-4 (P-13) 11:40
INTEGRATED SOLUTION OF ELECTROMAGNETIC STRIP STABILIZATION AND AIR KNIVES: FIRST INSTALLATIONS, EXPERIENCES AND RESULTS

Stefan Weber[1], Steffen Dombrowski[1], Jürgen Koch[1], Matthias Black[2], Edgar Owsianny[2], Daniel Plätzer[2]
[1]EMG Automation GmbH, Germany, [2]DUMA-BANDZINK GmbH, Germany

The strip vibration damping results and the increased added value to be achieved through the use of an electromagnetic strip stabilization system depend significantly on the optimum arrangement of the strip stabilization system in relation to the air knife system. The general rule is: the better the electromagnetic strip stabilization system is integrated into the air knife arrangement and the closer the strip stabilization system is located to the level of the air knife lips (i.e. the actual point of technology), the better the results for vibration damping and crossbow reduction are to be expected. Vice versa the best coating results and a uniform coating layer of the zinc layer defined by the air knives also depend on the optimum arrangement and performance of the electromagnetic strip stabilizer.

In 2016 EMG Automation and DUMA-BANDZINK developed a fully integrated strip stabilizer / air knife solution based on EMG's electromagnetic strip stabilizer and the advanced air knife technology of DUMA-BANDZINK: the "integrated solution".

This combination of the two high end technological solutions allows highest and most accurate zinc coating results, the creation of optimum conditions for a closed loop control circuit and an enhanced control of the overall coating process. The design of the "integrated solution" is optimized for free view of the running strip, easy maintenance as well as for lip cleaning issues and leads in addition to a significant noise reduction. The proximity of the electromagnetic strip stabilization system to the air knife lip enables the user to draw direct conclusions with regard to the strip position and shape between the air knife lips, thereby enabling corrections to be made to the position of the air knife without any delay.
Due to the exact knowledge of the strip position in two dimensions, the strip shape, the strip behavior and the direct mechanical (and electronically) coupling of the air knife arrangement with the strip stabilizer, a new quality of parameters is achieved for optimum air knife control. The fully integrated design promises not only best damping and coating results, but provides also an optimized system handling for the operators in case of any production line works. Above all the "integrated solution" allows the potential users to increase throughput and to produce coated strips with improved surface characteristics.

This paper will mainly concentrate on realized results and experiences of the first installations of the integrated solution. Additionally the technological framework conditions for the integrated system and the system design will be introduced.

B-7-5 (P-14) 12:00
IMPACT OF SNOUT HEAT INSULATION ON THE HNX FLOW

Michel Dubois
CMI Metals, Belgium

The current and claimed efficient practice against Zn dust is to heat insulate the snout supposedly because Zn cannot condensate on walls and so fall on the strip. That explanation is unfortunately very unsatisfactory because the HNX temperature in the snout is always lower than the zinc condensation temperature
The present work has the objective to analyze the HNX flow in the snout by CFD modeling using a simplified geometry. The purpose is to make a "differential study" considering various level of heat insulation as well as bottom water injection.
The key finding is that the buoyancy phenomena induced by the temperature difference between the walls, the snout shoe and the strip is the driving force of the flow. The strip has a much lower impact due to its relative low Reynolds number compared to the Grassof one. The lower the heat insulation and the higher the HNX circulation in the snout is. This could be the true reason why a good insulation is beneficial against the Zn dust defects.

C-7 Corrosion III

Date: Wednesday, November 15
Time: 10:40-12:50
Venue: Room C
Chairs: Michael Rohwerder (Max-Planck-Institut für Eisenforschung GmbH, Germany)
Tadashi Shinohara (National Institute for Materials Science, Japan)

C-7-1 *Keynote* 10:40
THE EFFECT OF DE-ICING SALTS ON THE CORROSION OF AUTOMOTIVE MATERIALS

Bo Rendahl, Bror Sederholm
Swerea KIMAB AB, Sweden

In an extensive work performed by Swerea KIMAB a large number of automotive materials have been exposed on the underbody of trailers. It included more than 20 trailers operating in North and South America, Europe and Asia for a period of three years. The relative corrosivity of the natural vehicle environment has been measured using standardized test coupons of carbon steel, zinc and zinc coated steel and aluminum both with and without a full automotive paint system. The obtained results showed that there is a very large difference in corrosivity between areas with de-icing salt and areas without de-icing salt. The results also indicated the very complex road environment that has a strong influence of the corrosion resistance of different materials. In addition to the exposure on running vehicles also stationary exposures with material representing road furniture has been performed along public roads, on bridges and inside a tunnel in Sweden.

C-7-2 11:10
ATMOSPHERIC CORROSION OF HOT DIP GALVANISED STEEL AND ZINC MAGNESIUM ALUMINIUM COATED STEEL

Dominique Thierry[1], Dan Person[2], Gerald Luckeneder[3], Karl-Heinz Stellnberger[3]
[1]French Corrosion Institute, France, [2]Swerea KIMAB, Sweden, [3]voestalpine Stahl GmbH, Austria

Hot dip galvanized steel and zinc alloyed coated steel such as ZnAl and ZnAlMg (ZM) are used in the building industry and in the automotive industry. However, In the case of zinc coated steel with Al and Mg, there is still relatively

scarce information on the long term performance under atmospheric weathering conditions. Although large efforts have been made to study the corrosion products formed on zinc under atmospheric weathering conditions, very few data exist on HDG and zinc alloyed coated steel.
This work is a part of a larger research program were steel with different zinc coatings are exposed on a worldwide basis on well characterized exposure sites in Europe, Asia and North America. Corrosion rates of hot dip galvanized steel and zinc magnesium aluminum (e.g. 2% w% of Al and 2w% of Mg) coated steel were determined after 1, 2 and 4 years of exposure under different climatic conditions.
The formation and development of corrosion products was followed by detailed analysis of samples exposed 0.5, 1, 2 and 4 years using XRD, FTIR-spectroscopy and SEM-EDS. For HDG the sulphate/carbonate ratio was highly dependent on the exposure site (with low values at marine sites and high values at industrial sites). The analyses of corrosion products on ZM coated steel revealed higher sulphate/carbonate ratio compared to HDG. This may be linked to the corrosion rate of the coating with less formation of hydrozincite. The data are discussed in view of current knowledge in atmospheric corrosion of zinc, HDG and ZM coated steel materials.

C-7-3 11:30
ON THE ANTI-CORROSION PERFORMANCE OF ZN-AL-MG SUBSTRATES UNDER NATURAL EXPOSURE

Beril Corlu[1], Corinne Dieu[2], Christian Allely[3], Tiago Machado[3], Luc Diez[3], Joost De Strycker[1]
[1]ArcelorMittal Global R&D Gent, Belgium, [2]ArcelorMittal Global R&D, Belgium, [3]ArcelorMittal Global R&D Maizières Automotive Products, France

The outstanding corrosion resistance of ZnAl3.7Mg3 (all in wt.%) coatings has been proven since the start of the development in Europe in the late 2000's. Also the corrosion mechanism was shown under different exposure conditions to support the understanding of this performance. However, with the ramp-up to mass production during the last decade, experience was built up with these new alloys under many different natural exposure conditions.
The perforating corrosion resistance and the ability to protect bare cut edges, thanks to the improved galvanic protection and self-healing mechanism, have been monitored for the different atmospheric corrosivity classes C1-C5 and even Cx (according to ISO 9223). In this work also the immersion categories Lm1-Lm3 (according to ISO 12944) were taken into account. Comparative testing between accelerated lab testing procedures and field exposures in different types of soils was executed and analysed. In a next step other environmental factors were studied. One extra parameter is certainly the presence of abrasive particles, like sand, in the atmosphere. After lab screening a field exposure phase was started and first results are available. A last screening was performed on the corrosion behavior in alkaline environment such as when the parts are in contact with concrete and on the galvanic coupling behavior between the metallic coated parts and fasteners of different types. In all cases ZnAl3.7Mg3 was compared with standard Zn coatings.

C-7-4 11:50
INVESTIGATION INTO THE EFFECT CUTTING TECHNIQUE HAS ON THE CUT EDGE CORROSION RESISTANCE OF ORGANICALLY COATED STEEL

David Penney, James Sullivan, David Worsley
Swansea University, UK

Organically coated steels are ubiquitous in the construction industry. They are produced on continuous coating lines before being profiled into large panels ready for installation on a building. Cutting the panels creates a cut-edge, exposing the underlying steel substrate. Contractors use a plethora of tools to cut panels to size; this study examines the effect of cutting technique on the cut-edge corrosion resistance. Samples were prepared from a sheet of typical OCS using the following methods:
· Guillotined
· Hacksawed
· Nibbled
· Polished
Microscopy and SVET studies showed differences in cut-edge morphology and corrosion resistance for each cutting technique. Nibbled edges demonstrated the highest corrosion rate (212µg of zinc loss over 24-hours in 0.1%NaCl) whilst the guillotined edges showed just 49µg over the same period. This is attributed to the action of the shear blades transfering zinc metal over part of the exposed steel, reducing the active cathodic area and affording barrier protection.

C-7-5 12:10
HYDROGEN PERMEATION BEHAVIOR OF SIZE CONTROLLED SCRATCH FORMED COATED STEELS DURING WET-DRY CYCLE CORROSION TESTS

Masatoshi Sakairi, Takumi Hashimoto
Hokkaido University, Japan

The effects of scratch on the hydrogen permeation behavior of Zn coated steel during constant dew point type wet and dry cycle corrosion tests were investigated. The permeated hydrogen through the steels was detected by electrochemically using micro-cell and a area controlled scratch was formed on the coated steels with a laser machining technique. The hydrogen permeation current was observed to be independent of the area of the formed scratches. After the tests, the corrosion products of hydroxychloride (simonkolleite) was observed at initially placement of NaCl solution. The hydrogen permeation current of the coted steels with and without the formed scratches decreased with number of cycles of the wet and dry tests. It was elucidated that the corrosion products play an important role in the hydrogen permeation behavior during wet and dry corrosion. The total amount of permeated current did not proportionally increase with increasing the scratched area. The result suggests that the surroundings of the formed scratch is prone to generate and entry of hydrogen.

C-7-6 12:30
HOT DIP GALVANIZING POT ALUMINUM CONTROL AND POT ROLL CORROSION

Frances Bleich[1], Igor Komarovskiy[2]
[1]ArcelorMittal Cleveland Works, USA, [2]ArcelorMittal Global R&D, USA

The present work is based on a case study at an industrial coating line. Following several AHSS trials, heavy corrosion damage was observed on all pot rolls (stabilizer, correcting and sink). During the same time frame, the continuous pot

aluminum monitoring device showed values below internal control limit. The normal zinc charging practice based on an ingot feeding prediction model did not work.
Aluminum and iron in zinc coatings were measured and the inhibition layer was evaluated. Samples of correcting and stabilizing rolls were cut from damaged and intact areas of roll journals and shells for metallurgical investigation. Effect of pot aluminum on corrosion evolution was discussed. The investigation concluded that the root cause of the low pot aluminum was high strip immersion temperature. It was found that the scanning pyrometer at the snout read about 12˚C degree lower than actual temperature because the pyrometer window was contaminated with dust. This resulted in the accelerated iron dissolution and high aluminum consumption in the pot. It is believed that low aluminum content in the melt enhanced the Zn corrosion attack.

D-7 Heat Cycle and Temprature Control

Date: Wednesday, November 15
Time: 10:40-12:40
Venue: Room D
Chairs: Monojit Dutta (Tata Steel Ltd., India)
Kuniyasu Araga (Kobe Steel, Ltd., Japan)

D-7-1 (P-11) *Invited* 10:40
OPTIMISATION OF AHSS ANNEALING CYCLES BY ON-LINE CONTROL OF STRIP SURFACE EMISSIVITY AND TENSILE-STRUCTURE PROPERTIES

Alessandro Ferraiuolo, Aldo Fiorini, Stefano Pantarotto, Umberto Liuzzo, Michele Manaresi, Luigi Pocaforza, Marco Cocco, Giuseppe Ruggeri
Marcegaglia Carbon Steel S.p.A., Italy

This paper presents the results of the development of an approach using advanced online devices to improve the overall HDG process control in terms of strip temperature, tensile properties and product microstructure. The furnace consists of high performance direct flame burners and radiant tubes fed by natural gas to achieve the desired metallurgical properties for the automotive product mix. Online strip emissivity measurement is fundamental in order to produce a variety of steel grades from interstitial free to advanced high strength steels with different C and Mn contents and different surface conditions. To comply the demand of consistency of structure-properties it was implemented a new mathematical model to skin pass mill aiming to online monitoring the tensile properties and microstructural features of the AHSS strip. This model can give important indications for a metallurgically based definition of the HDG process parameters.
The online measured yield stress as a function of the applied skin pass strain allowed calculating the MA fraction by means of the theory of Ashby. The proposed method could represent a new solution to define the optimized processing conditions to achieve the target microstructure for improved mechanical properties and forming-ability properties of dual-phase steels. Laboratory tensile tests and metallographic investigations confirmed a good agreement with the online structure-properties characteristics calculated with the mathematical model.
The analysis of online measured strip emissivity and online mechanical properties resulted the key strategy to guarantee the targeted strip quality, properties and low global energy consumption.

D-7-2 11:00
ANNEALING HSLA STEELS WITHOUT SOAKING PHASE

Angel Garcia-Martino[1], Valeriano Barrón[2], Santos Fernández[2], Jesús Santiago[2], Maria Manuela Prieto[3]
[1]Global R&D ArcelorMittal, Spain, [2]ArcelorMittal Asturias, Spain, [3]Universidad de Oviedo, Spain

High Strength Low Alloyed (HSLA) steels are commonly used in automotive industry due to their mechanical characteristics, enabling a weight reduction in comparison with traditional carbon steels. In case of HSLA steels produced in a hot dip galvanizing (HDG) line, the mechanical characteristics mainly depend on the chemical composition and the applied thermal cycle. The classical thermal cycle in a HDG line has four stages: heating, soaking, cooling and overaging.
During the revamping of a HDG line, new radiant tubes were installed in the soaking furnace with the purpose of increase the line capacity. This modification eliminated the soaking stage and forced to redesign the thermal cycles of the furnace. As the classical cycles proposed for the HSLAs worrisomely increased the percentage of rejections, it was defined successfully a new control parameter based on time and temperature to guarantee the mechanical characteristics of the these steels.

D-7-3 11:20
RADIANT TUBE HEATING ENERGY SAVINGS WITH NEW SILICON CARBIDE HEAT EXCHANGER

Shinichi Koga[1], Yuta Hirano[1], Tom Briselden[2], Tom Reilly[2], Jacob Briselden[2]
[1]Nisshin Steel Co., Ltd., Japan, [2]Spinworks International Corp., USA

Energy savings in radiant tube heating systems is very important for reduction in both natural gas usage and greenhouse gas emissions. Even though there are a number of highly efficient heating technologies on the market [1-4], they are often too expensive to partially or wholly renovate existing heating equipment. Spinworks and Nisshin Steel have worked together on the development of a new high efficient burner, which can be installed on the existing equipment at Nisshin Steel. Nisshin decided to install the prototype burner, designed by Spinworks, on our galvanizing line at Sakai Works. We have been improving it through trial and error for many years. Finally, in 2015 we succeeded in developing a new highly efficient burner with a silicon carbide (SiC) heat exchanger without changing the existing radiant tube and the existing burner control system. The final model has maintained a stable operating condition for more than 2 years while operating at an efficiency exceeding 85%. The exhaust gas heat loss of the new radiant tube is successfully very low, 15-20%, and the nitrogen oxide emissions are also lower than the existing radiant tube configuration, due to installing a new ceramic NOx-reduction recirculation tube in the current radiant tube, also developed by Spinworks. This new radiant tube burner can be applied to any type of radiant tube and contribute to energy savings without the costs associated with modifying furnace controls and orientation.

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D-7-4 11:40
ZINC POT TEMPERATURE CONTROL IN CONTINUOUS GALVANIZING LINE

Changwoon Jee
POSCO, Korea

In continuous galvanizing line(CGL), it is required to keep the temperature of the zinc pot of coating section within limited range for yielding uniform products and sustaining sound process as long as possible. However, if heat inflow into zinc pot by annealed hot strip is larger than natural cooling, surplus heat will be accumulated and the zinc pot temperature will rise. In order to manage the zinc pot temperature in such cases, the zinc pot temperature control technology which uses pot cooling equipment and temperature control system was introduced, and the application results were investigated. After many campaigns of operation that strictly manages the pot temperature within suggested range of ±1.5℃ off the operation target with the temperature control system, it is shown that we've got the results of decreased bottom dross formation due to the decreased Fe dissolution and the uniform pot temperature, the ease of controlling contents of Al and Fe in zinc pot and decreased zinc ash in snout due to the lowered temperature operation that is available for the temperature control system.

D-7-5 12:00
FLEXIBLE AND FAST COOLING TECHNOLOGY FOR THE PRODUCTION OF NEW ADVANCED HIGH STRENGTH STEELS

Michel Renard[1], Olivier Pensis[1], Pietro Sablone[1],
Jean-Baptiste Gouriet[2], Mathieu Delsipée[2],
Jean-Marie Buchlin[2]
[1]Drever International S.A., Belgium, [2]von Karman Institute for Fluid Dynamics, Belgium

The production of AHSS grades in continuous annealing lines and hot dip galvanizing lines leads to new developments in the furnace technology. Drever International has developed patented atmosphere gas management system and Ultra Fast Cooling technology to get high cooling performances and control of strip vibrations. The Ultra Fast Cooling system is implemented worldwide in more than 20 lines up to now. Now Drever International is developing a flexible and fast cooling technology, D-Storm®, by means of liquid cooling offering higher cooling rates and control of the strip cooling cycle.

To study this new technology, a semi-industrial prototype has been built: it allows the characterization of heat transfer coefficients in the cooling of a movable hot steel strip by water sprays. Various spray types and geometries are tested in the semi-industrial prototype. The cooling performances are measured as a function of numerous operating parameters.

D-7-6 12:20
INDUCTION HEATING OF ADVANCED HIGH-STRENGTH STEELS

Gerald Vellente, David Lazor
Ajax Tocco Magnethermic, USA

The production of Advanced High Strength Steels (AHSS) is gaining more importance in order to provide lighter weight steels and, at the same time, maintain safety. Part of the process of producing these steels is reheating the steel prior to entering the coating pot. Most producers, whether in a new line or retrofitting an existing line, are considering induction heating to accomplish this reheat. One of the difficulties in determining what induction equipment is required is the magnetic properties of the steel at the point where the reheating is required. This paper will review the background information in determining these properties, setting up and preforming lab tests, and comparing the theoretical information with the test data. We will then discuss a typical application using the information developed and package an induction heating system.

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