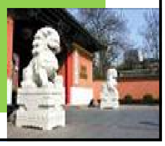
Advanced Lightweight Materials Processing Technology

1 - High Vacuum Die Casting and Squeeze Casting of Aluminum and/or Magnesium Alloys

Baicheng LIU
Tsinghua University

2 - Manufacturing and Assembly Processes of Lightweight Car Body (HSS)

Xinmin LAI
Shanghai Jiaotong University



Light weight materials Processing Technologies

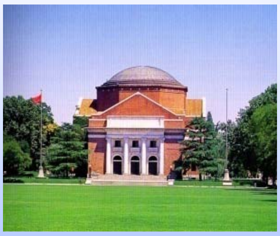
- Light-weight materials and processing technologies are one of the key technologies to reduce energy consumption. When vehicle weight is reduced by 10%, fuel consumption can be reduce by 6-8%, and CO_2 emission by 13%.

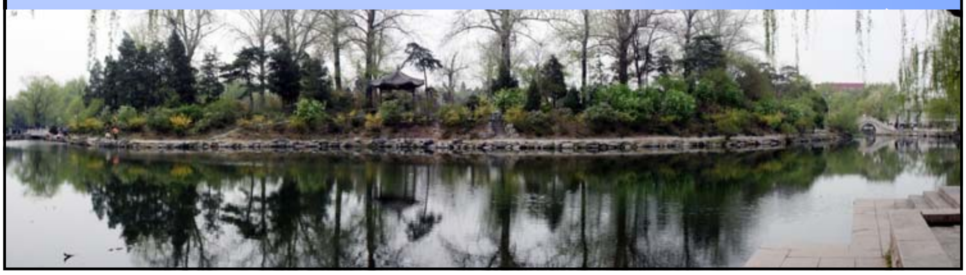
	Light weight Materials	Traditional	Reduction Ratio %
SJTU	HSS (UHSS)	Steel	10
	Aluminum	Steel/Iron	40～60
TH	Magnesium	Steel/Iron	60～75
	Magnesium	Aluminum	25～35
	Composite	Steel	25～35

High Vacuum Die Casting and Squeeze Casting of Aluminum and / or Magnesium Alloys

Department of Mechanical Engineering
Tsinghua University
Baicheng LIU, Shoumei XIONG, Zhiqiang HAN
liubc@tsinghua.edu.cn

Tsinghua University

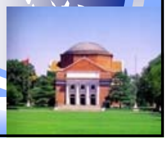




OUTLINE

High Vacuum Die Casting and Squeeze Casting of Aluminum and Magnesium Alloys

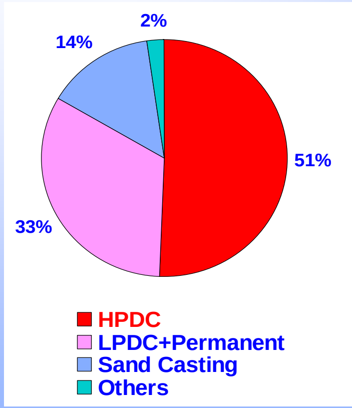
- Motivation
- Objective and Target
- Background and Resources



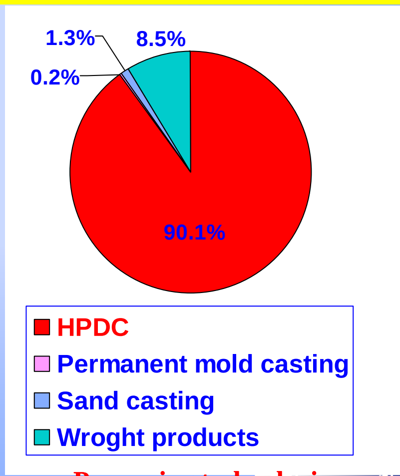
1. Motivation

- High pressure die casting technology is the main technology used to produce aluminum and magnesium alloy castings
- However, because of the porosity defect it is difficult to produce high integrity aluminum and magnesium alloy castings for advanced clean vehicle
- High vaccum die casting and squeeze casting technologies are new potential technologies for high integrity Al and Mg alloy castings
- Multi-scale modeling and simulation will be an important tools to save both R & D time and cost

High Pressure Die Casting(HPDC) Process for Aluminum and Magnesium Alloys



Casting processes of Aluminum alloys

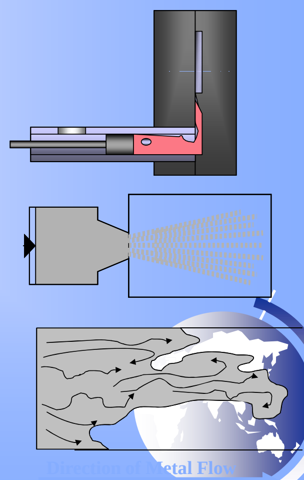


Processing technologies of Magnesium alloys

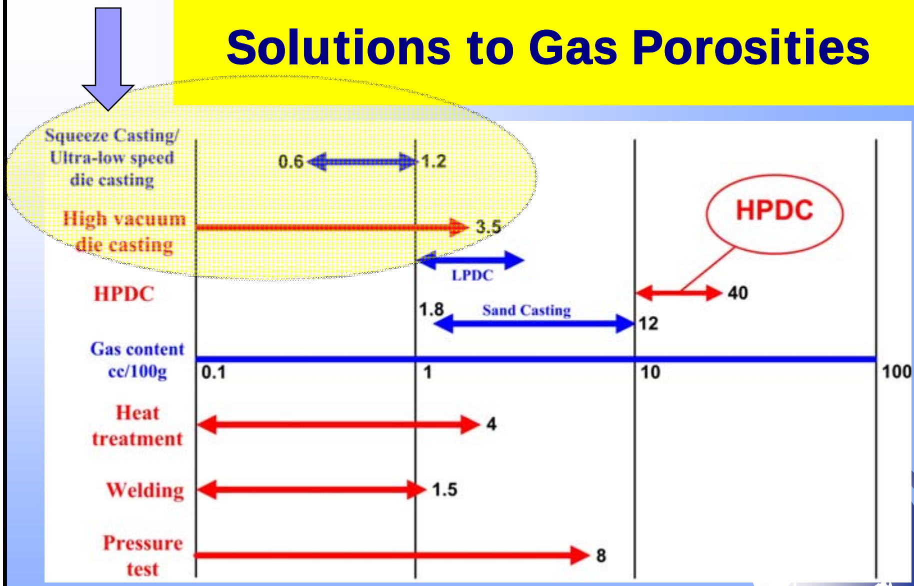
(Data source: United States Geological Survey Mineral Resources Program, 2006)

Porosities in High Pressure Die Castings

- **Limitation on applications:**
  - Mechanical properties
  - Pressure tight requirements
  - No Welding
  - No Heat treatment (precipitation hardening)
- **Sources of Porosities**
  - Gas porosities (entrapped gases, die lubricant, dissolved gases)
  - Shrinkage porosity due to solidification



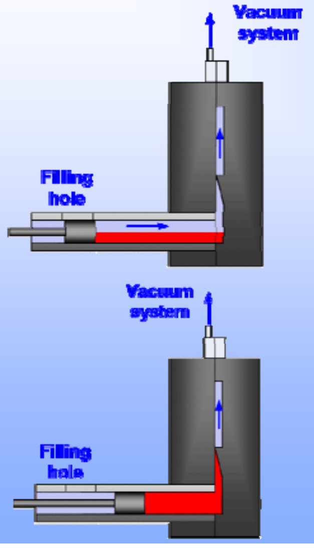
Solutions to Gas Porosities



Gas content of different casting processes

(Data source: *High Integrity Die Casting Processes* by Edward J. Vinarcik, 2003)

High Vacuum Die Casting Process

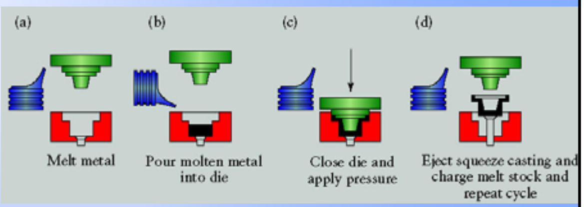


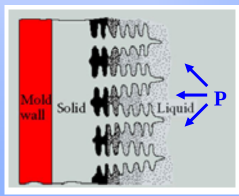
Application of High Vacuum Die Casting Process in Aluminum Body Structure of AUDI A2

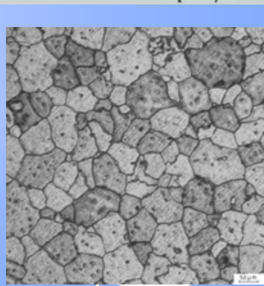
Red color : structural components

Squeeze Casting of Al and Mg Alloys

- **High integrity casting** process, almost free from porosity defects including microporosities
- **Very fine equiaxed grains**
- **Heat treatable, high strength and toughness, high fatigue property**
- Near net shape, high yield of liquid metals (no riser and gating system for direct squeeze casting), and energy efficiency
- Tolerance for fluidity even suitable for forging alloys

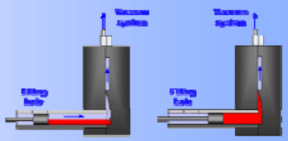


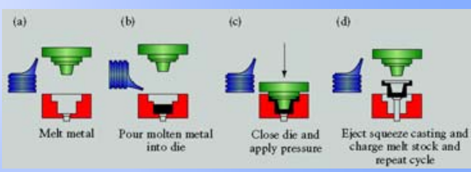




2. Objective and Target

Objective:
Develop high vacuum die casting and squeeze casting technologies for producing advanced aluminum and/or magnesium components for electric vehicles.





Deliverable:
High vacuum die casting and squeeze casting technologies for producing aluminum and/or magnesium components of electric vehicles.
Modeling and simulation technologies for high vacuum die casting and squeeze casting processes.

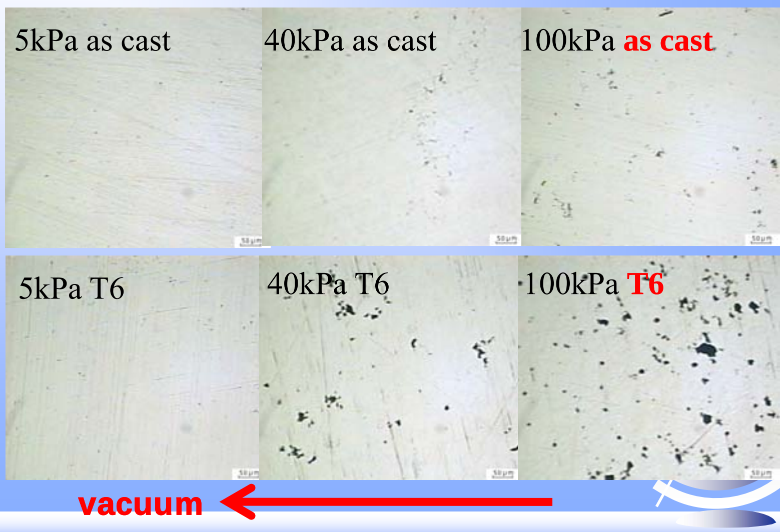
2. Objective and Target

- Experimental study on the process-structure-property of high vacuum die casting and squeeze casting of advanced aluminum and magnesium alloys castings
- Development of multi-scale modeling and simulation technology for high vaccum die casting and squeeze casting process
- Technological support for critical component manufacturing of electric vehicles by combining both the experimental and simulation approaches

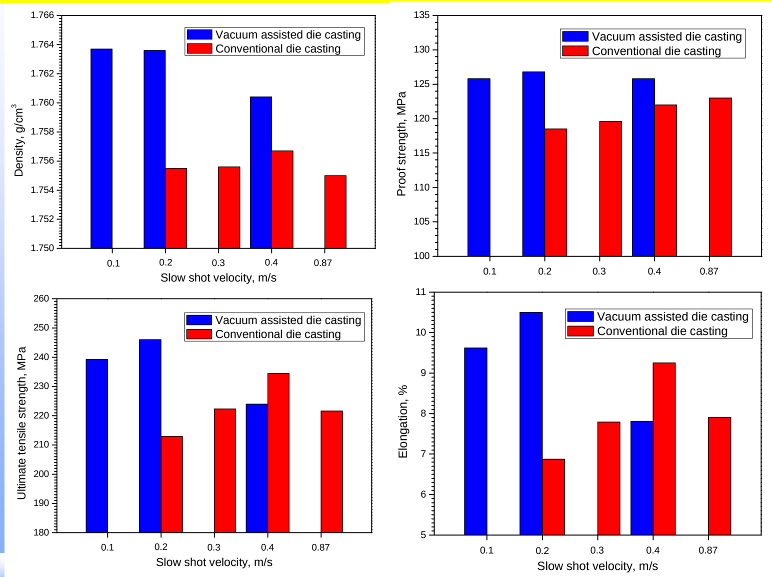
3. Background and Resources

- Both experiment and simulation have been extensively studied with Al and Mg alloys in Tsinghua University.
- Multi-scale modeling and simulation based on cellular automaton (CA) methods are used for processing – microstructure – property prediction of Al and Mg alloy castings.
- Advanced computational software and hardware available
- Experimental as well as physical simulation facilities are equipped in the lab

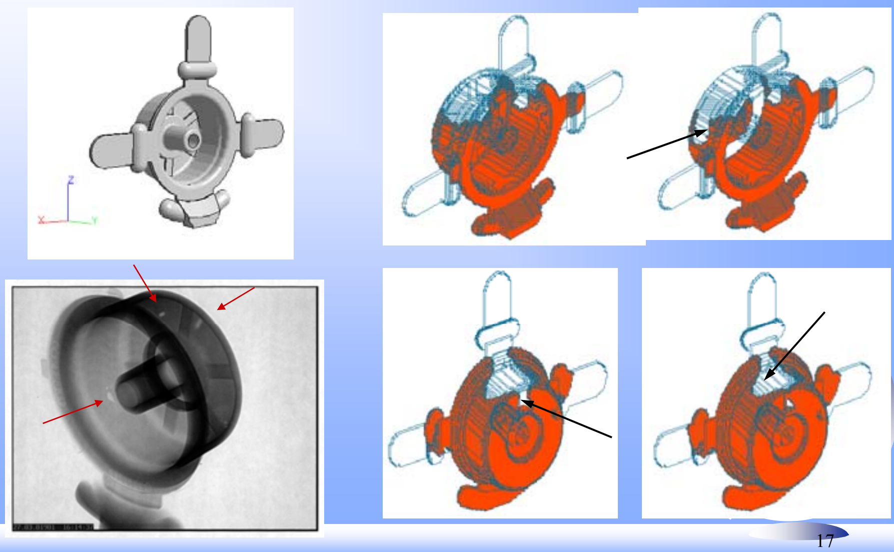
Porosities of as-cast and T6 samples at different vacuum conditions (AZ91D)



Mechanical Properties of AM60B alloy under vacuum and conventional die casting conditions



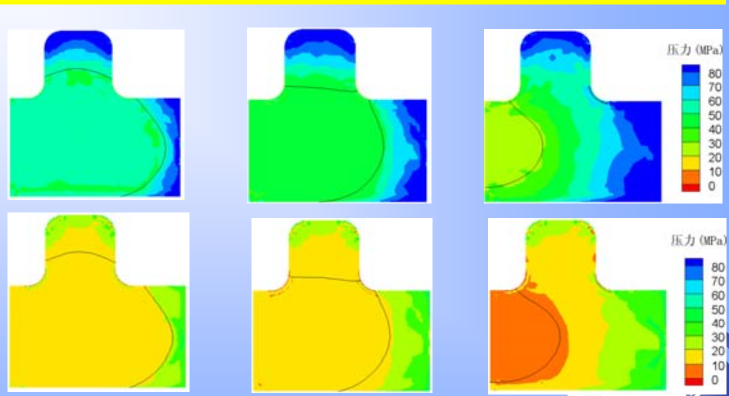
Porosity prediction of Al alloy die casting by macro simulation



Squeeze Casting of Al and Mg Alloys

Pressure 75MPa
Punch 200℃
Die 250℃
Ejector 250℃

Pressure 25MPa
Punch 200℃
Die 250℃
Ejector 250℃



t=4s t=8s t=16s

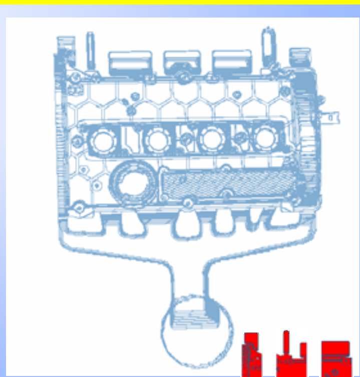
Modeling and Simulation of Thermomechanical Phenomena and Pressure Transfer in Aluminum Squeeze Casting

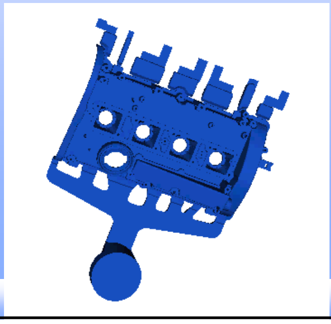
Computation efficiency significantly improved by Parallel Computational Method

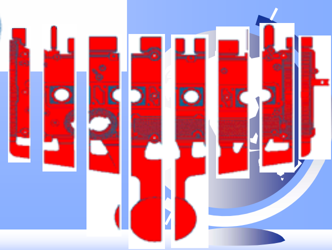
Thickness: 2mm

Sizes:
477X560X108mm

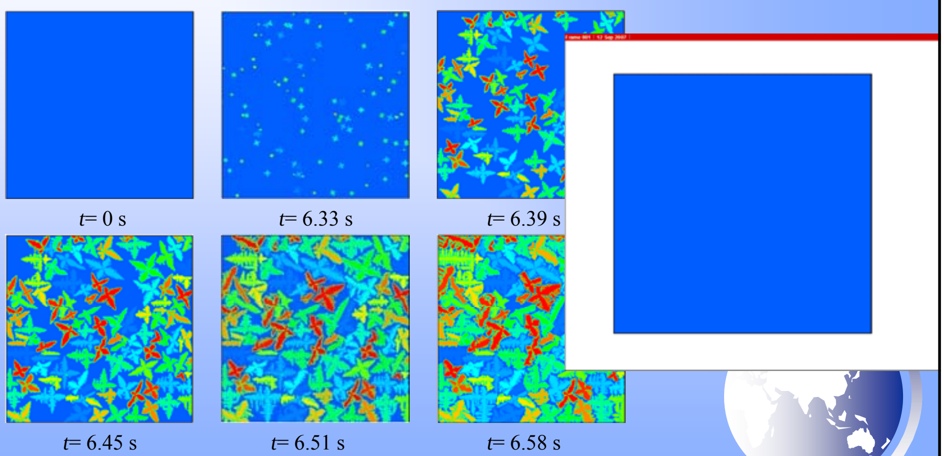
Mesh number :
19.21million



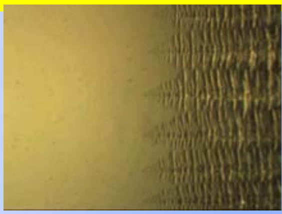


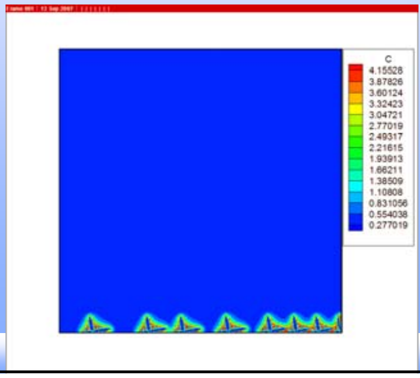


Microstructure Simulation of Aluminum Alloy by CA Method



In-Situ Observation of Dendrite Growth of Transparent Materials





10 degree inclined

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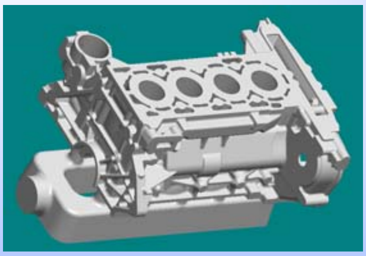
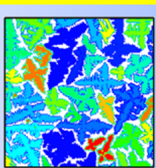
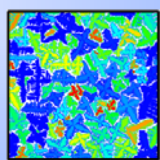
Process-microstructure-property Prediction of Al alloy casting

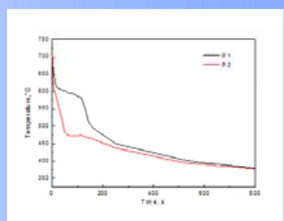


P1



P2





Mesh number	4,545,783
Macro-mesh	3 mm
Micro-mesh	2μm

λ_2(P1): 84 μm

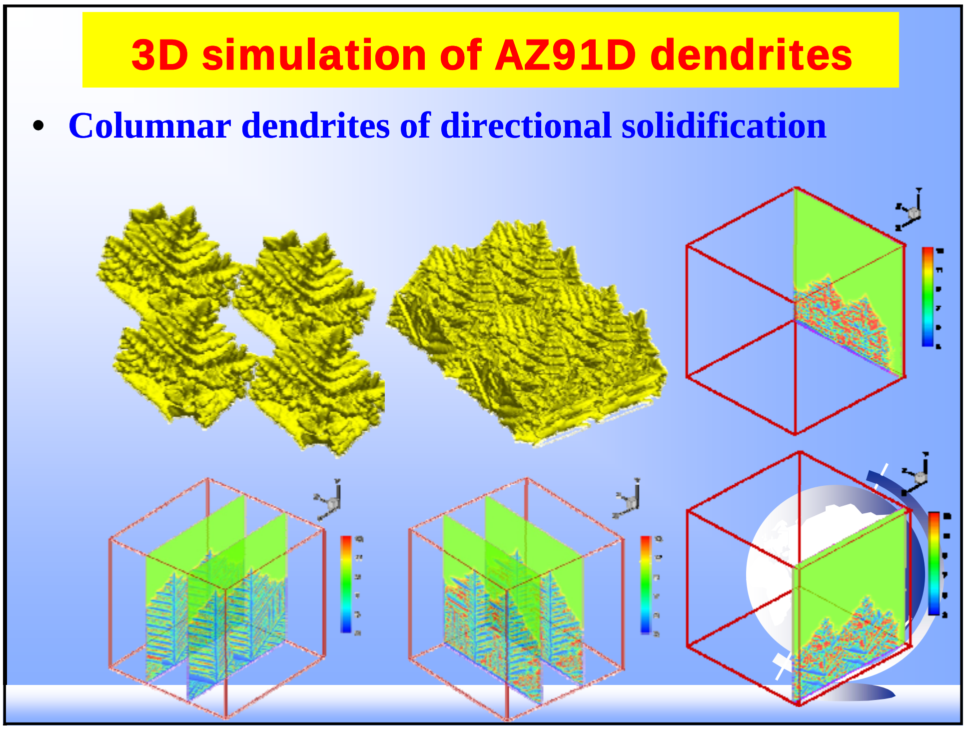
λ_2(P2): 62 μm

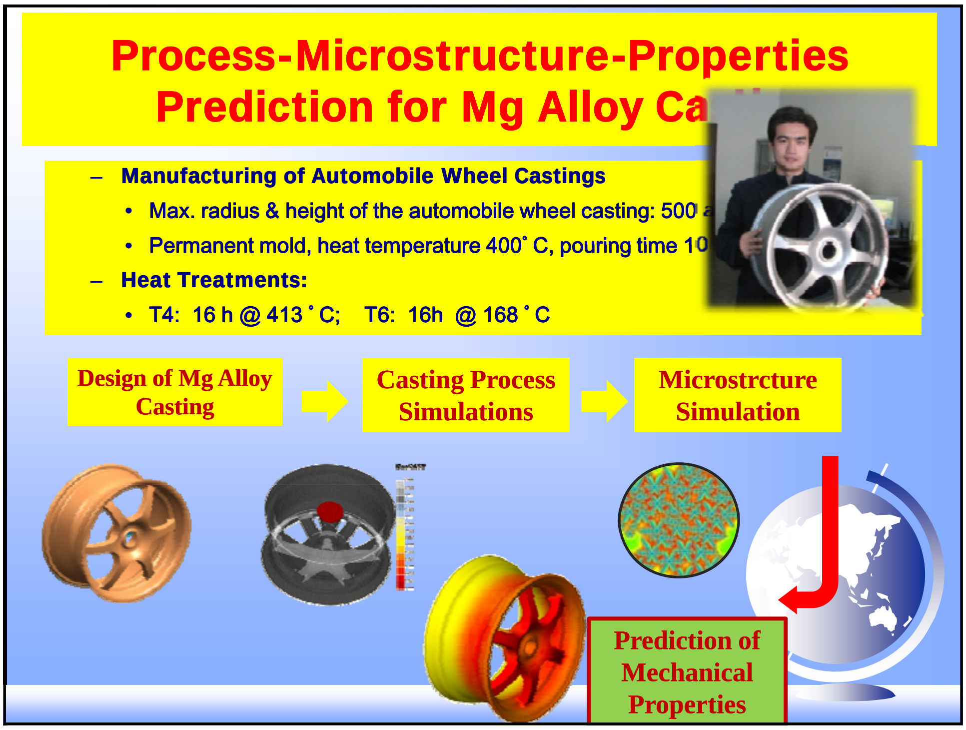
$UTS = 271.02 - 0.814 DAS$

UTS (P1): 206 MPa

UTS (P2): 220 MPa

> Requirement: 200 MPa


3D simulation of AZ91D dendrites
• Columnar dendrites of directional solidification


Process-Microstructure-Properties
Prediction for Mg Alloy Ca
– Manufacturing of Automobile Wheel Castings
• Max. radius & height of the automobile wheel casting: 500
• Permanent mold, heat temperature 400° C, pouring time 10
– Heat Treatments:
• T4: 16 h @ 413 ° C; T6: 16h @ 168 ° C
Design of Mg Alloy Casting
Casting Process Simulations
Microstrcture Simulation
Prediction of Mechanical Properties

Related Research Projects and International collaboration

- Fundamental Study on Modeling and Simulation of Near Net Shape Casting Technology, No. 2005CB724105, National 973 Program
- Research and Development of High Vacuum Die Casting Technology for Magnesium Alloys, National 863 Program, 2009AA03Z114
- Modeling and Simulation of Microstructure and Property of Near Net Shaped Magnesium Alloys, No. 2006CB605208, National 973 Program
- Modeling and Simulation of Thermomechanical and Transport Phenomena in Squeeze Casting of Light Metallic Alloys, No. 50675113, National Natural Science Foundation of China
- Macro, Micro, and Nano-scale Modeling of Alloy Solidification under Transient Pressure, No. 50875143, National Natural Science Foundation of China
- Closely collaborated with FAW at home and GMC & FMC abroad
- Magnesium Front End Research and Development – Task 9: Integrated Computational Materials Engineering, Canada-China-USA Collaborative Research Project

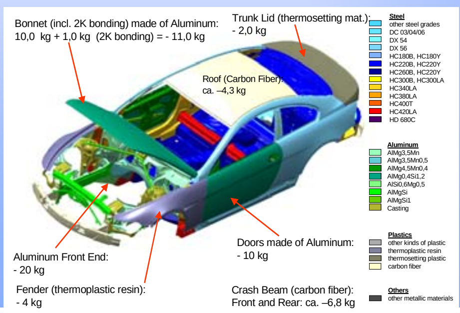
上海交通大学
SHANGHAI JIAO TONG UNIVERSITY

Manufacturing and assembly processes of lightweight car body

Xinmin LAI
Shnghai Jiaotong University

Motivation

- Body weight is 25-30% of the total vehicle, thus is the heaviest part of the car, and is the most crucial parts for lightweighting;
- "Multi-material body" using HSS (UHSS), aluminum and magnesium in the car body, has become an inevitable choice for lightweight car body.



BMW M6

Aluminum-steel hybrid car body,

Maximum velocity can reach 340km/h

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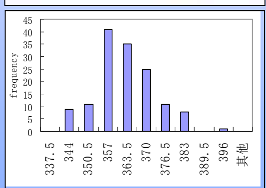
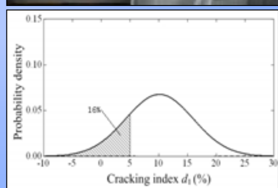
Challenges to Forming Process

- In HSS (UHSS) forming, panel manufacturing quality is sensitive to materials and process, affecting the quality stabilization.





Material variations | process variations | Stabilization of quality

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Challenges to Joining Process

- Because of the differences between steel and light metals, such aluminum and magnesium, it is very difficult to join light metal to steel with traditional fusion welding methods for the occurrence of inter-metallic compound and large distortion.

	Unit	Steel	Aluminum	Effects
Melting point	° C	1536	660	Cannot be welded with fusion method
Thermal expansion coefficient	△l/l° C	12×10^{-6}	23.9×10^{-6}	Large distortion
Thermal conductivity	W/mK	46	222	Fast heat dissipation
Standard voltage（25° C）	V	-0.44	-2.34	Galvanic corrosion

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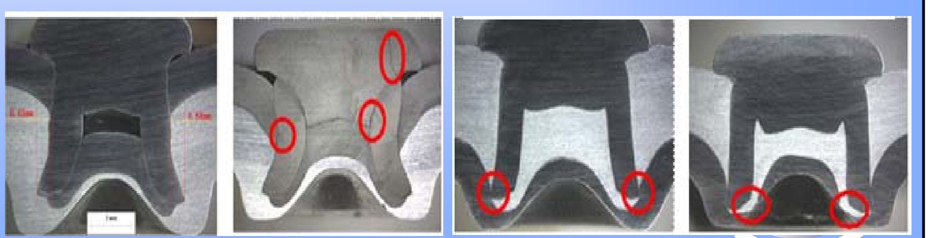
Challenges to Joining Process

- SPR (self-pierce riveting) is the most popular joining method of dissimilar materials, however, it is very difficult to apply SPR to following materials:
  - When riveting AHSS and UHSS, the rivet deforms severely, and cannot produce effective interlock in the lower sheet;
  - When riveting brittle magnesium and casting aluminum, cracks inevitably occur and greatly reduce the joint performance.
  - Many other joining method have been developed, however, the manufacturing cost of the car body is greatly increased.



（a）空腔（钢→铝）；（b）铆钉开裂（钢→铝）；（c）没有自锁（铝→钢）（d）铆穿（铝→钢）

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Research Objectives

- **Forming**
  - ✓ Develop robust optimization method of forming process in HSS panels stamping.
- **Joining**
  - ✓ Develop a new SPR method aided by external field to improve the joining ability between HSS and light material.
- **Assembly**
  - ✓ Improve the accuracy of multi-materials auto body assembly variation prediction

Proposed Research Projects

- **Robust optimization design of forming process of lightweight panels considering stochastic factors**
- **Electro-plastic self-pierce riveting**
- **Assembly variation prediction and assembly fixture robust design**

Deliverables

- **Constitutive model of materials under the electric current**
- **FE model of electroplastic riveting process**
- **Process optimization method of electroplastic riveting process**

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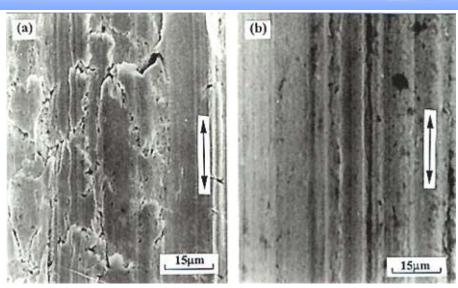
What is Electro-plasticity?

- **Electro-plasticity is a phenomenon that by the application of moving electrons (in the form of an electric current or electric field) to the deformation zone, it is possible to improve the plasticity of a material (e.g. metal, ceramic) and to reduce its resistance to deformation.**



Surface morphology of stainless steel wire under drawing process
(a) conventional drawing; (b) Electro-plastic drawing

Test apparatus of electro-plastic effect

Research Task

- Study mechanism of electro-plastic riveting through modeling and simulation
- Develop an integrated electro - plastic riveting apparatus, which can apply both electricity and force uniformly and coaxially
- Study the influencing laws of current density on riveting ability
- Typical applications:
  - ✓ Ultra HSS
  - ✓ Magnesium
  - ✓ Casting aluminum

Electric Current input mode in current electro-plastic riveting setup

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SJTU Auto-body Manufacturing

2000.10.29, Signing Ceremony of GM-SJTU Auto-body Manufacturing Satellite Lab

2002.6.14, Signing Ceremony of SJTU PACE Center

- 6associate professors
- 10 lecturers & engineers
- 45 Ph.D candidates
- 50 M.E candidates

THANKS !