



Research Activities on Magnesium Alloys in Korea

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- **Introduction**
- **Research Activity at Magnesium Technology Innovation Center, Seoul National University**
- **WPM Magnesium Project**
- **Development of Corrosion Resistant Nonflammable Mg Alloys at KIMS**

Magnesium

マグネシウム

마그네슘

Magnesium



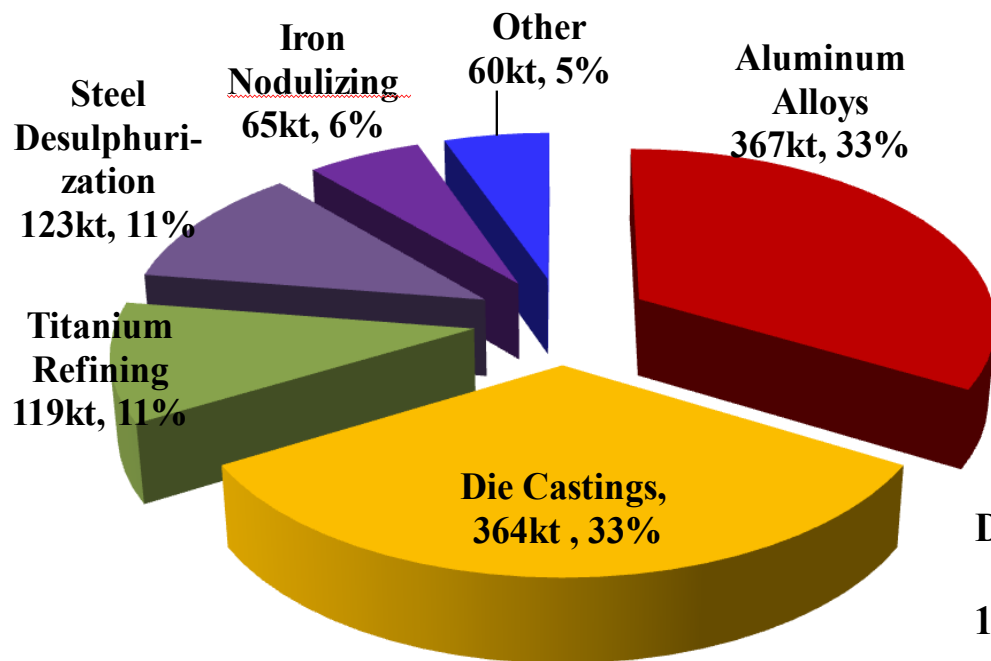
镁

Magnesium

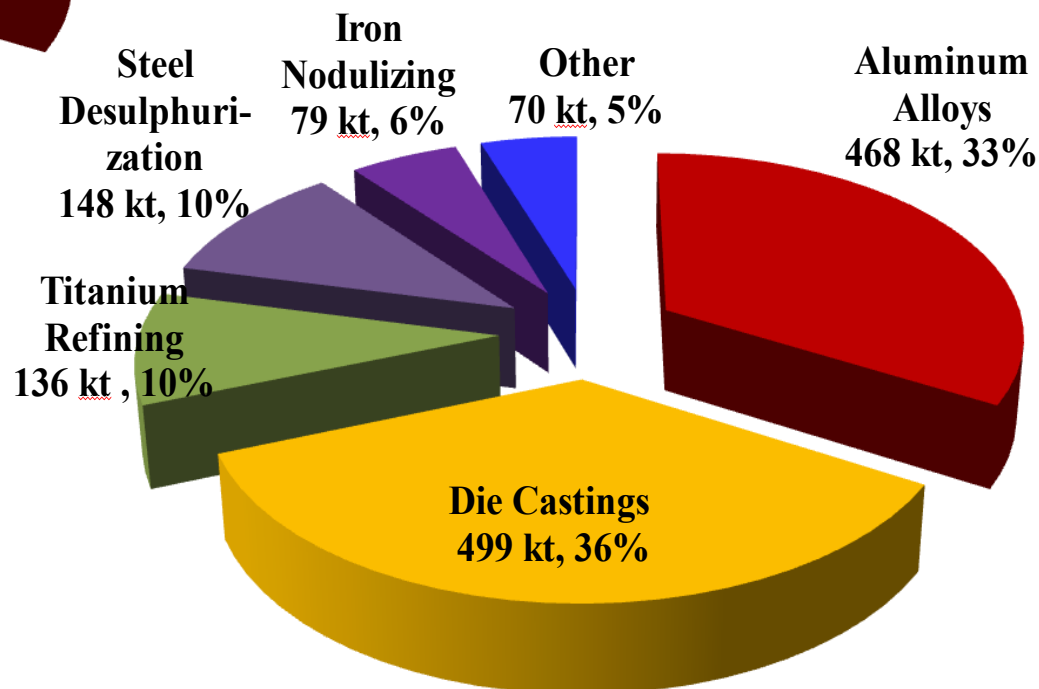
МАГНЕЗИЯ

Magnesium Crown Formed in the Pidgeon Process

Magnesium Consumption by Application

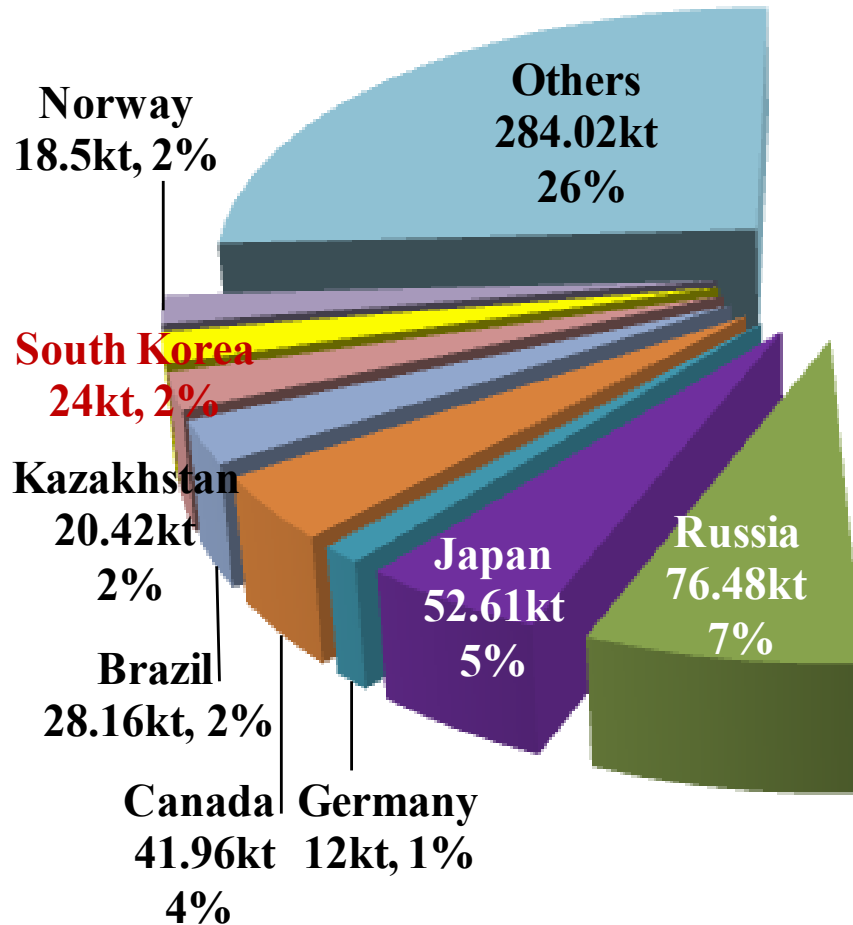


	2012	2017	CAGR(%)
Al Alloys	367	468	5.0
Die Casting	364	499	6.5
Ti Refining	123	136	2.0
Steel Desul.	119	148	4.5
Iron Noduli.	65	79	4.0
Other	60	70	3.5
Total	1,098	1,400	5.0

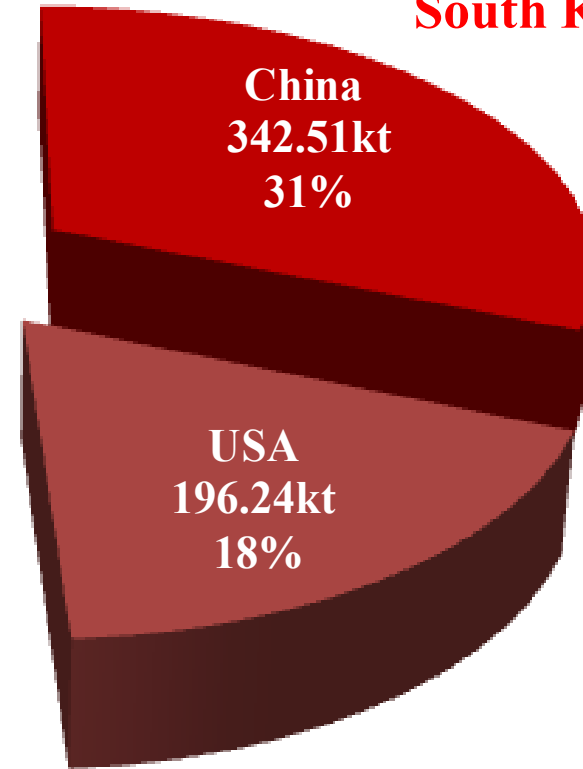


Magnesium Consumption by Country (2012)

Unit: kt, %)

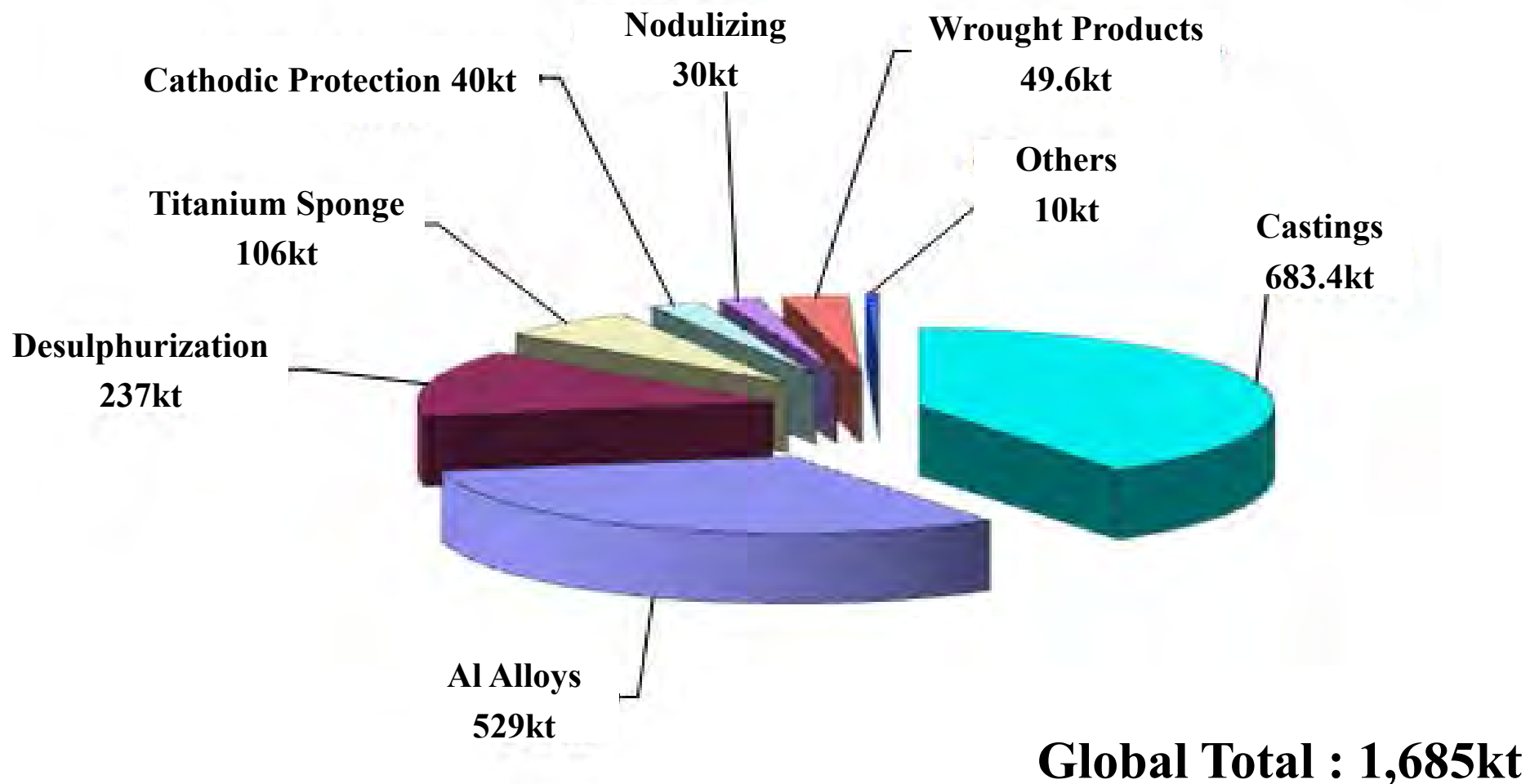


Actual Consumption in South Korea : 35kt

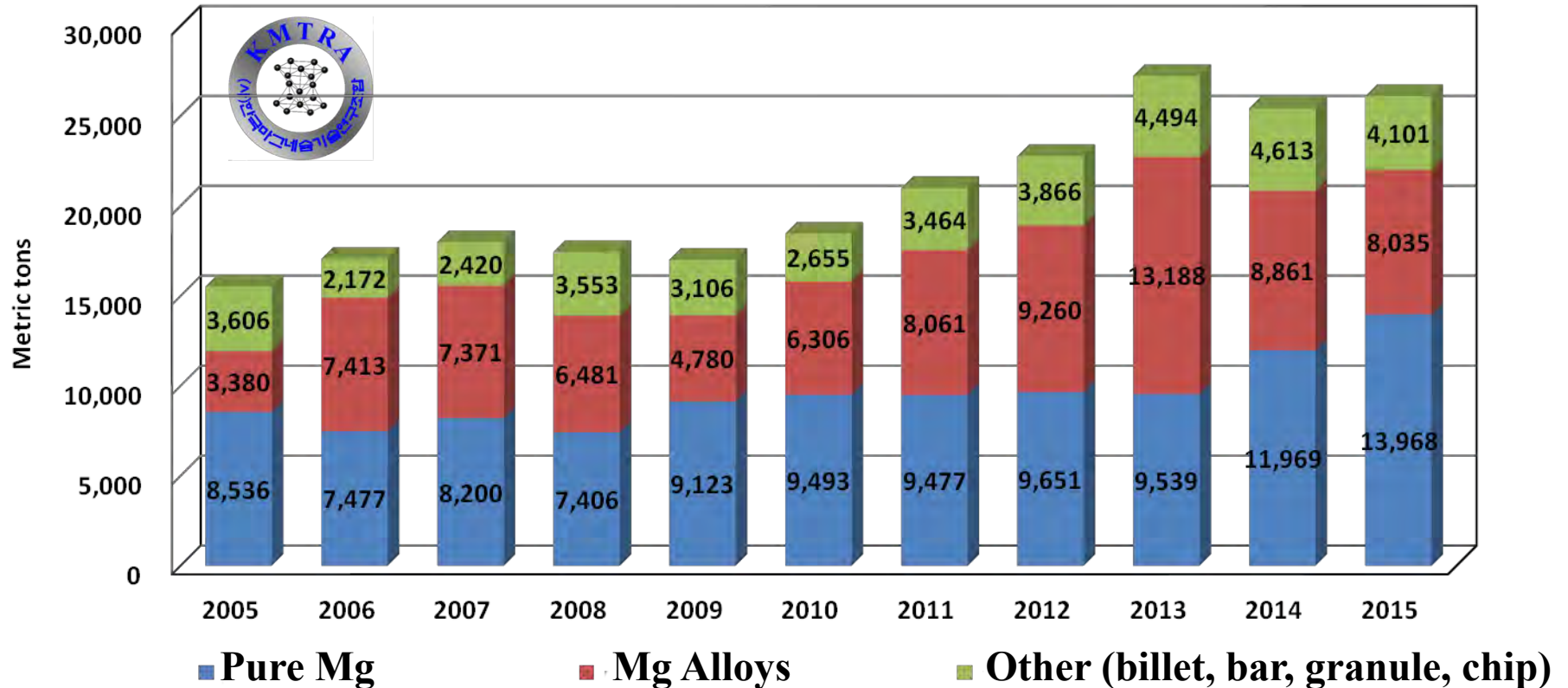


Global Total : 1,096.9kt

Prospect of World Demand of Primary Mg Ingot (2020)



Magnesium Consumption in Korea



POSCO Mg Business Overview



Completed Construction of Mg Extracting Plant

Started Construction of Mg Extracting Plant

Completed #1 Plant (600mm) Construction

Started Construction of Mg Sheet Plant

Succeeded in Production of 0.4mm Mg Sheet

Succeeded in Mg Twin Roll Casting at Pilot Plant

Started R&D on Twin Roll Casting Process

Executed Business Feasibility Research



2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015

Proposal and Consulting for Mg Business

POSCO Twin Roll Cast 2,000mm Magnesium Sheet



POSCO Twin Roll Cast 2,000mm Magnesium Sheet



Application of POSCO Mg Sheet to Automotive Body

- Sep. 2014, SM7 Nova : POSCO Mg Plate to Luggage Retainer
- World First Application of POSCO Mg Plate to Commercial Vehicle
- Luggage Retainer : 61% Lightweight
- Steel (3.6kg) → Mg Sheet (1.4kg)



- Renault 1Liter Concept Car EOLAB (Seoul Motor Show, April 2015)
- Roof of Vehicle
- Steel 10kg → 4.5kg Reduction
- Total 130kg Lightweight



- Porsche 911 GT3 RS Roof (Geneva Motor Show, March 2015)
- Lower Center of Total Vehicle's Mass
- Increase Safety Handling of Vehicle



High Performance Magnesium Alloys

- **Low Cost**
- **High Formability**
- **Corrosion Resistance**
- **High Strength**
- **Nonflammability**
- **Isotropic Mechanical Properties**
- **Low Density**
- **High Modulus**
-

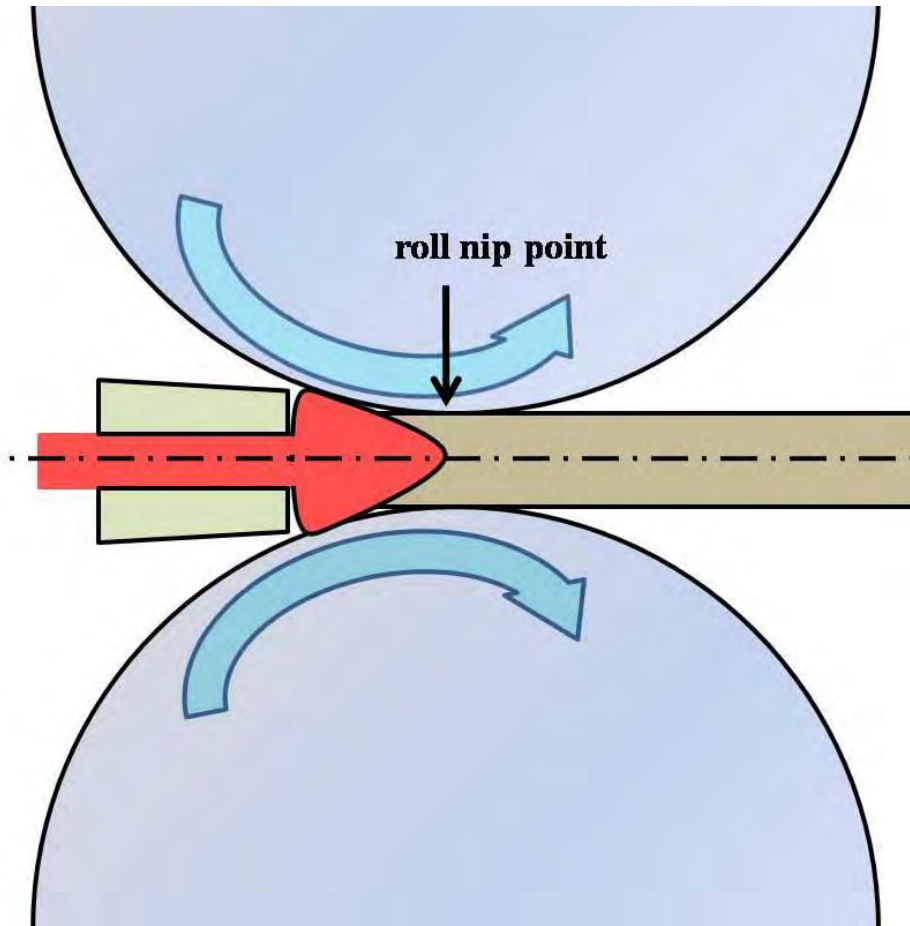
Research Activities at Magnesium Technology Innovation Center

- **Development of Advanced Mg Alloys**
 - **Computer Simulation of Stable Phase Formation and Flow/Solidification Behavior by Thermodynamic Calculations**
 - **High Strength/High Formability Alloys**
 - **High Temperature Alloys**
 - **Corrosion Resistant Alloys and Biomaterials**
- **Characterization of Microstructure/Texture and Mechanical Properties**
 - **Prediction of Deformation Behavior by VPSC-GA Simulation**
 - **Analysis of Microstructure/Texture, Dislocation, Twin**
 - **Manufacturing and Characterization of Mg Single Crystal**
 - **Mechanical and Corrosion Behavior**
 - **Characterization of Creep and Fatigue Properties**
- **Development of Strip Casting/Extrusion/Rolling Processes**
- **Semi-Solid Processing of Mg Alloys**
- **Surface Treatment: Plasma Electrolytic Oxidation Coating**
- **Development of Mg Die Casting Components for Automobile and Electronic Industries**



Development of High Strength Magnesium Sheet with High Formability

Twin Roll Casting Process



Schematic Diagram of Twin Roll Casting

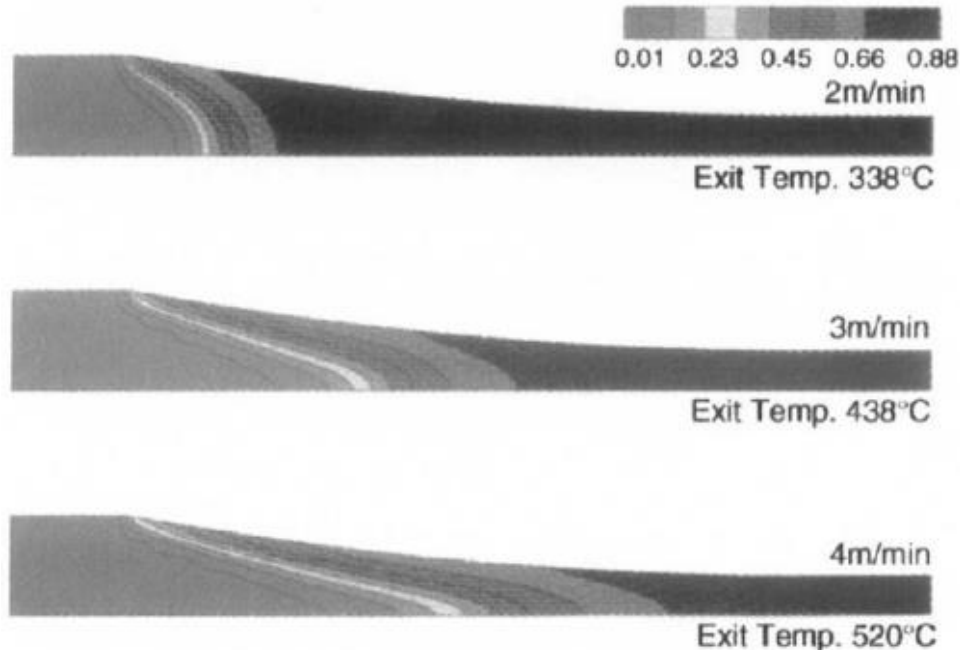
■ Advantages

- ▶ Low Production Cost
- ▶ Fine Grain Size

■ Casting Defects

- ▶ Centerline and Inverse Segregation
- ▶ Inclusion and Porosity
- ▶ Surface Cracking and Oxidation
- ▶ Sticking-related Defects

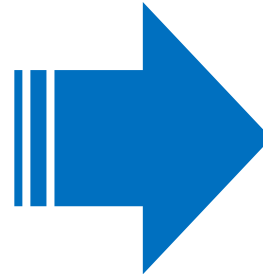
Solidification Behavior & Segregation



Increasing Roll Speed: Increasing Exit Temp.

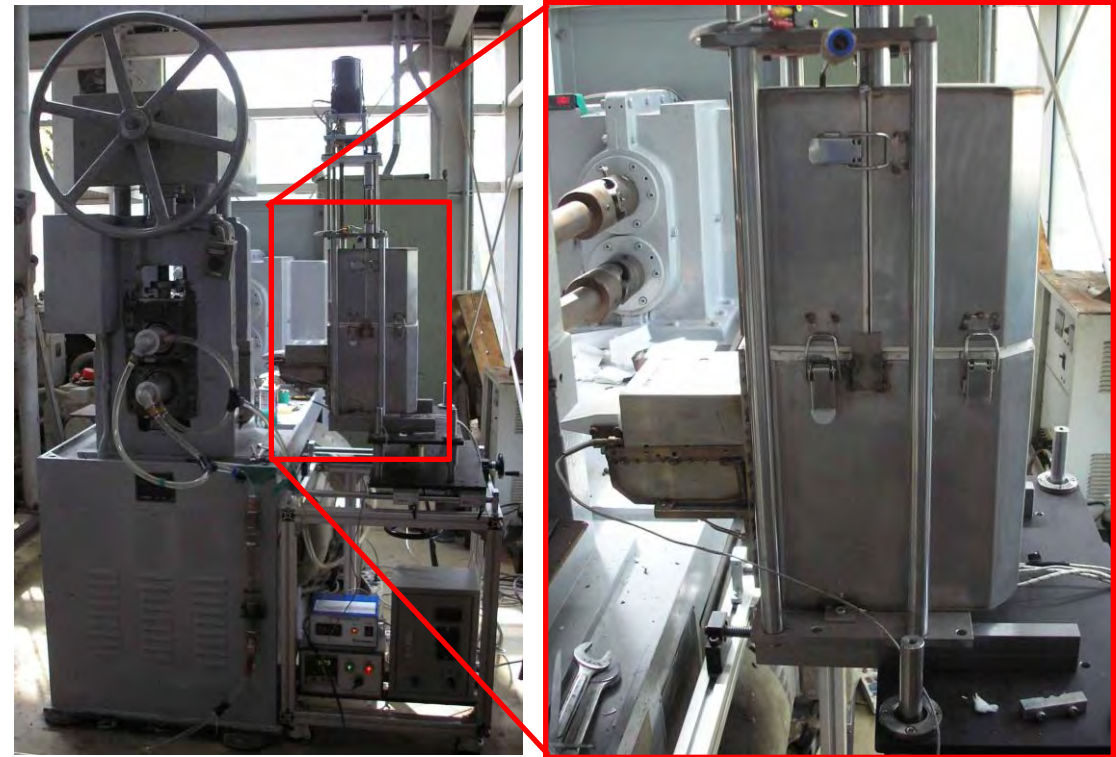
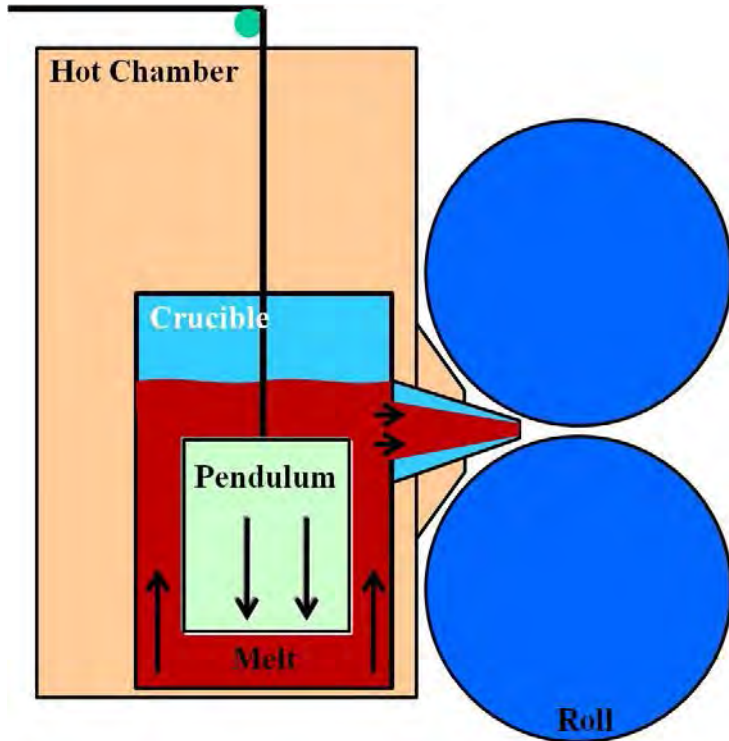
■ Factors Affecting Solidification Behavior

- ▶ Freezing Range of Alloys
- ▶ Thermal Properties of Alloys
- ▶ Roll Speed
- ▶ Roll Separating Force
- ▶ Melt Temperature
- ▶ Setback Distance



- Development of New Mg Alloys for TRC Process
- Optimization of Processing Parameters

Manufacturing Process for TRC Plates



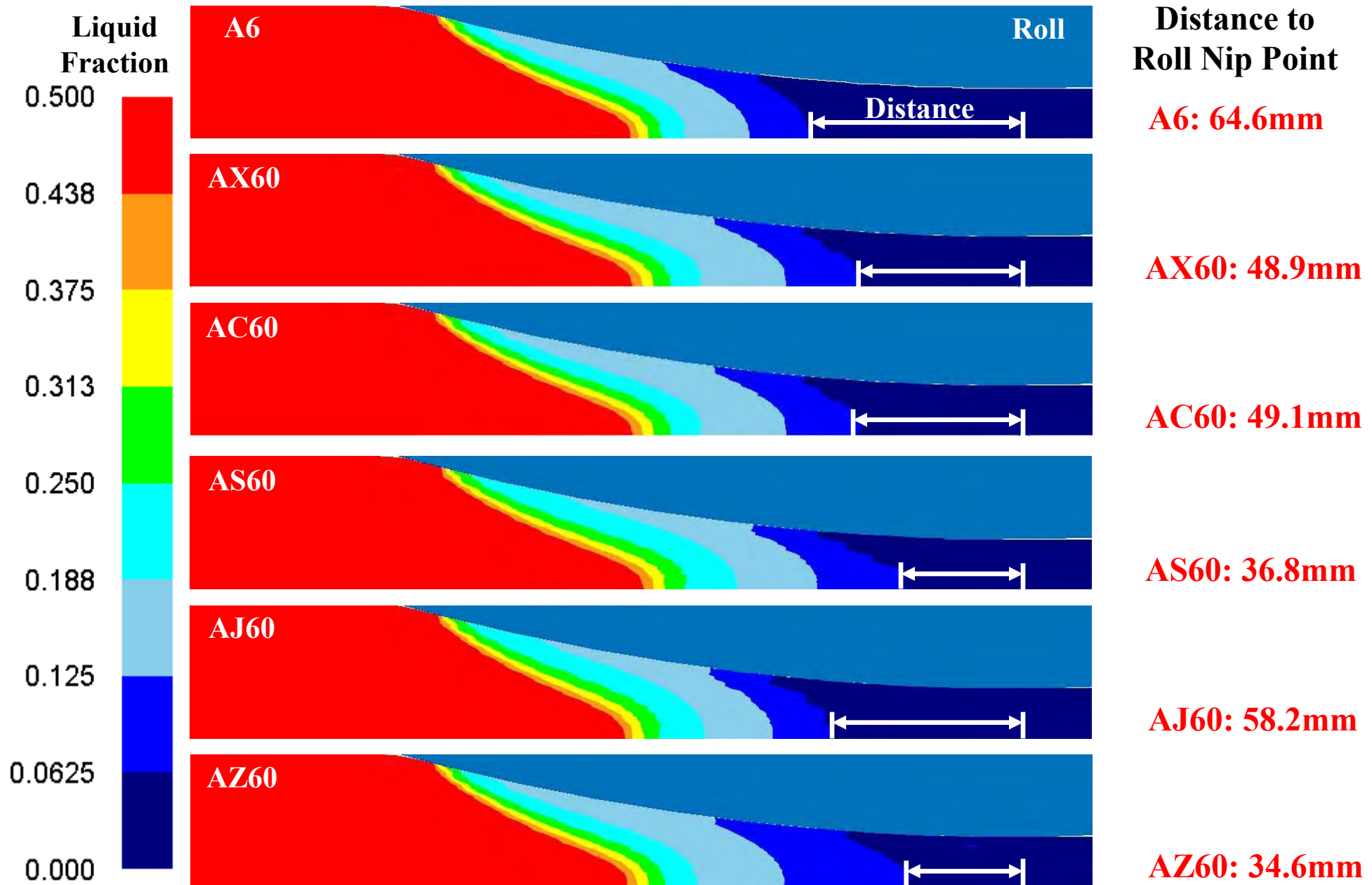
■ Fabrication of TRSC Mg-6Al-0.3X Plates

- ▶ Thickness: 3.0~3.3mm
- ▶ Width: 50~65mm

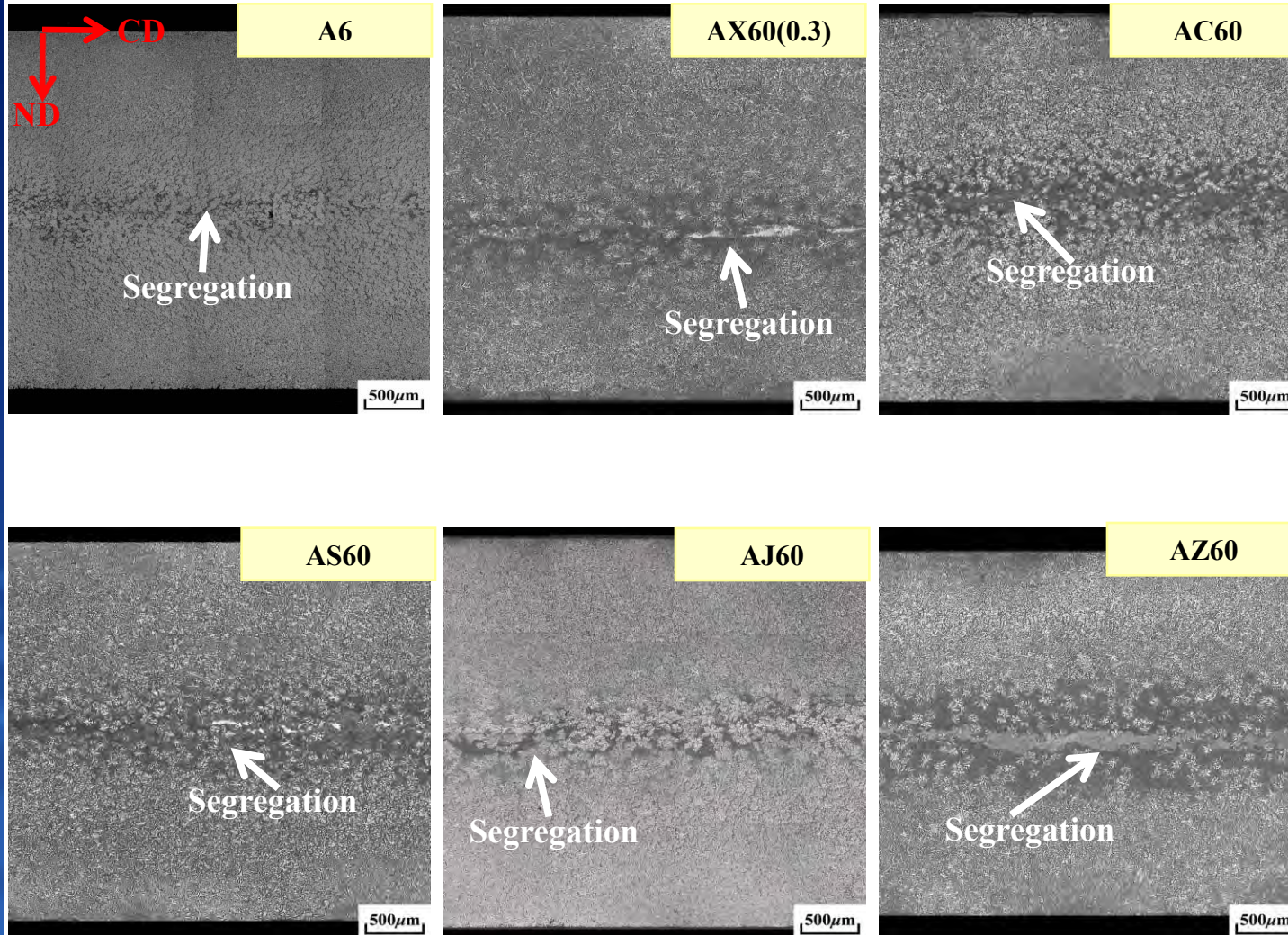


■ Development of New TRC Mg Alloys with Low Segregation & Improved Formability

Simulation of Liquid Fraction During TRC Process



Microstructure of TRC Mg-6Al-0.3X Alloys

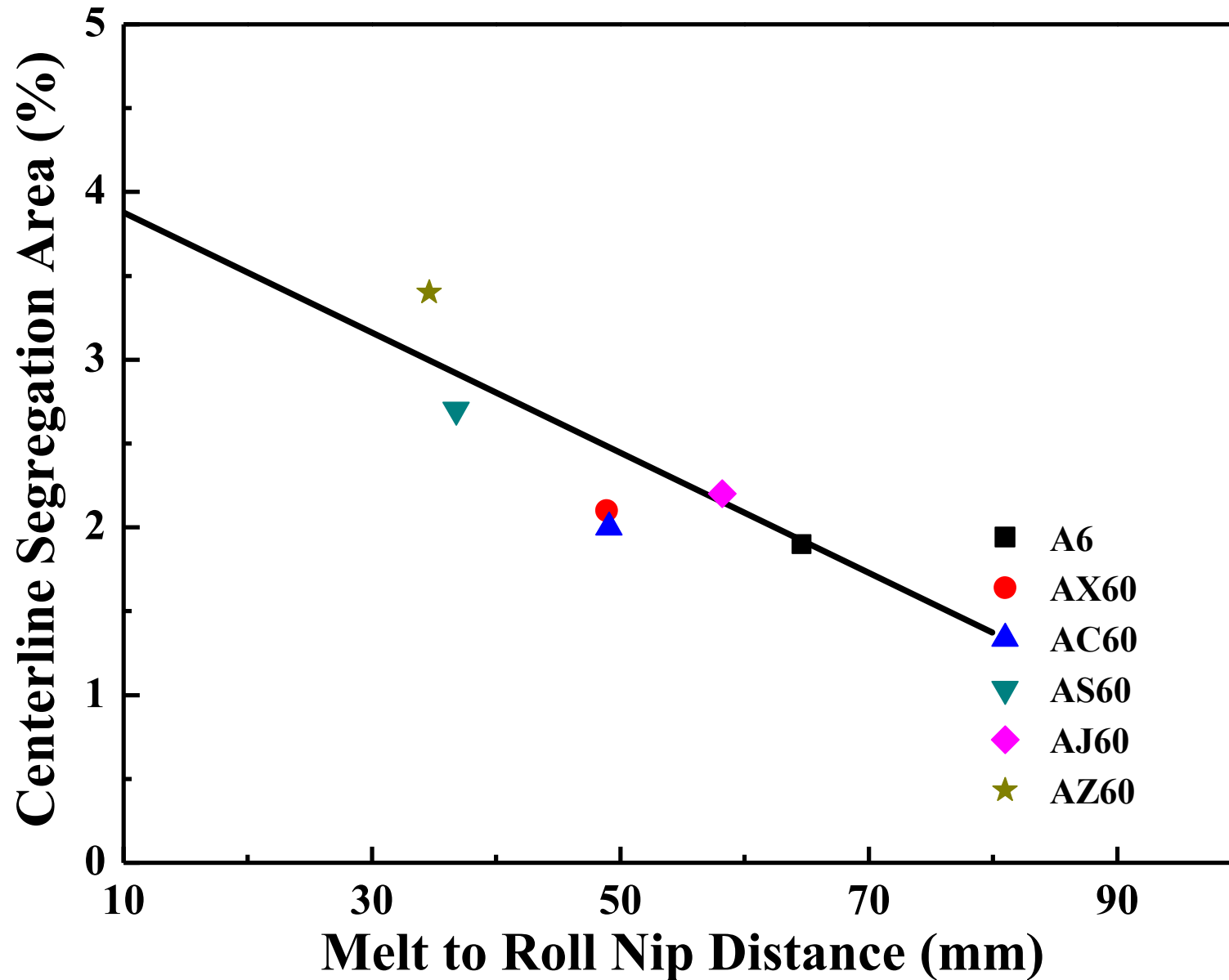


■ Segregation Factors

- ▶ Freezing Range
- ▶ Second Phase
- ▶ Solidification Behavior
- ▶ Partition Coefficient

Mg Alloys	Centerline Segregation %
A6	1.9
AX60	2.1
AC60	2.0
AS60	2.7
AJ60	2.2
AZ60	3.4

Centerline Segregation Area and Melt to Roll Nip Distance



Samples of Mg-6Al-X Alloys after Erichsen Tests

Pre-heating: 350°C

A6: 3.3mm

AX60: 3.4mm

AC60: 3.5mm

AS60: 3.3mm

AJ60: 3.4mm

AZ60: 3.4mm

Pre-heating: 450°C

A6: 4.8mm

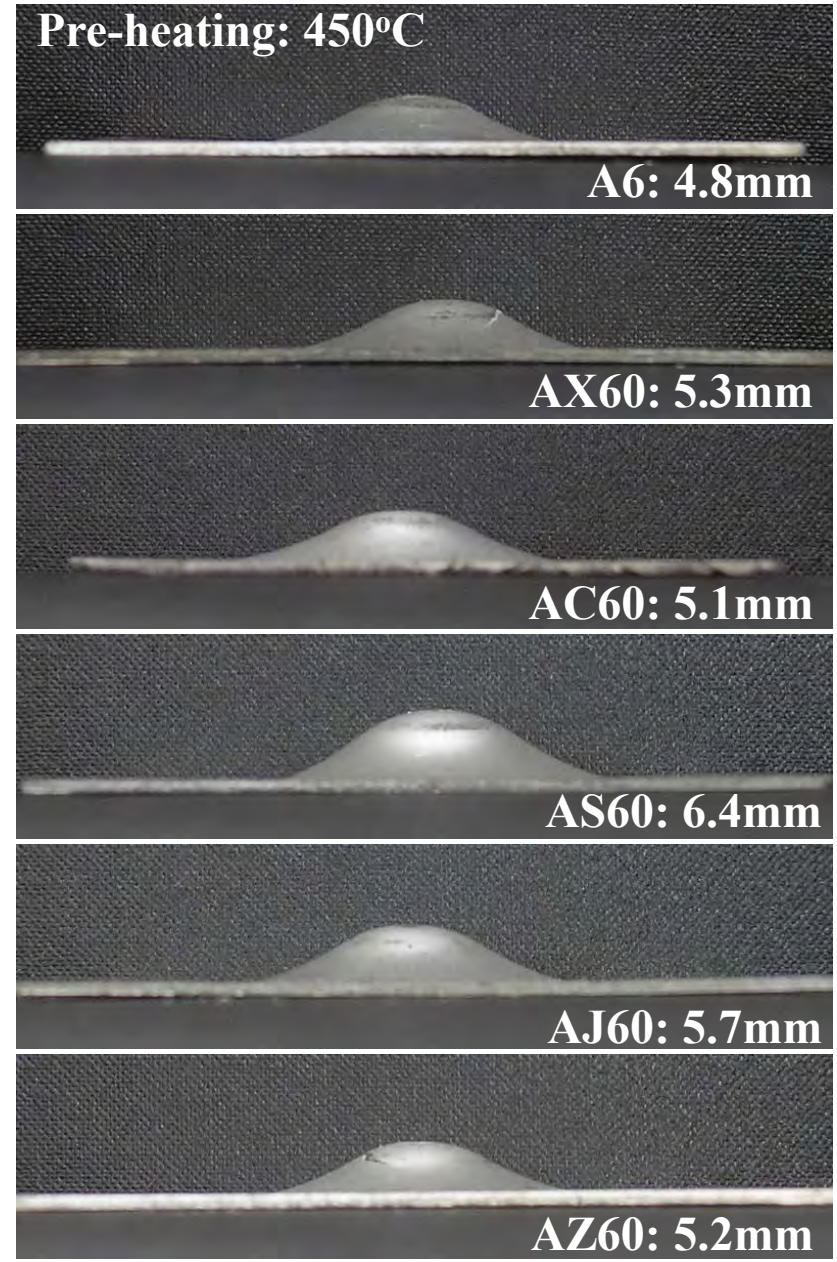
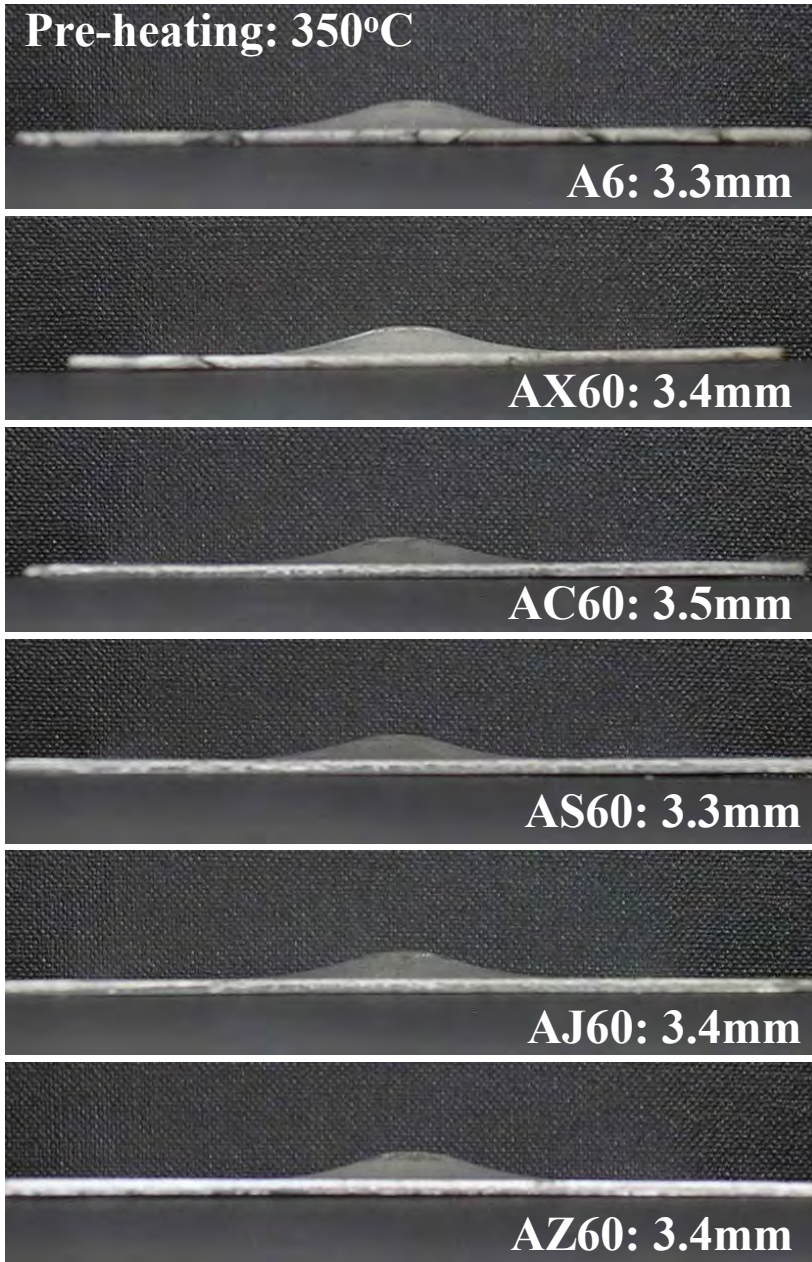
AX60: 5.3mm

AC60: 5.1mm

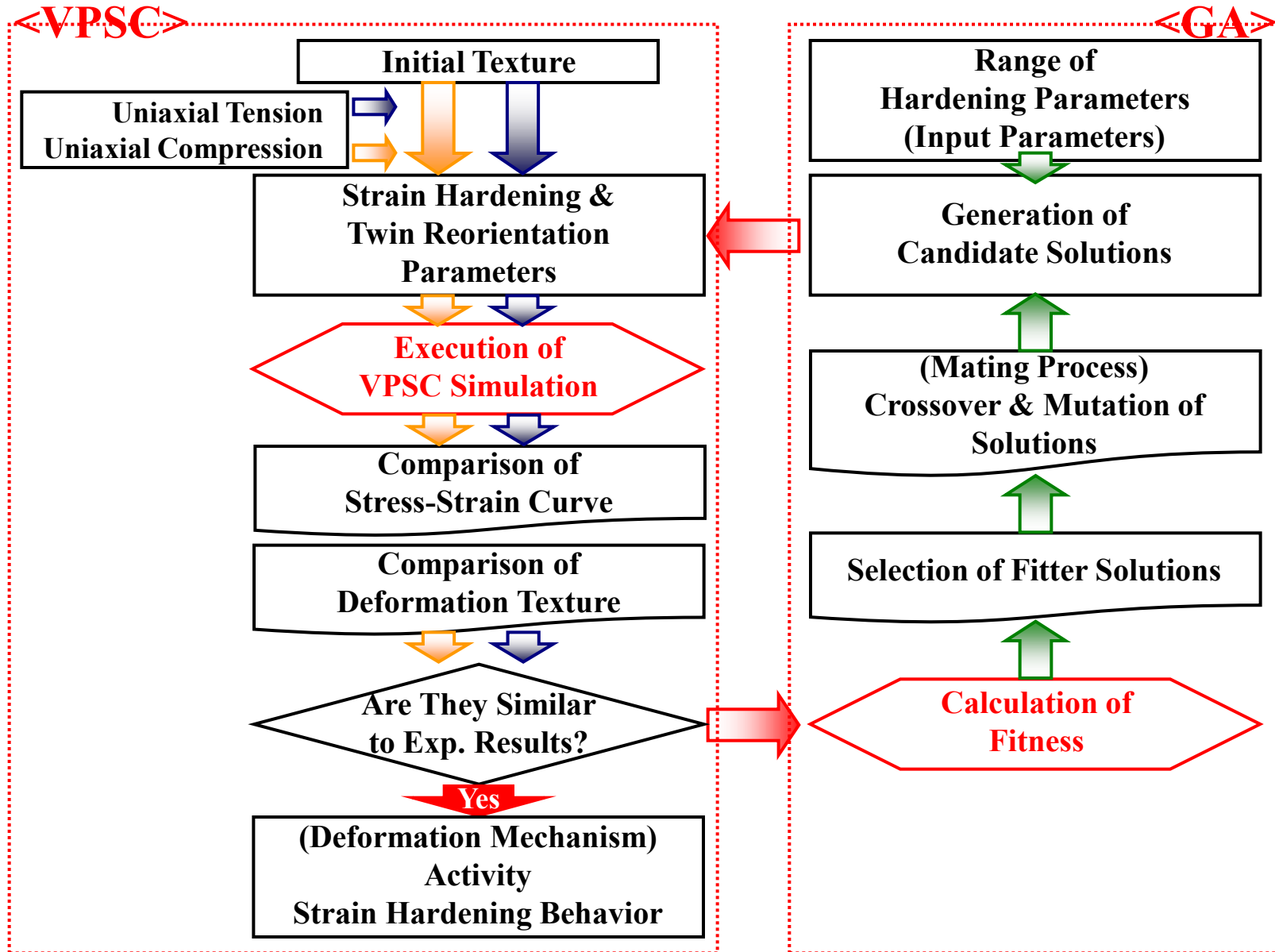
AS60: 6.4mm

AJ60: 5.7mm

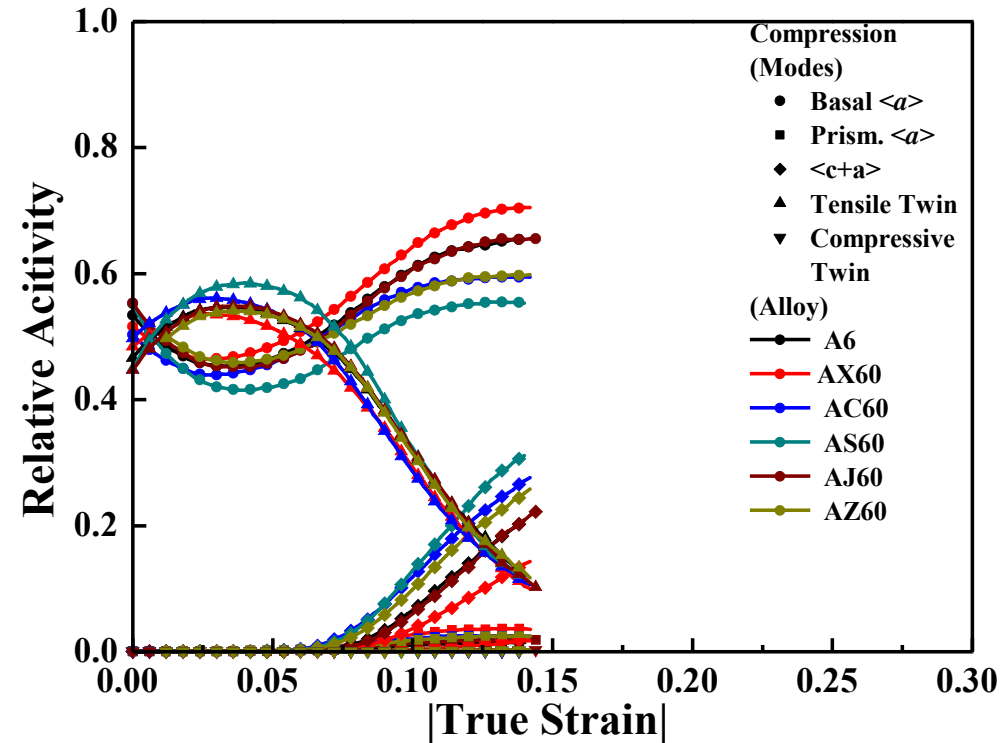
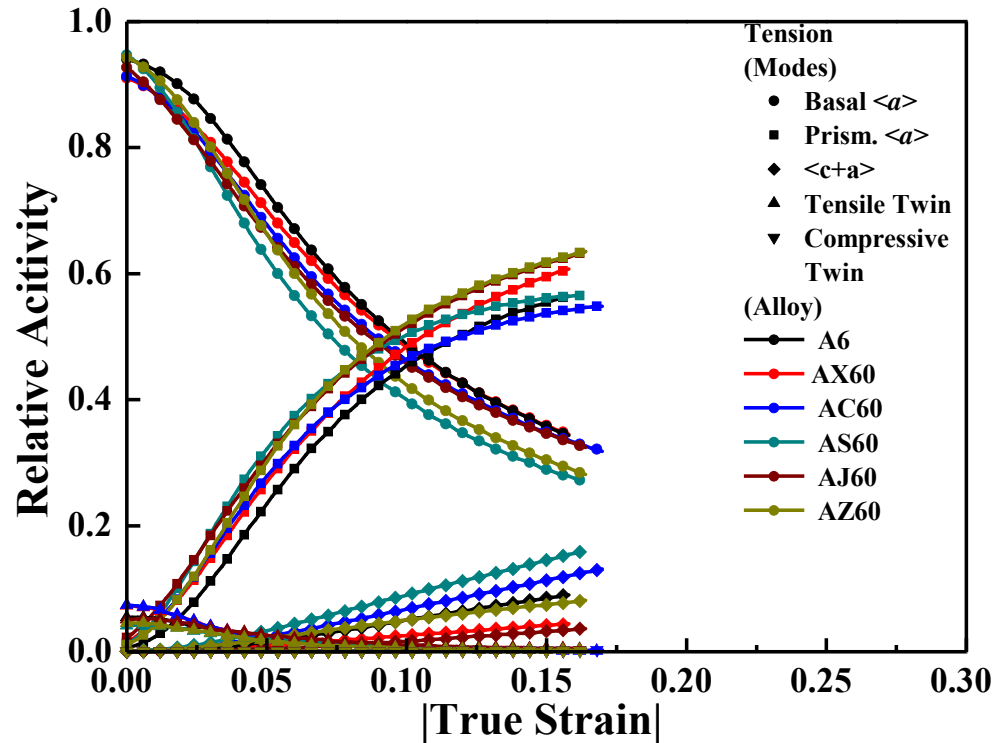
AZ60: 5.2mm



Procedure for VPSC-GA Simulation



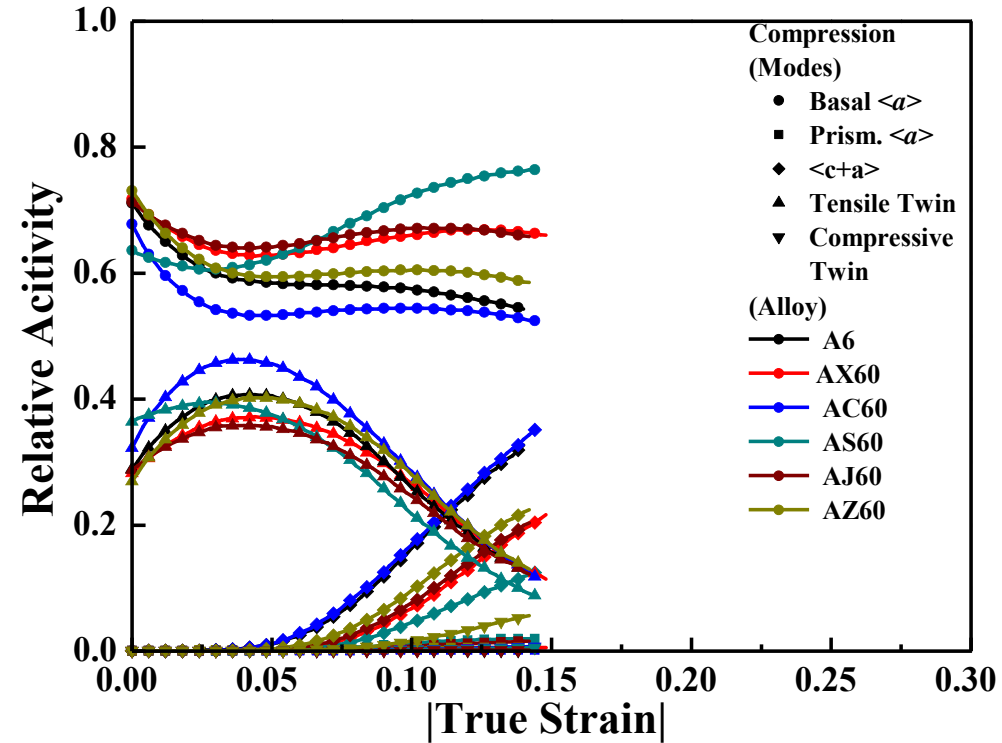
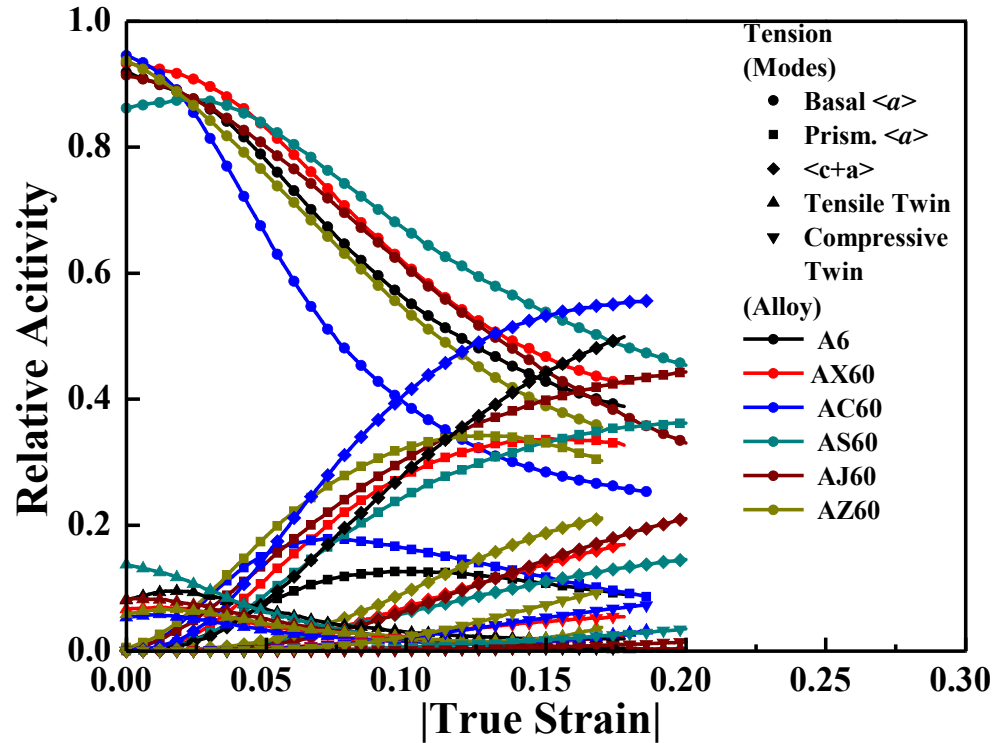
Activities of Deformation Modes (Pre-heating: 350°C for Rolling)



■ Deformation Modes

- ▶ **Tension: Initially Basal $\langle a \rangle$ Slip & Later Prismatic $\langle a \rangle$ Slip Activated**
- ▶ **Compression: Mainly Basal $\langle a \rangle$ Slip & Tensile Twin Activated**

Activities of Deformation Modes (Pre-heating: 450°C for Rolling)



■ Deformation Modes

- ▶ **Tension: Significant Increase in Activities of Basal and $\langle c+a \rangle$ Slip**
- ▶ **Compression: Mainly Basal $\langle a \rangle$ Slip & Tensile Twin Activated**

Conclusions

■ Thermodynamic Properties

- ▶ AZ60 alloy has the largest solidification range.

■ Simulation Results of TRSC Process

- ▶ AS60 and AZ60 show high segregation tendency.

■ Centerline Segregation Tendency

- ▶ AZ60>AS60>AJ60>AX60>AC60>A6

■ Mechanical Properties and Formability

- ▶ AX60 and AJ60 show good combination of tensile properties and Erichsen values with weaker basal texture.

■ Effects of Rolling Condition on Texture and Formability

- ▶ Increase in Pre-heating Temp.: Decrease in Max. Intensity of (0002) and Significant Increase in Erichsen Values.

■ Deformation Mode

- ▶ Increase in Pre-heating Temp.: Increase in Activity of Non-Basal Slip
- ▶ There exist some relationships between Erichsen value and CRSS ratio.



WPM 全세구간 최경량 Mg 소재 R&D
Mg Material R&D Project for the
Super-light Vehicle

WPM Mg Program;

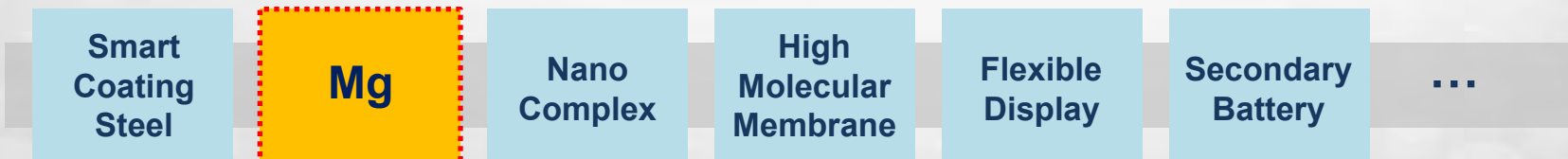
Structure and Sheet Technology

WPM (World Premier Material) Project



Purpose	R&D Project for 10 world best materials
Characteristics	Long-term (2010~2019), New market creating
Philosophy	Company-led , Break through, Open innovation

10 WPM Projects (World Premier Material)

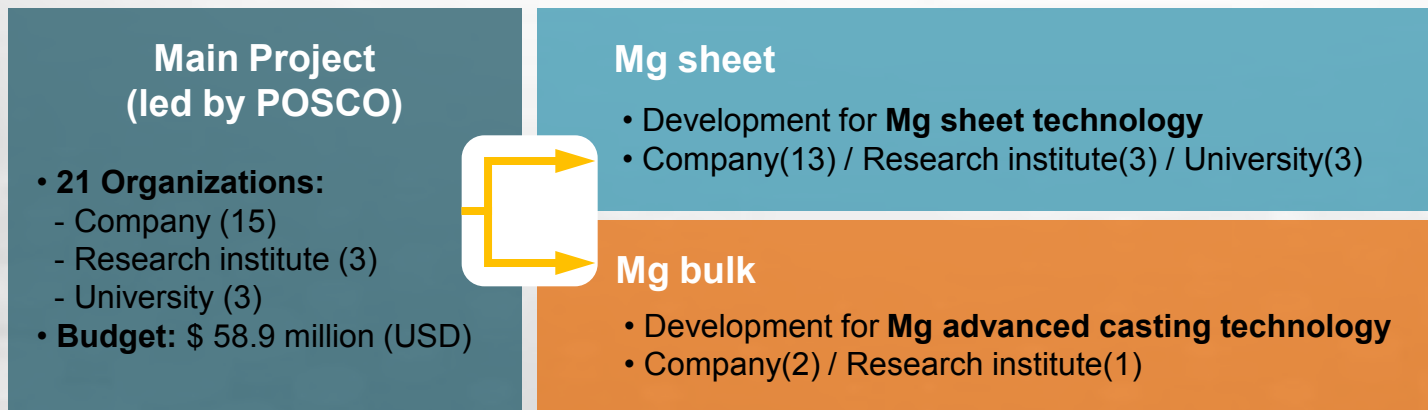


+ Mg material R&D project for the super-light vehicle

- Improving the technology level on alloy & application Tech. from initial basic study to commercialization



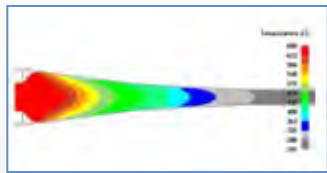
+ Project group



+ Mg Sheet Material with High Properties Specialized in Vehicle Development



New Alloy (for strip cast)



Thermal Analysis



Texture Analysis

High Perform. Extracting



Thermal Reduction
Furnace

Coil Making

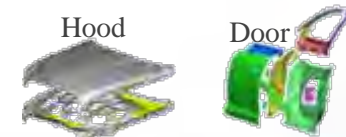


Strip Caster



RWM
(Reversible Warm
Rolling Mill)

Forming, Welding Surface Treatment



Sheet Forming



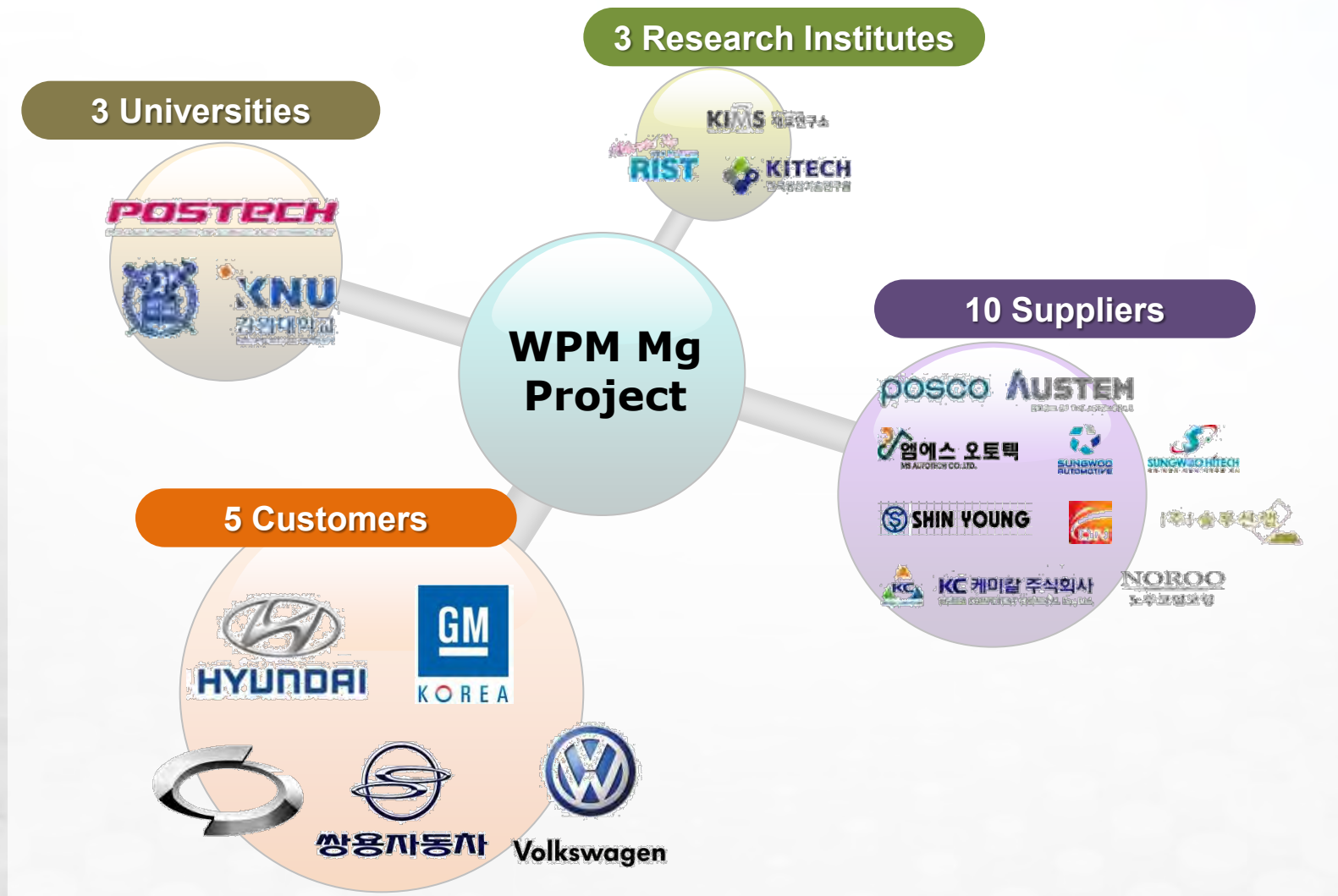
Surface Treatment



Welding

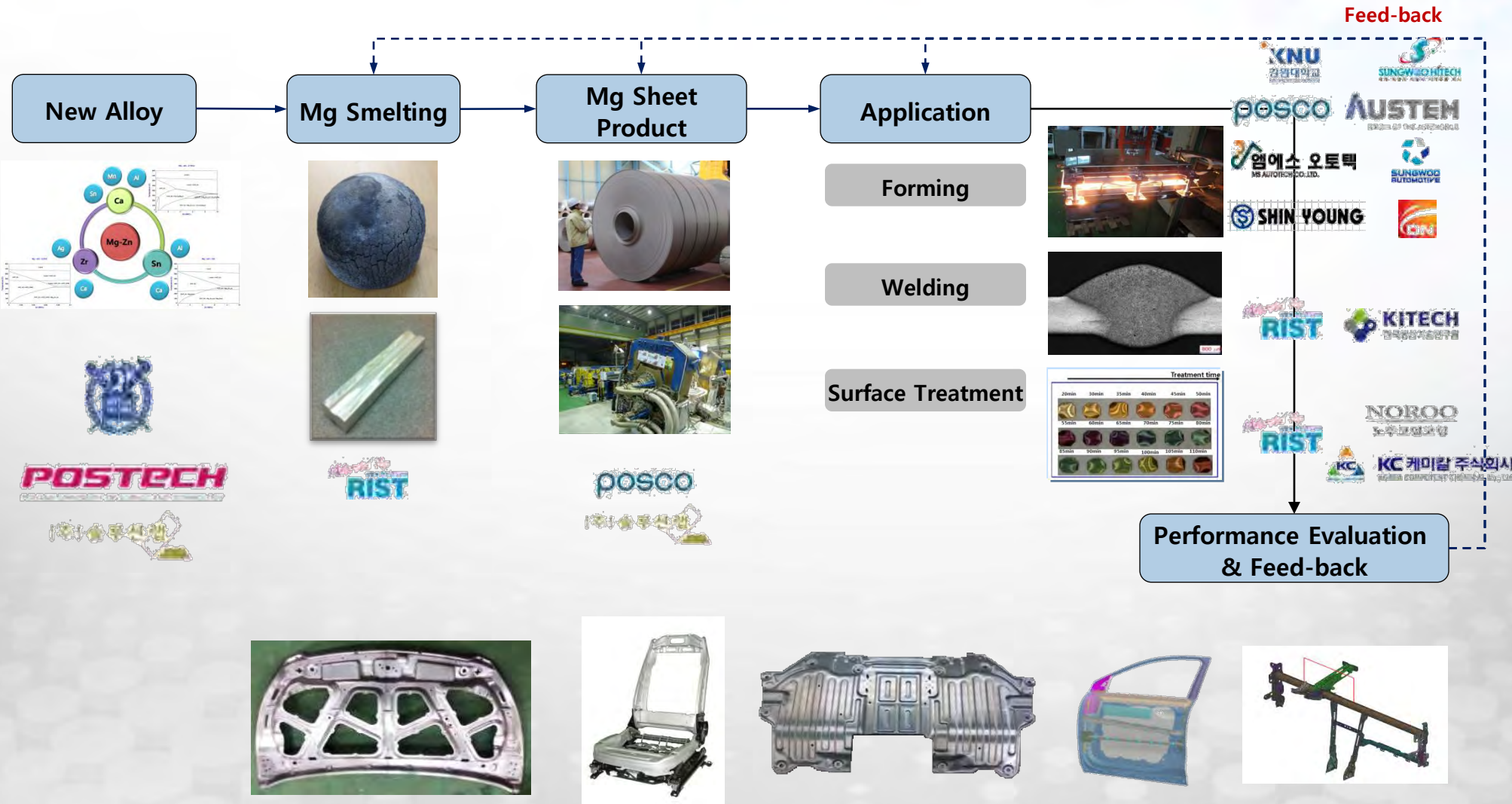
WPM Mg Project System

+ 21 Organizations for the project

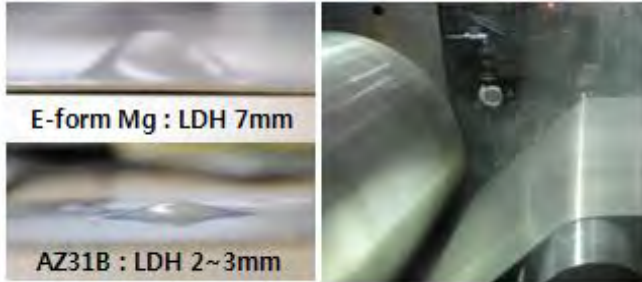


Technology Development Structure

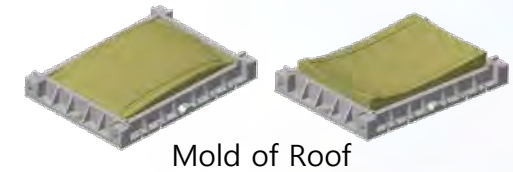
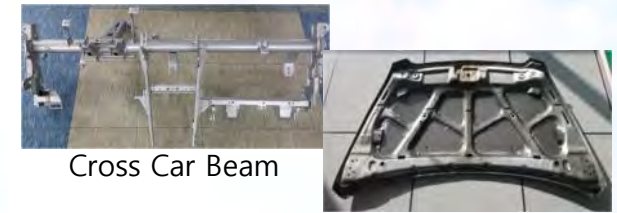
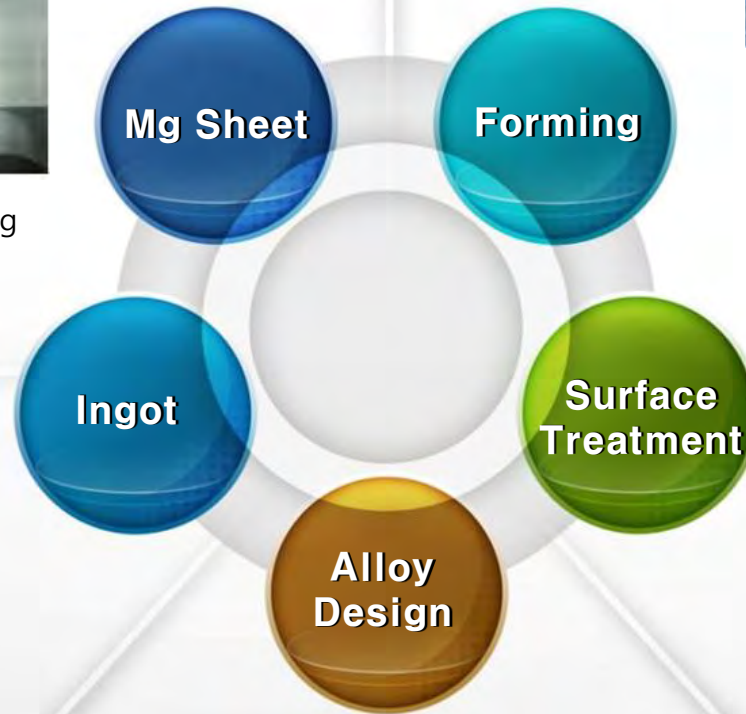
Mg Plate



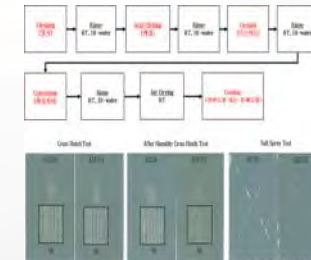
Principal Results (Sheet Technology)



Development of wide strip casting & rolling technology



Recycling & Alloying



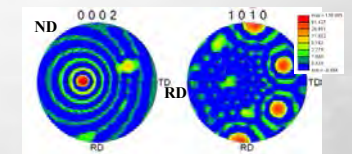
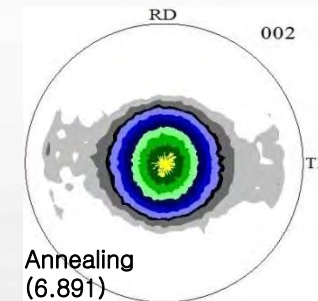
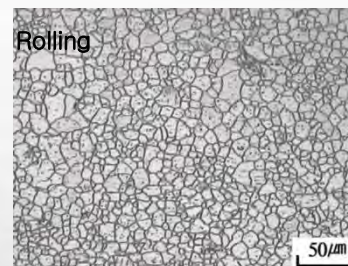
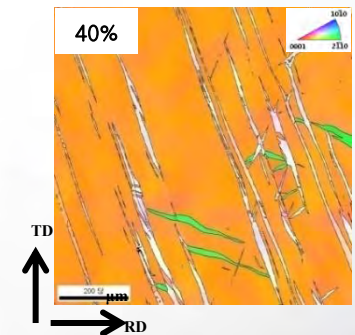
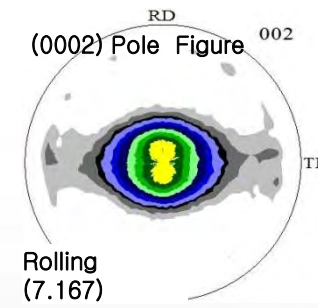
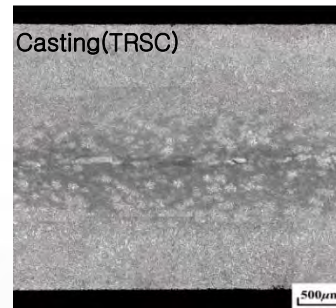
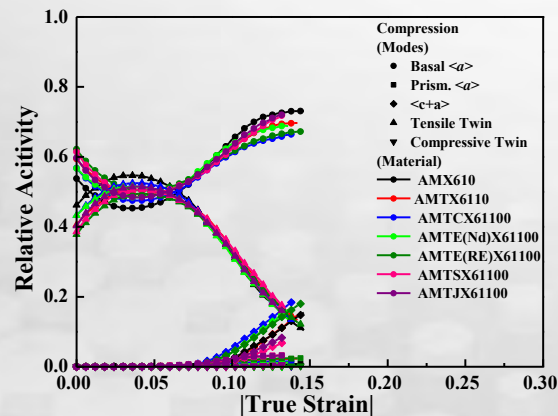
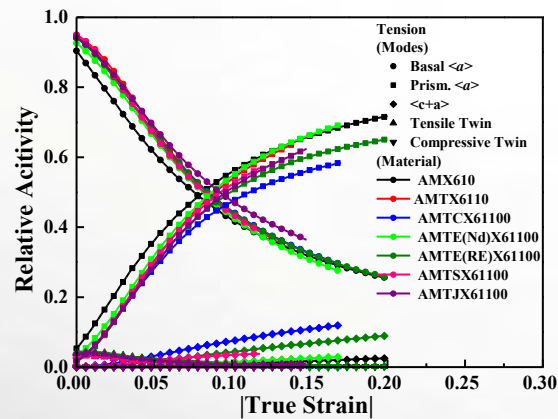
Alloy	YS (MPa)	UTS (MPa)	Er. (mm)
AX607	212.2	305.6	7.0
AX61	216.2	307.0	7.5
AZ62	219.8	336.9	6.6



+ New Alloy: Sheet

• Development of new alloy with high strength & formability

- Analysis of plastic deformation behavior and texture
- Analysis of recrystallization behavior



Study on the change of microstructure and texture

+ Wide sheet casting & rolling

- **Development of rolling technology**

- Width: casted coil 2,000mm, rolled coil 1,270mm
- Thickness: 6mm ~ 0.15mm

- **Commercialization to the development of a wide sheet and thin plate**



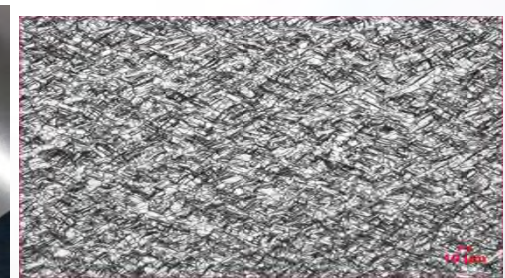
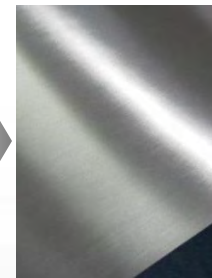
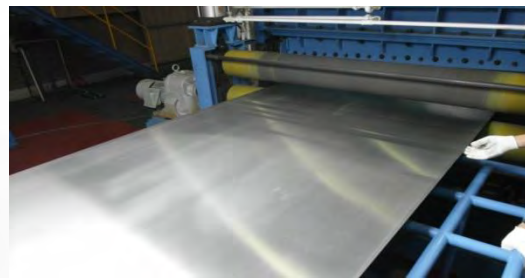
EOLAB roof & dash panel



Korando C Speaker cone



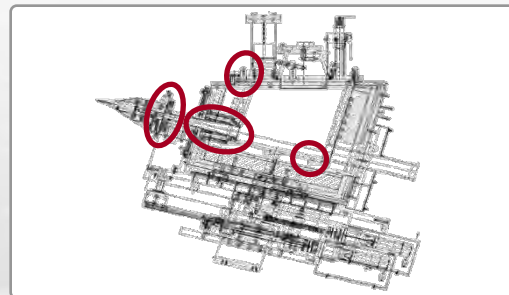
GT3 RS roof



Development of Rolling & after-treatment technology

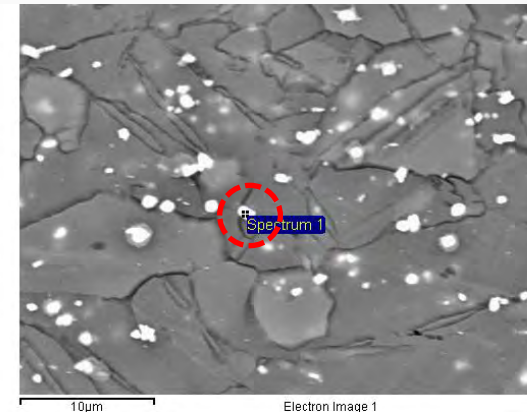
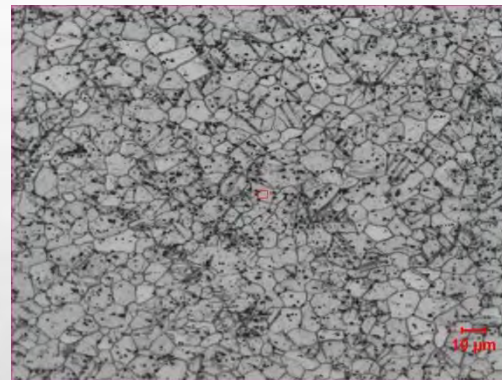
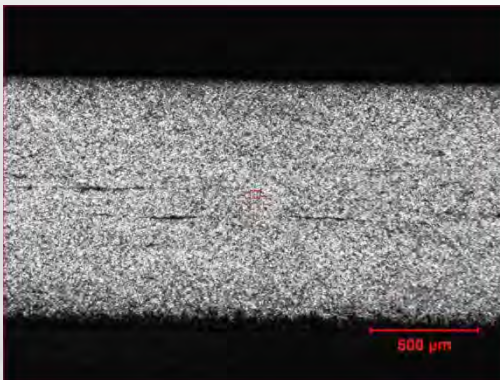
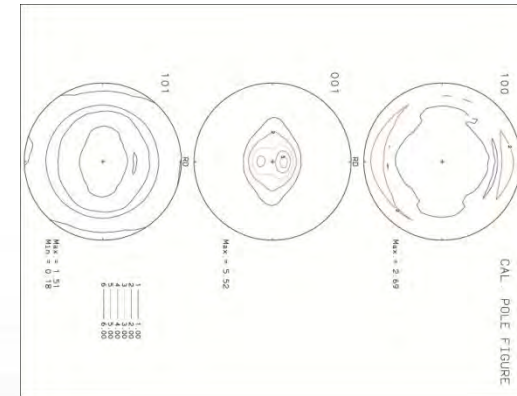
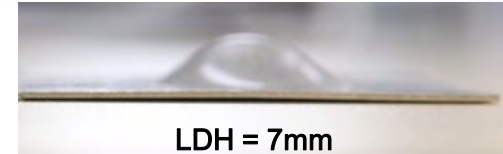
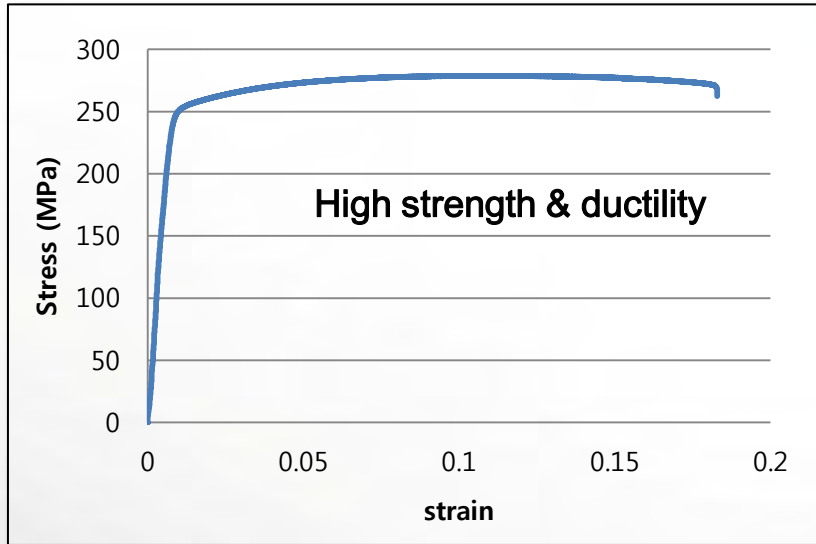


수모델 PIV 촬영 - 레이저 투입



Continuous rolling process of width 2,000mm casted coil

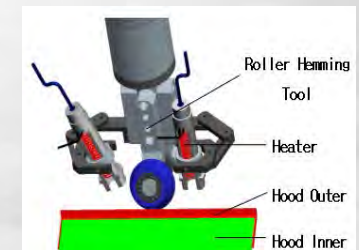
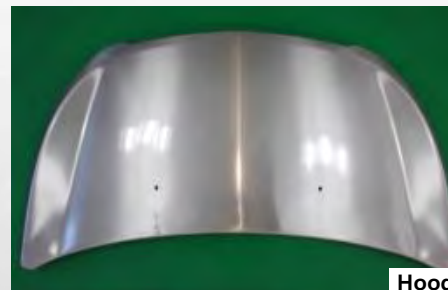
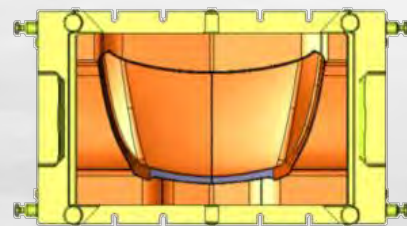
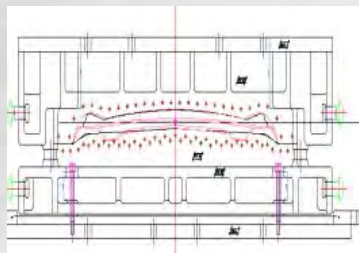
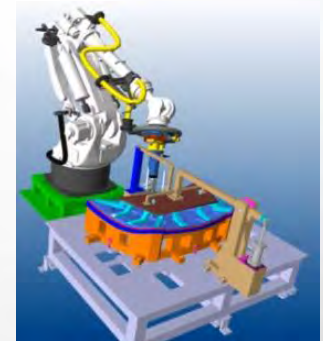
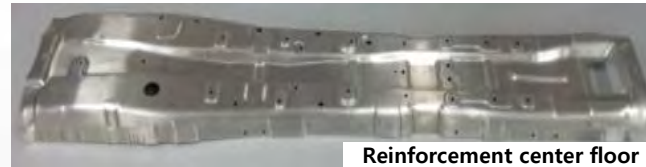
+ Sheet casting & rolling (E-form[®])



- : low fraction of center segregation, high fraction of twins, weak texture
- : distributed thermally stable particles

+ Development of car body part

- **Development of stamping technology**
 - Warm forming die design, Hemming
- **Development of car body parts**
 - Reinforcement center floor, Hood assembly



Optimum design

Prototype manufacturing

Development of hemming process

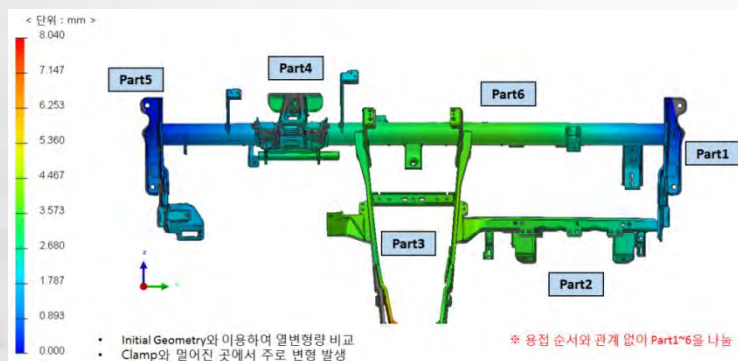
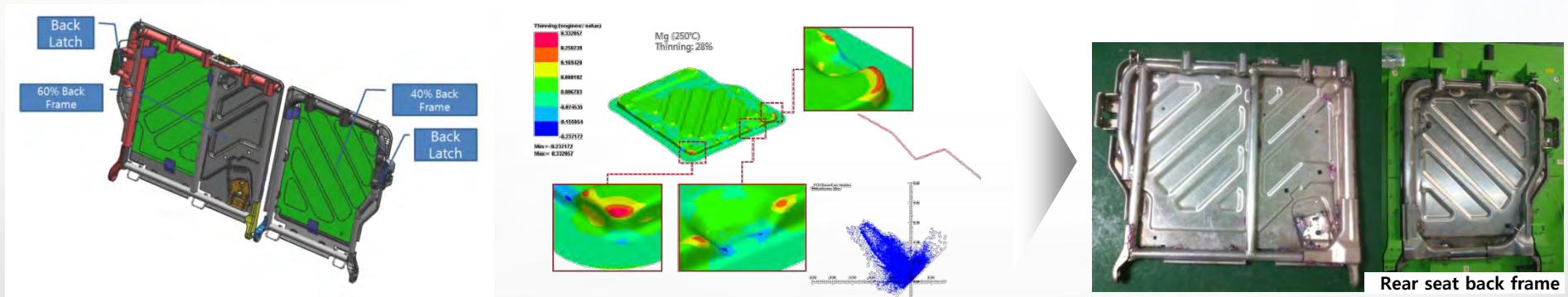
+ Development of car body part

- Development of stamping technology

- Optimization of mold design

- Development of car body parts

- Rear seat back frame, Cross car beam



Optimum design



Prototype manufacturing

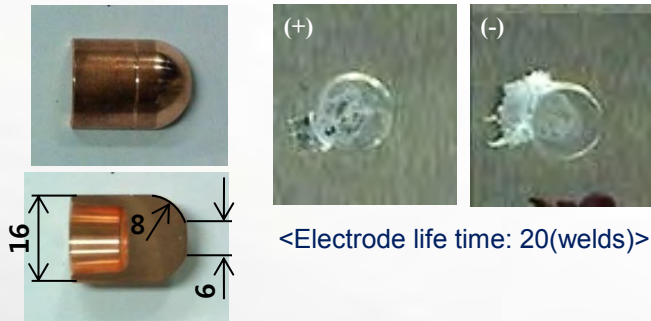
+ Joining

• Development of joining Technology

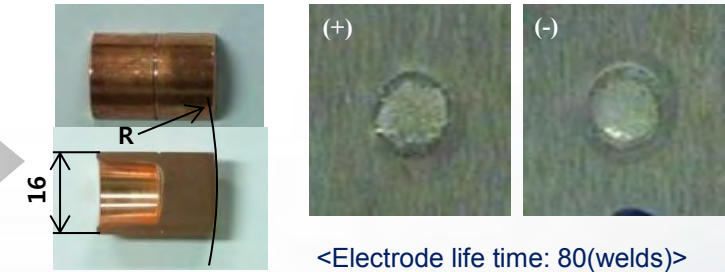
- Evaluation of weld zone: Dynamic Properties, Strength, etc.

✓ Spot welding

- Dome type electrode

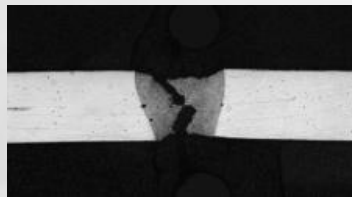


- Radius type electrode



Improvement of
Electrode life time
by shape change

✓ Laser welding



- YS: 188MPa
- TS: 270MPa
- El: 5.3%

※ Bare metal YS: 220MPa TS: 280MPa El: 12%

✓ CMT welding



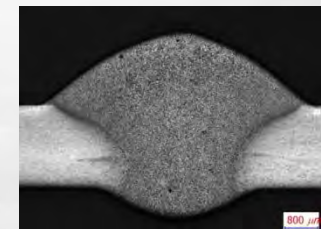
- YS: 177MPa
- TS: 252MPa
- El: 8.5%

✓ FSW welding



- YS: 132MPa
- TS: 228MPa
- El: 2.8

✓ MIG welding



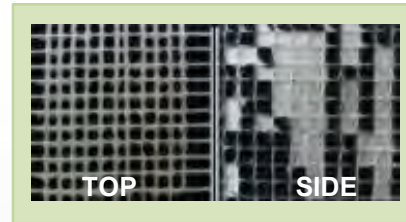
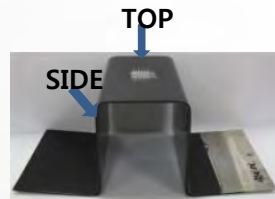
- YS: 178MPa
- TS: 231MPa
- El: 3.1%

+ Surface Treatment

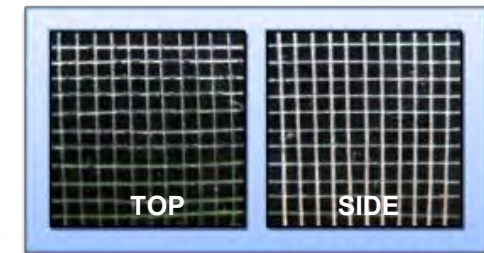
• Development of surface treatment

- Development of chemical conversion coating process
- Development of plasma electrolytic oxidation

✓ Improvement of coating quality by new pretreatment

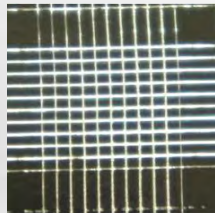


Better quality
by acid etching
& desmut

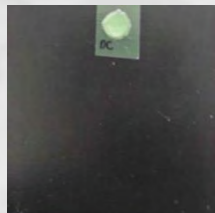


✓ Comparison with various surface treatment

- Plasma electrolytic oxidation (PEO)

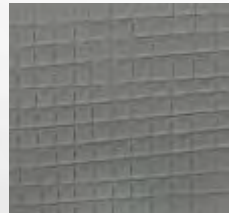


<Cross cut test>



<Cycle corrosion test 10 Cycle>

- Chemical conversion treatment

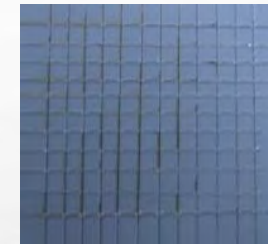
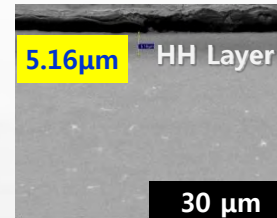


<Cross cut test>



<SST 600hr>

- Heat treatment with humidity (under study)



<Cross cut test>

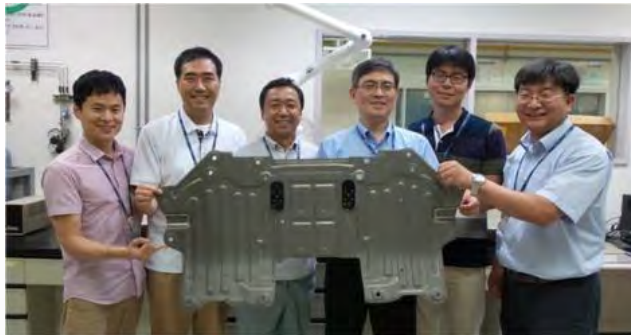


<SST 720hr>

Commercialization: Mg Luggage retainer

Renault Samsung Motors New SM7

- Weight
 - steel: 3.6 kg
 - Mg: 1.4 kg



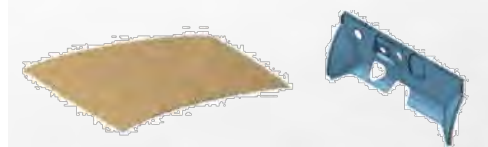
Commercialization: Mg Roof, Dash panel

Renault EOLAB

- Weight reduction
 - roof: 55%
 - dash lower: 60%



EOLAB : AN ULTRA LIGHT BODY
THE RIGHT MATERIAL IN THE RIGHT PLACE



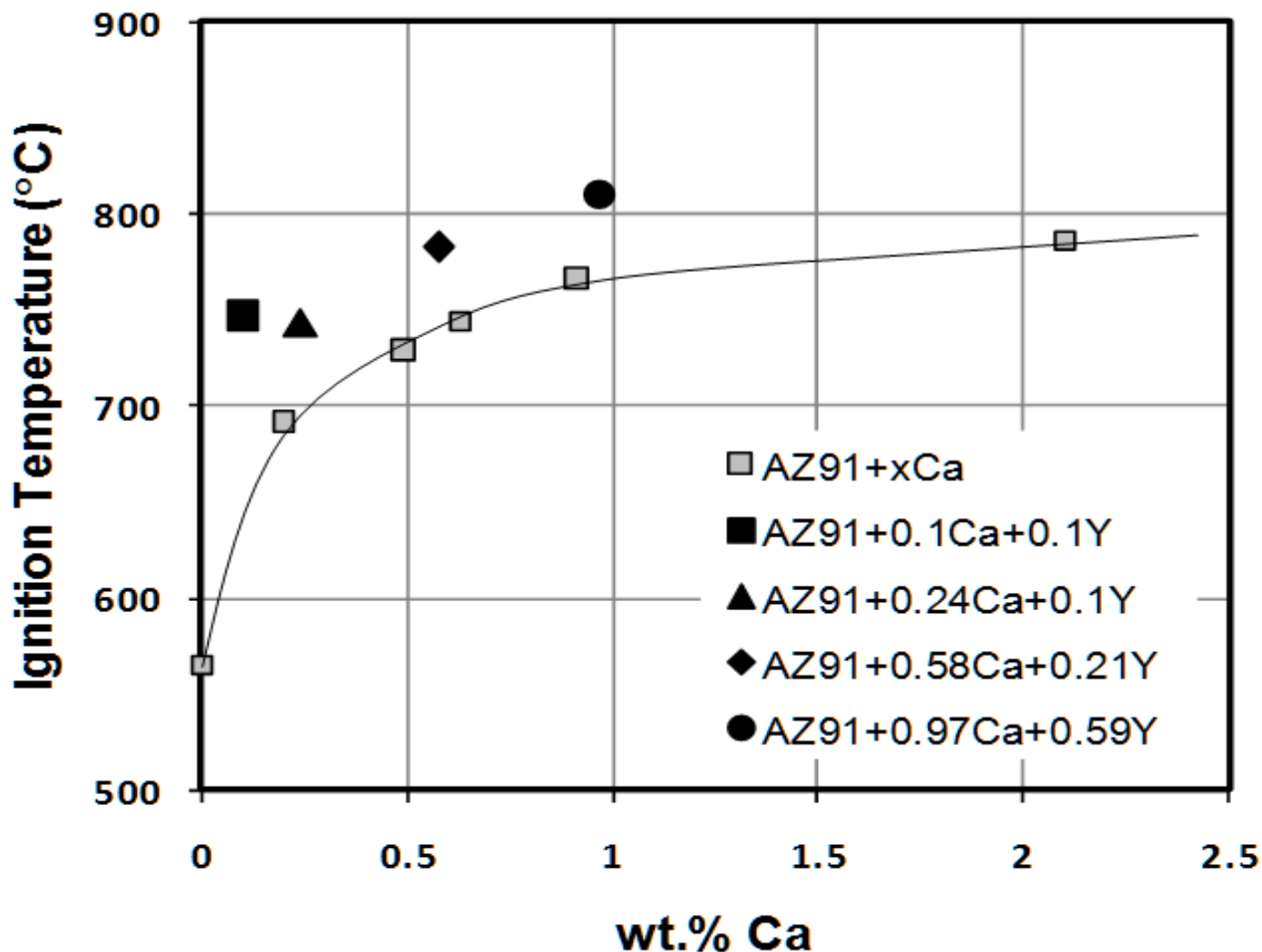
<Mg roof>

<Mg dash lower>

Corrosion Resistant Non-flammable Alloys **(SEN alloy)**

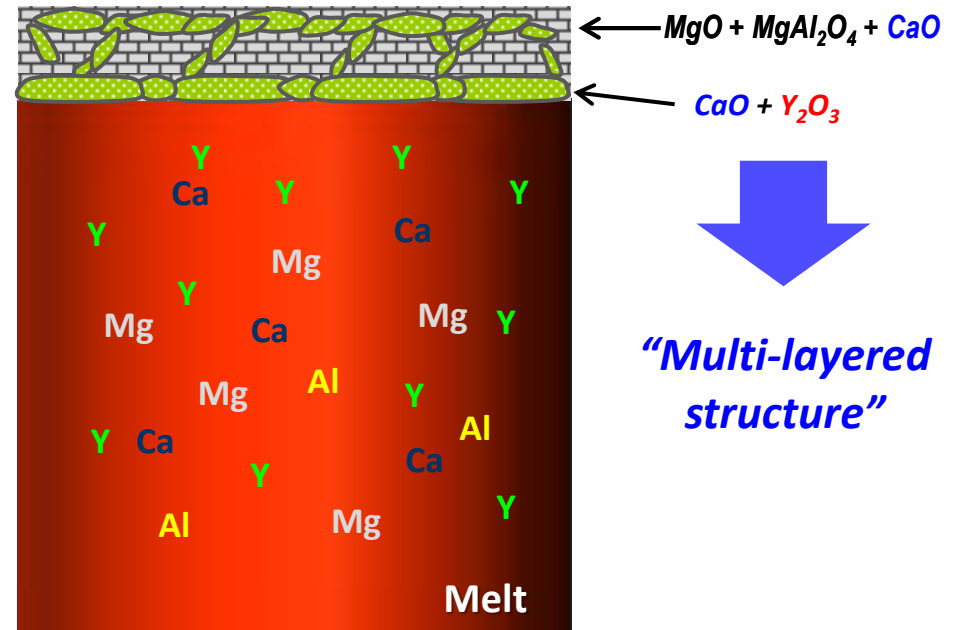
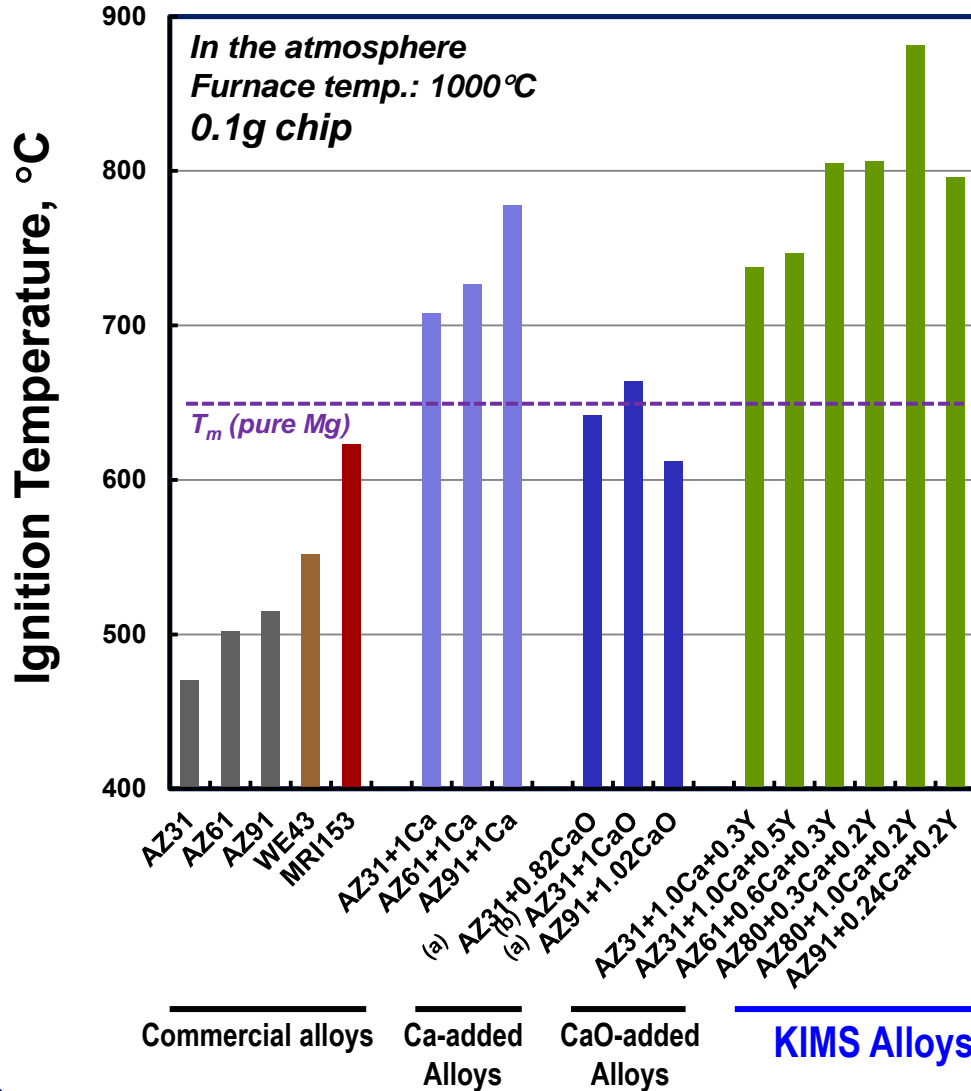
Korea Institute of Materials Science (KIMS)

Synergy Effect of Ca and Y Addition



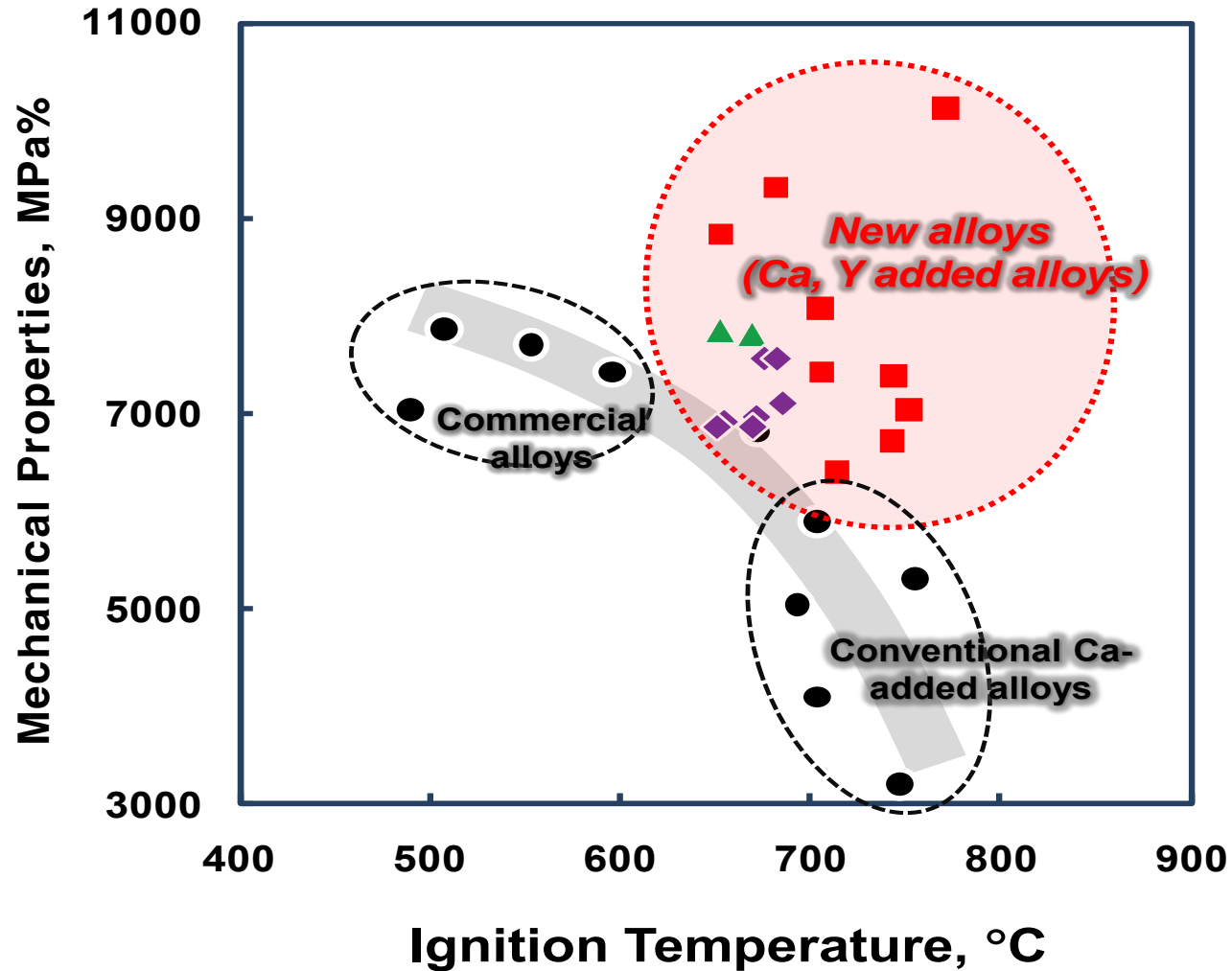
Non-flammability

◆ New non-flammable alloys



< Non-flammability mechanism of AZ-Ca-Y alloys >

New Non-flammable Alloys



Oxidation Behavior



<SEN-9 : AZ91-0.3Ca-0.1Y>

Corrosion Behavior



ALDC

SEN-9

AZ91D

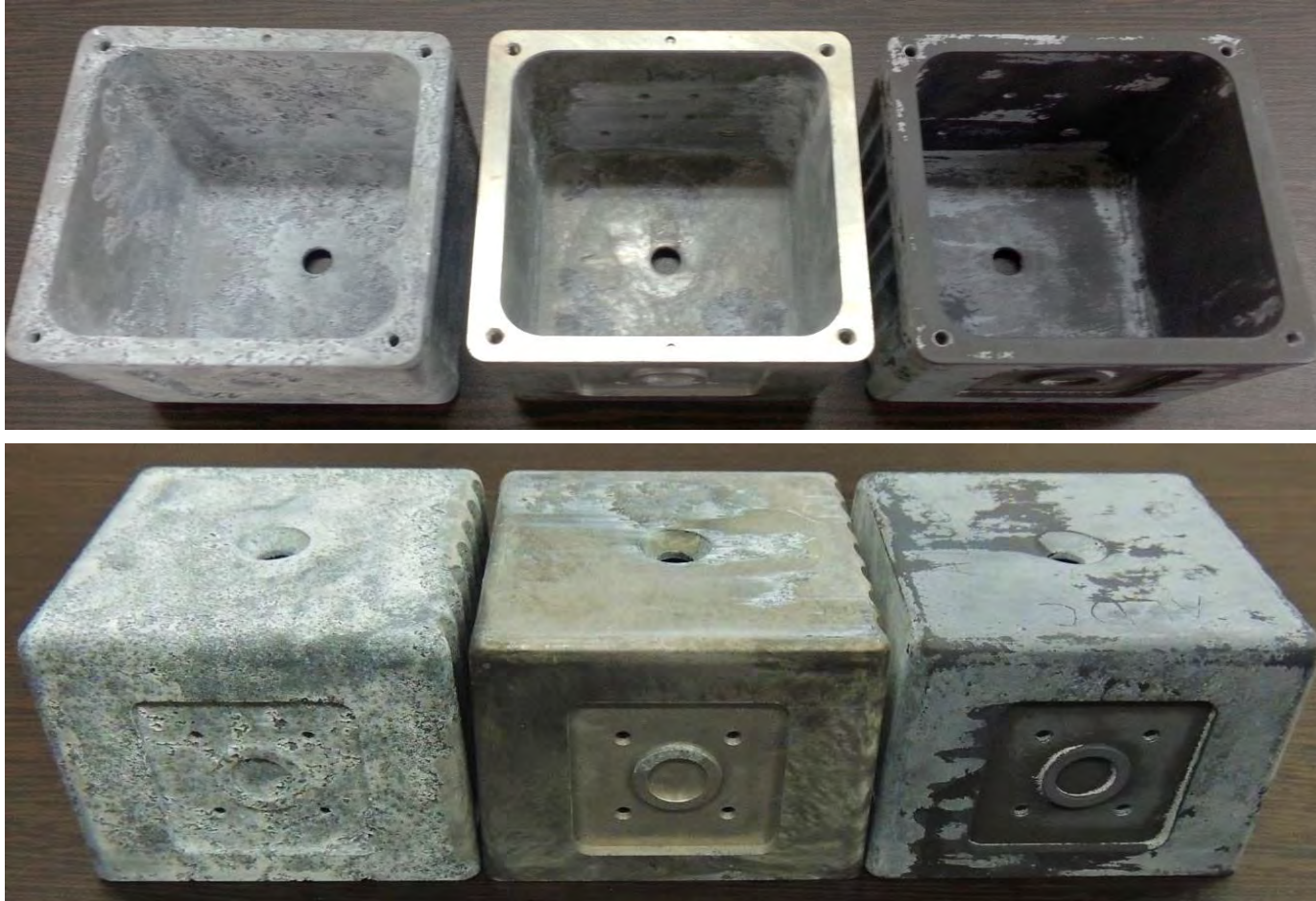
Corrosion Behavior

After immersion for 3 day in 3.5 wt% NaCl solution at RT .

(a) AZ91D

(b) SEN-9

(c) ALDC

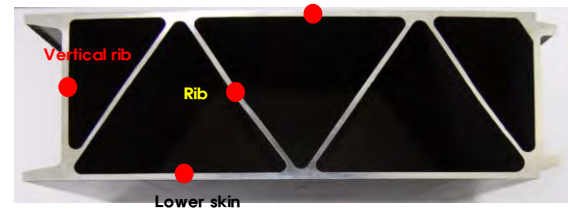
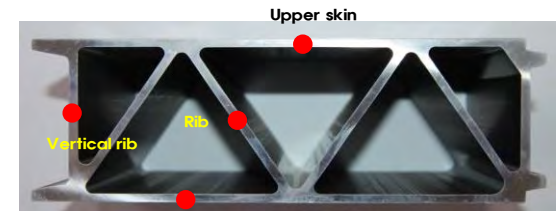
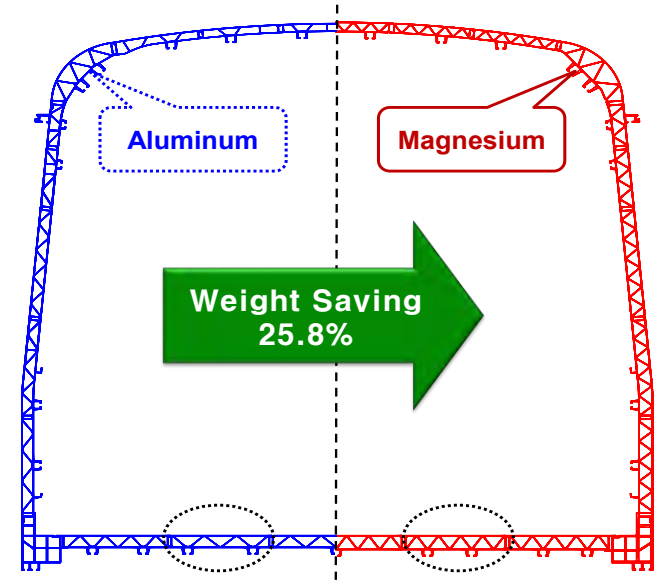
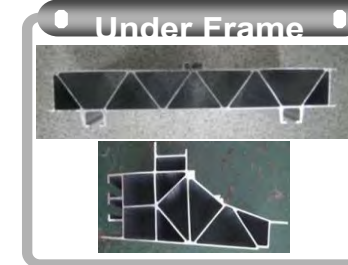
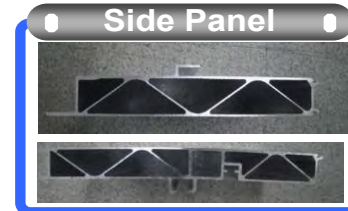
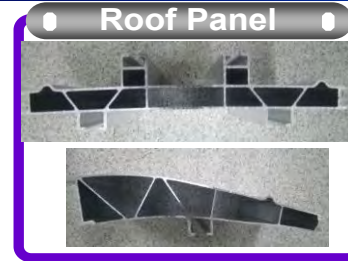
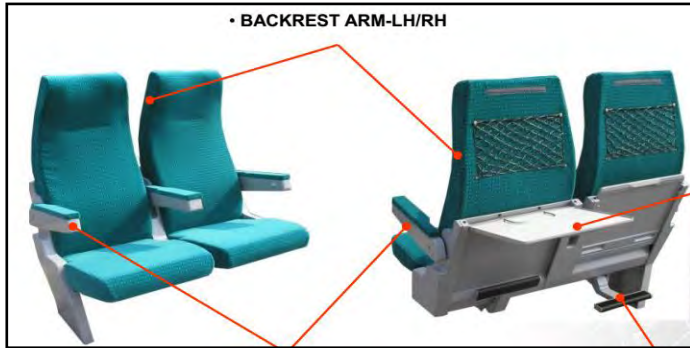


<SEN-9 : AZ91-0.3Ca-0.1Y, ALDC : Al-11Si-2.5Cu>

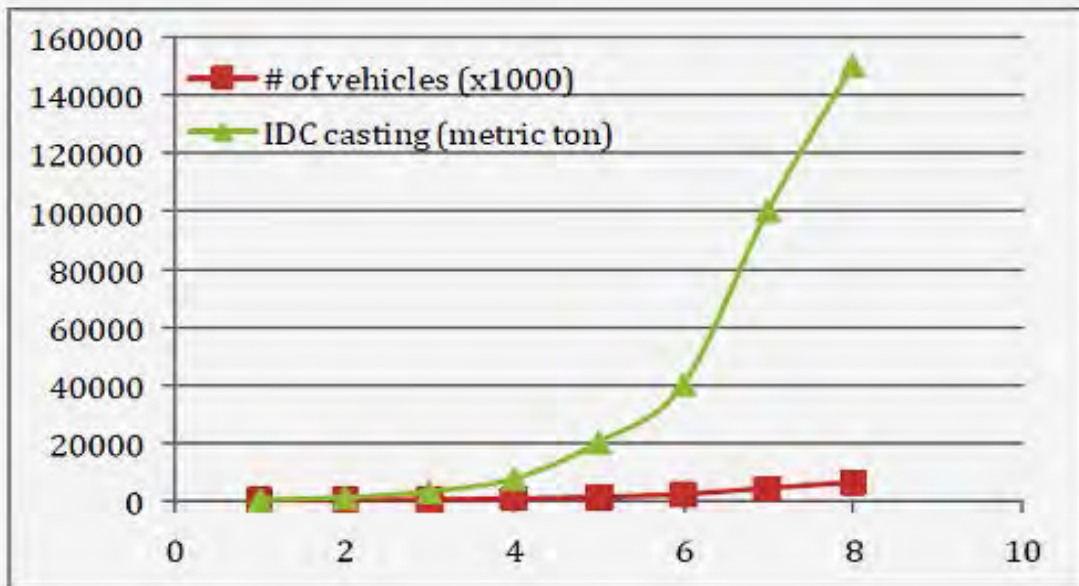
Die-casting



Al/Mg profiles for extrusion



GM Door Inner Panel (Die cast)

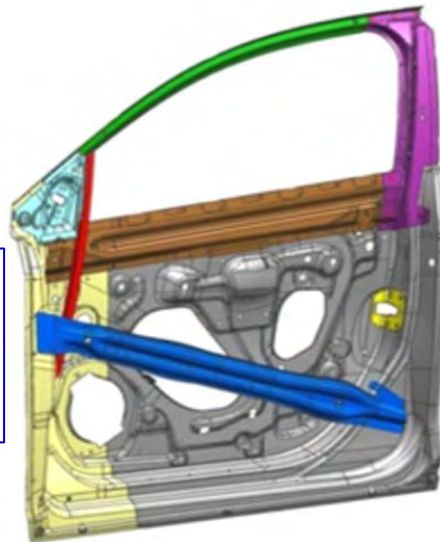


Benefits

- Reduced part count
- Fewer manufacturing steps
- 50% less embodied energy
- 50% less weight
- Improved fuel economy

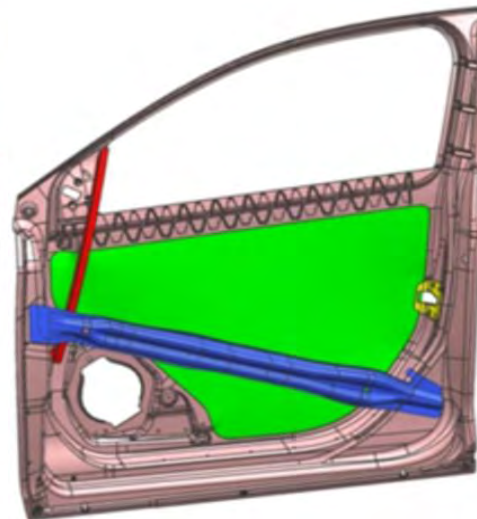
Steel stamped

- 다수부품의 용접/
다단계 공정

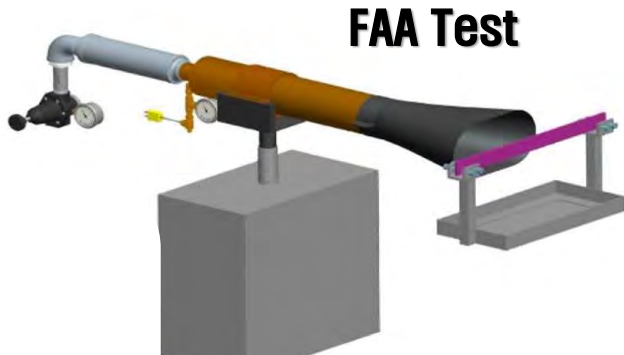


Magnesium stamped

- 단일부품의 die casting



FAA Test & Mg Seat Frame



Only 5 parts permitted by FAA for Magnesium design: cross beam, front leg, horizontal bar, spreader, (table arms- accepted during run of the project)

Mg Extrusion ; Seat Frame



- Backrest structure up to approx. 20% as welded subassembly

(Source: [1])



Summary

- **Development of High Strength Magnesium Alloys with High Formability at Magnesium Technology Innovation Center at SNU**
- **WPM Magnesium Project**
 - **TRC Mg Sheet with 2,000mm Width**
 - **Forming, Joining, and Surface Treatment Technology**
 - **Applications: Hood, Retainer**
- **Development of Non-flammable Mg Alloys at KIMS**

The Magnesium Age



THE MAGNESIUM AGE
is just around the corner!