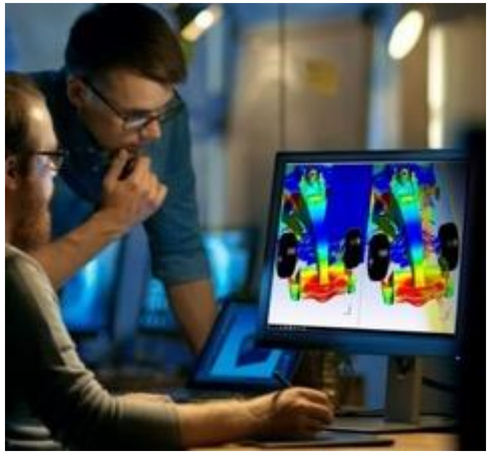
Ansys

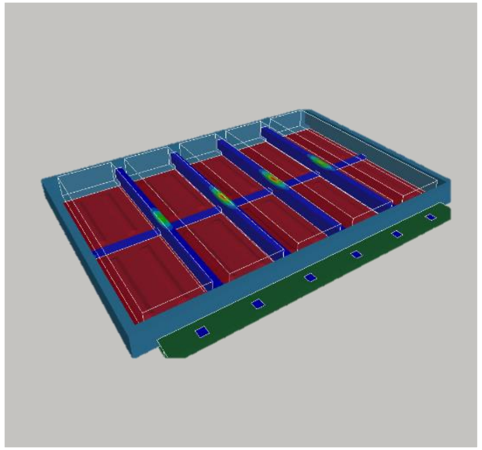
Powering Innovation That Drives Human Advancement

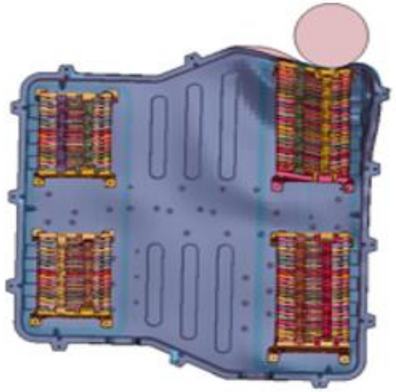
LS-DYNA在电池应用上的最新更新

王强 2025

目录







前言

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电池相关先进模拟方法

电池包仿真中的接触经验

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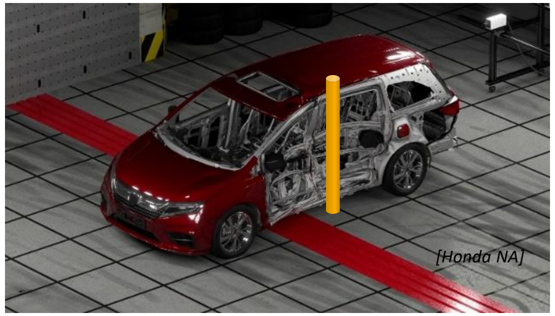
电池研发中主要的结构/流体问题

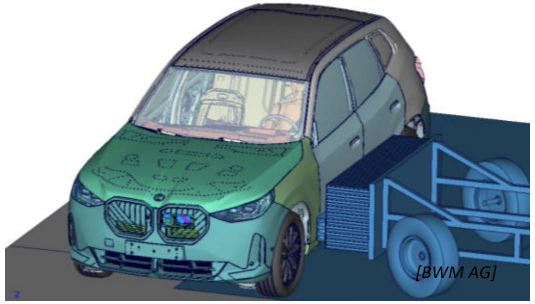
电池研发中主要的系统/工艺问题

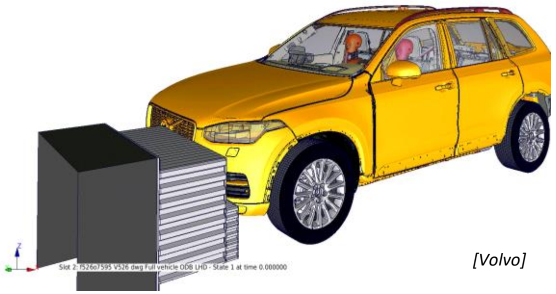
LS-DYNA市场覆盖率

全球95%以上的汽车主机厂使用LS-DYNA

20+Mio. finite elements
Complex constitutive models
Sophisticated connection modelling
15,000 simulation runs per model







全球动力电池Top10前9家使用LS-DYNA

CABIA 中国汽车动力电池产业创新联盟

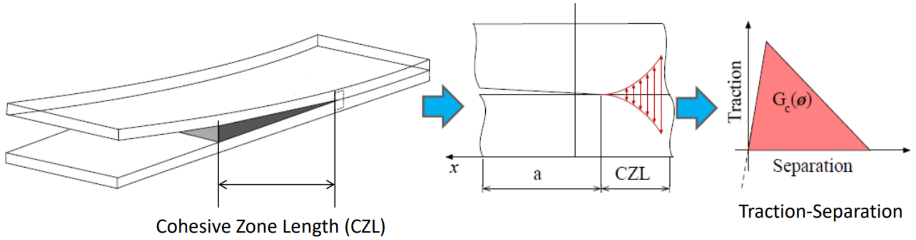
3.8 2024年1-12月国内动力电池企业装车量前十五名

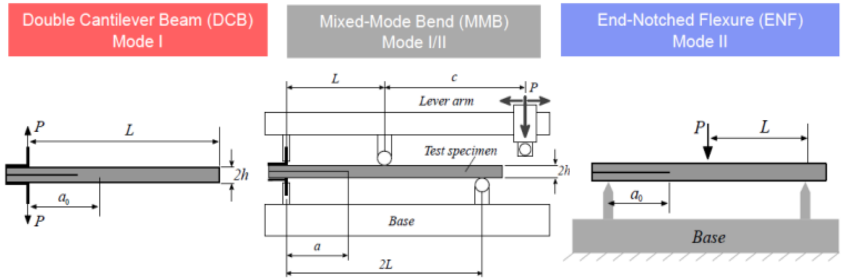
序号	企业名称	装车量（GWh）	占比	与上年同期比占比变化/百分点
1	宁德时代	246.01	45.08%	1.89
2	比亚迪	135.02	24.74%	-2.52
3	中创新航	36.48	6.68%	-1.82
4	国轩高科	25.04	4.59%	0.48
5	亿纬锂能	18.70	3.43%	-1.03
6	蜂巢能源	17.36	3.18%	0.93
7	欣旺达	15.79	2.89%	0.75
8	瑞浦兰钧	12.14	2.22%	0.90
9	正力新能	9.85	1.80%	0.41
10	爱尔集新能源	7.66	1.40%	-0.75
11	极电新能源	6.27	1.15%	1.10
12	孚能科技	3.44	0.63%	-0.91
13	多氟多	3.08	0.56%	0.01
14	因湃电池	2.23	0.41%	——
15	耀宁新能源	1.97	0.36%	——

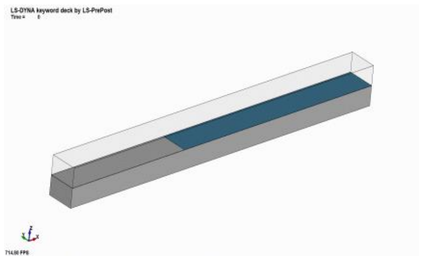
国内动力电池Top10前6家使用LS-DYNA

电池相关材料模型

胶的失效（内聚力模型）







LS-DYNA Material Model	Traction-Separation Law/Shape	Initiation & Propagation Criteria	Comments
***MAT_138:** COHESIVE_MIXED_MODE	Bilinear (linear softening)	Quadratic mixed-mode. Supports power law (XMU > 0) and B-K law (XMU < 0)	Simplification of *MAT_COHESIVE_GENERAL.
***MAT_184:** COHESIVE_ELASTIC	Linear	Stress based criteria governed by normal and/or tangential strengths	Simple cohesive elastic model
***MAT_185:** COHESIVE_ELASTIC_TH	Tri-linear	Quadratic mixed-mode governed by dimensionless separation parameter λ (i.e. traction drops to zero when λ =1)	Cohesive model by Tvergaard and Hutchinson. Same loading and unloading path; completely reversible
***MAT_186:** COHESIVE_GENERAL	Arbitrary normalised traction-separation law given by a load curve (TSLC)	Three general irreversible mixed-mode interaction cohesive: 1. TES = 0: Power-law (XMU) 2. TES = 1.0: B-K law (XMU) 3. TES = 2.0: Dimensionless separation parameter	
***MAT_240:** COHESIVE_MIXED_MODE ELASTO_PLASTIC_RATE	Tri-linear	Quadratic yield and damage criterion in mixed-mode loading. Damage evolution is governed by a power-law	Rate-dependent, elastic-ideal plastic

14th European LS-DYNA Conference 2023, Baden-Baden, Germany

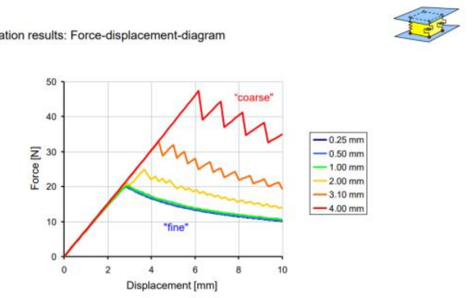
Characterization of a cohesive zone model for adhesives with *MAT_240 and curve mapping method in LS-OPT

Nicole Betz[1], Martin Holzapfel[1], Tobias Behling[1], Mathieu Vinot[1], Nathalie Toso[1]

[1]German Aerospace Center, Institute for Structures and Design

标定案例参考论文

– simulation results: Force-displacement-diagram



Coarse discretization: Maximum force AND fracture energy too high!

单元大小的影响（有实际项目是用的2mm）

技术支持经验分享:

1. 单元公式:

两侧都是SOLID，选ELFORM19;

两侧都是SHELL，选ELFORM20;

一侧是SHELL，另一侧是SOLID选ELFORM20

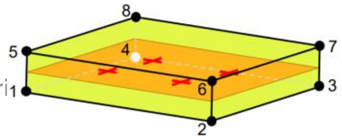
2. Tie接触:

Cohesive To shell:*CONTACT_TIED_SHELL_EDGE_TO_SURFACE_CONSTRAINED_OFFSET_ID_MPP

Cohesive To solid:*CONTACT_TIED_SHELL_EDGE_TO_SOLID_MPP

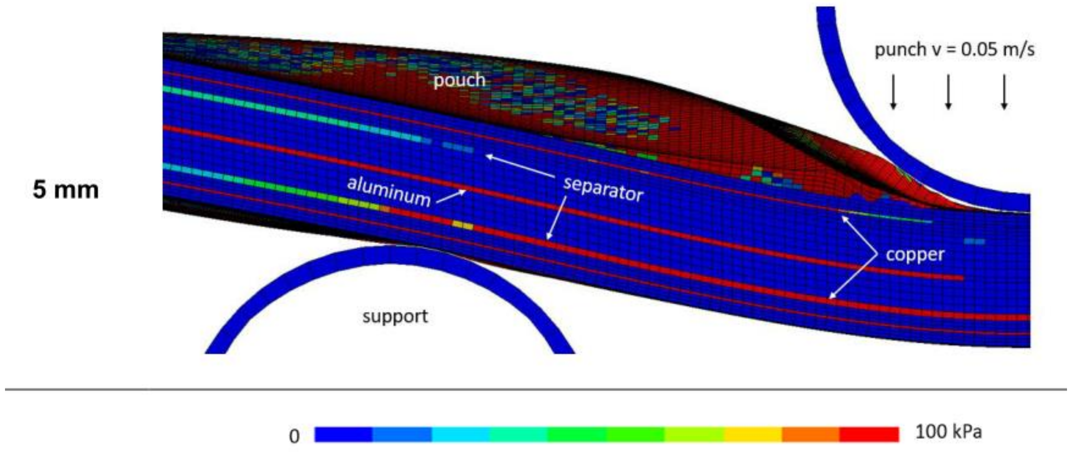
3. 实体单元方向:

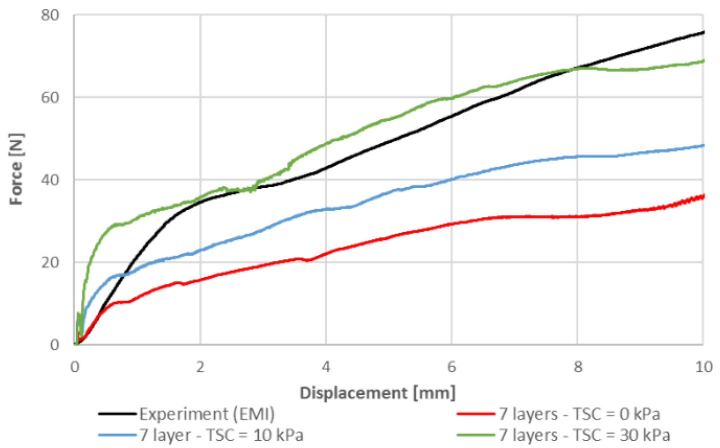
必须为厚度方向



电芯材料模型

活性材料（石墨与NMC）	*MAT_CRUSHABLE_FOAM
铜箔、铝箔	*MAT_PIECEWISE_LINEAR_PLASTICITY
隔膜separator (porous polyolefin)	*MAT_ANISOTROPIC_VISCOPLASTIC （* MAT_103）

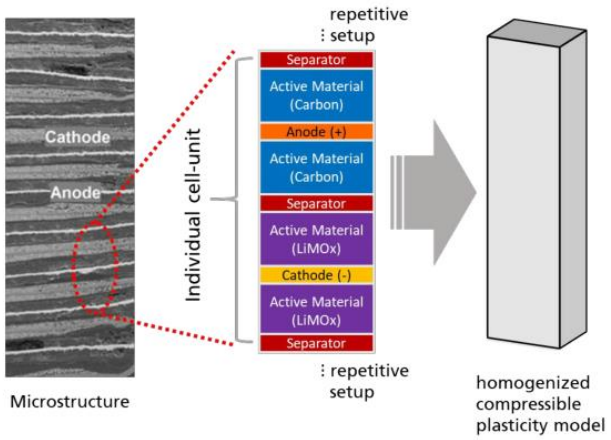


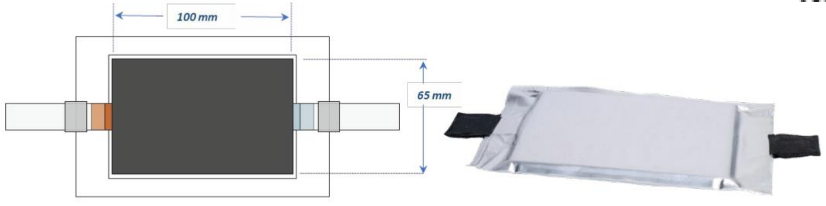


Modeling the Mechanical Behavior of a Li-Ion Pouch Cell under Three-Point Bending，13th European LS-DYNA Conference 2021, Ulm, Germany

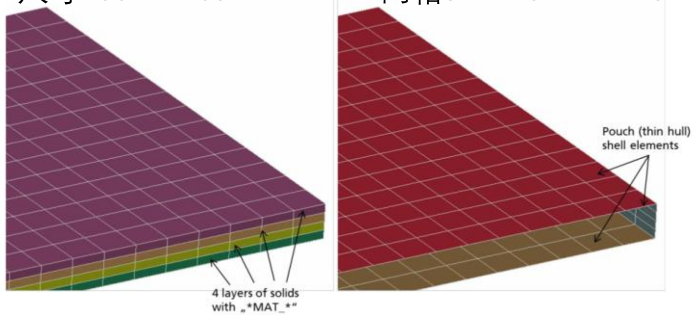
电芯均质化材料模型

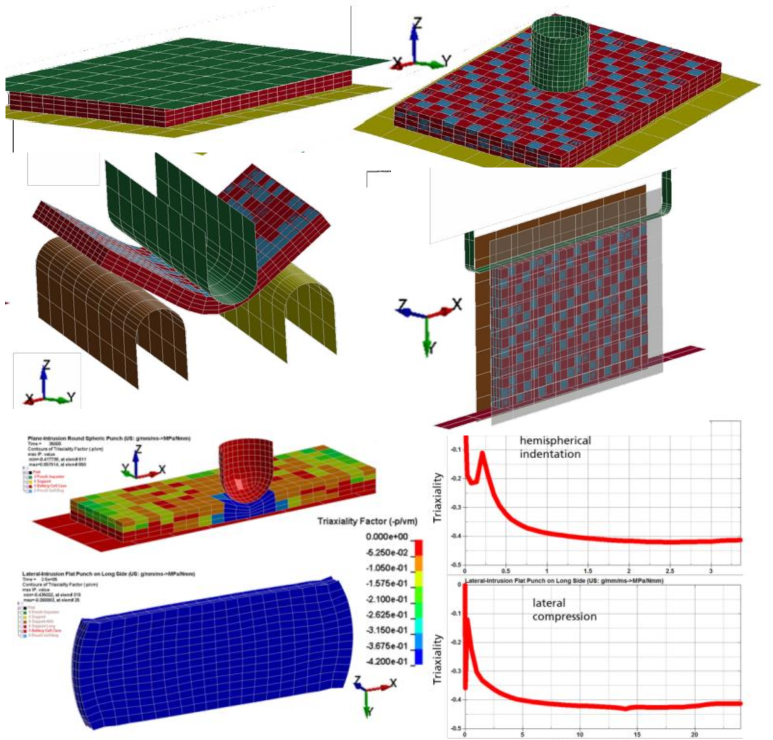
Fraunhofer IWM





尺寸100mm*65mm*7mm 网格5mm*5mm*1.75mm

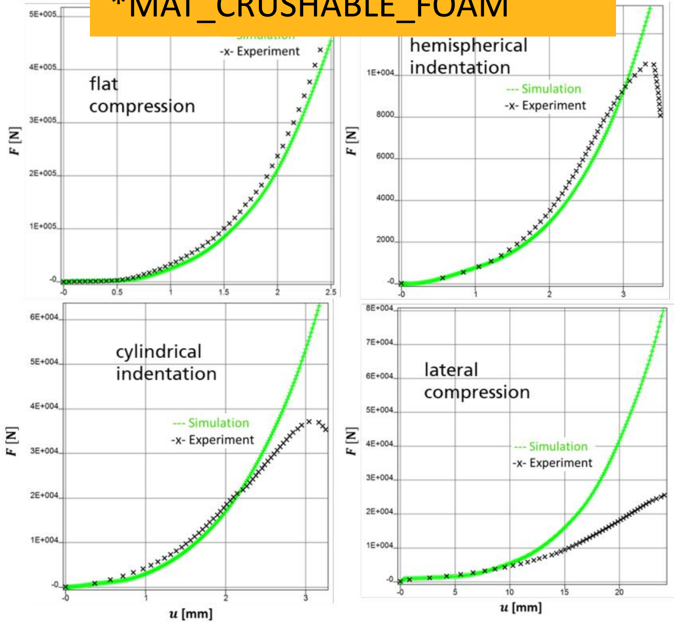




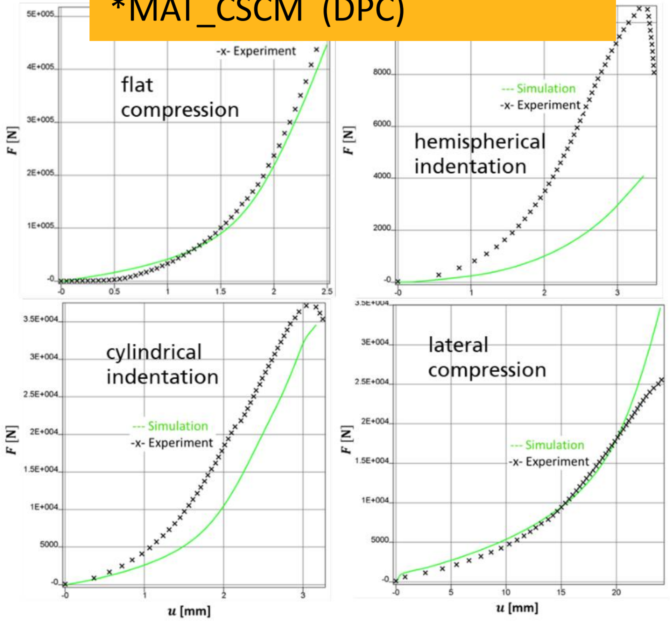
三种均质化材料模型比较

仿真（绿线）
实验（黑线）

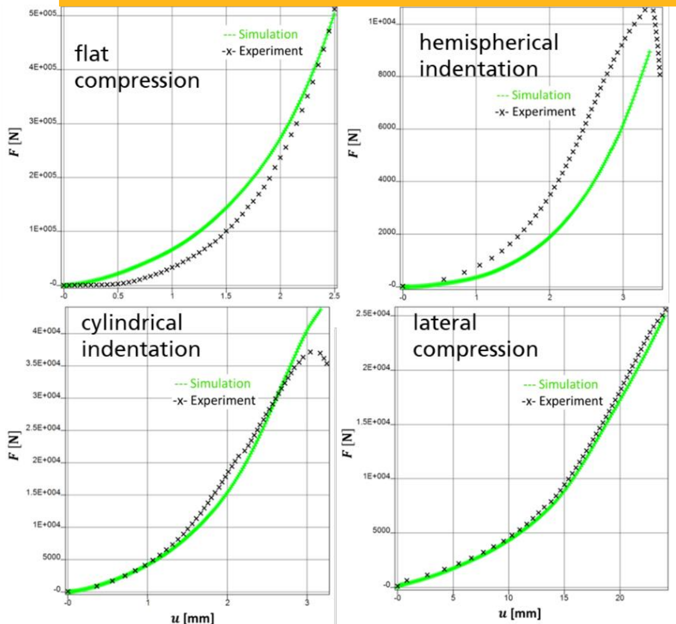
*MAT_CRUSHABLE_FOAM



*MAT_CSCM（DPC)



*MAT_MODIFIED_HONEYCOMB （推荐）

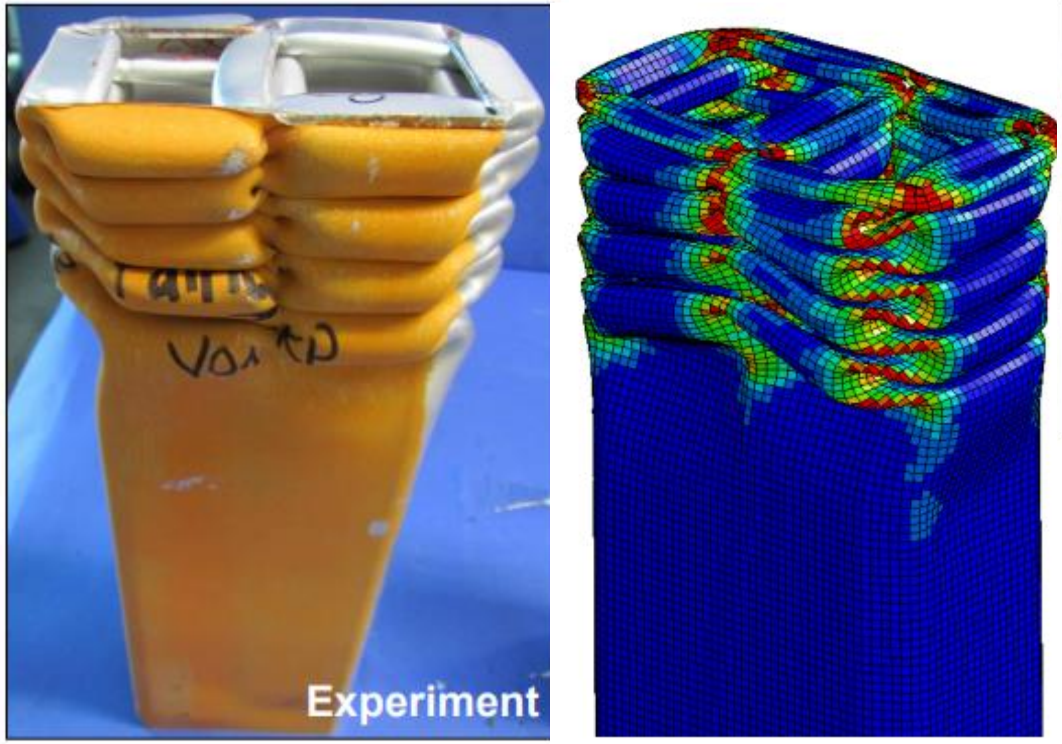


Simplified modeling of pouch cells under different loadings, 13th European LS-DYNA Conference 2021, Ulm, Germany

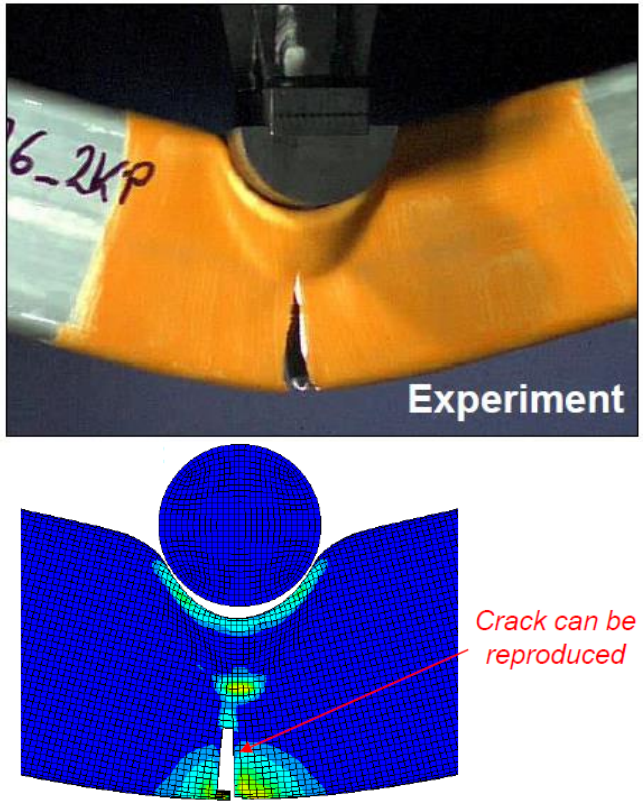
GISSMO材料本构 | 应用

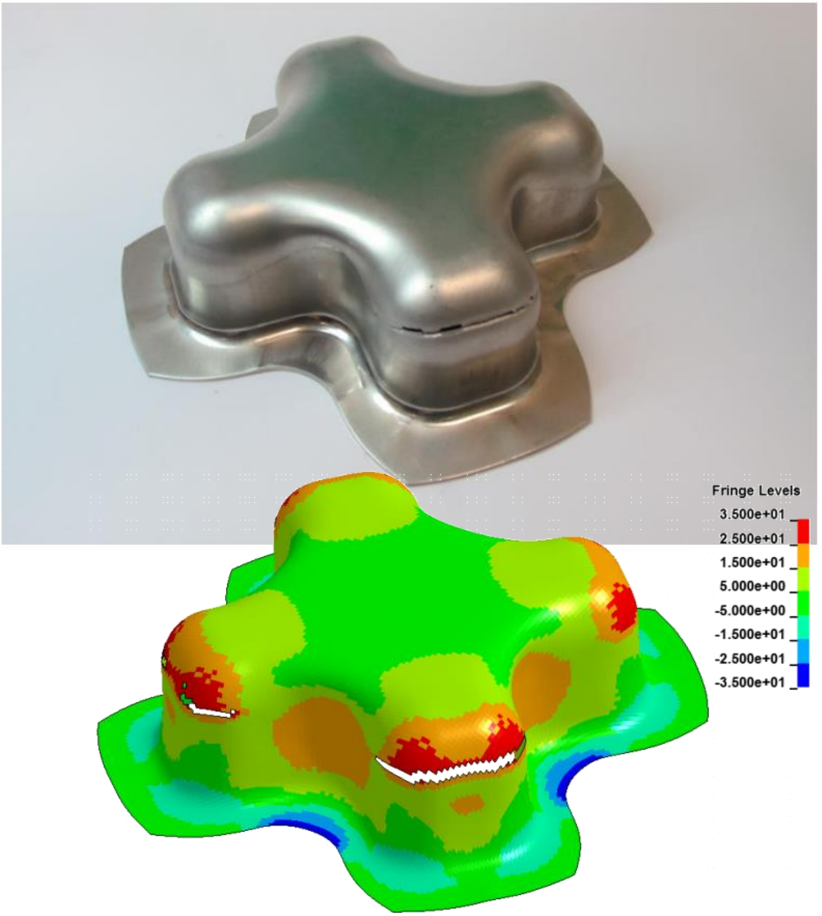
失效应变的应力三轴度相关、非线性路径相关损伤累计、网格无关性

AUSTRIAN INSTITUTE OF TECHNOLOGY



挤压铝型材冲压模拟





铝材冲压成型模拟

F. Andrade, M. Feucht – Oct 2018 – Failure prediction in crash simulations with the GISSMO model

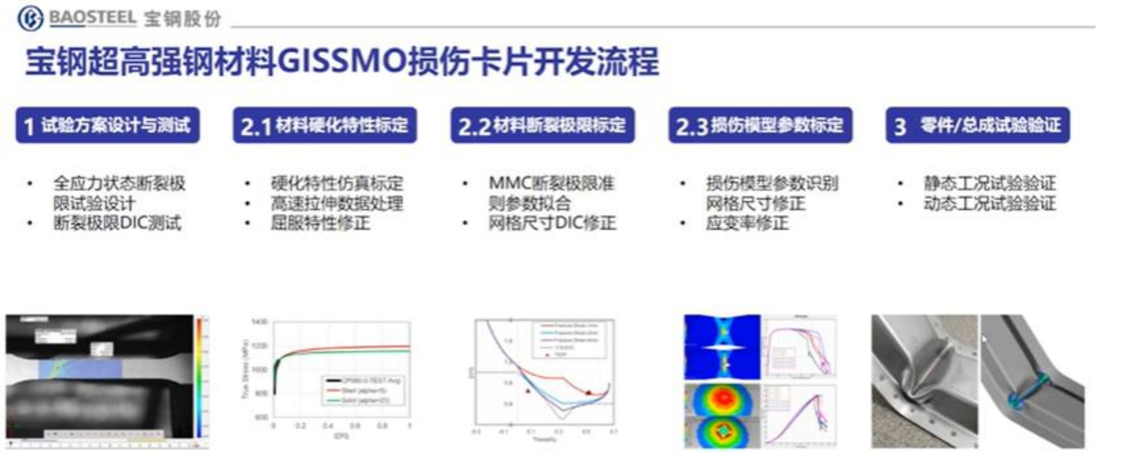
Falkinger, Georg, Nikolay Sotirov, and Peter Simon. "An investigation of modeling approaches for material instability of aluminum sheet metal usi the GISSMO-model." 10th European LS-DYNA Conference, Wurzburg. 201

宝钢LS-DYNA Gissmo应用

BAOSTEEL 宝钢集团

主题介绍

随着汽车环保和安全的要求，应用高强钢和超高强钢进行车身轻量化成为重要的技术手段。材料高强化后带来硬化特性复杂度和碰撞断裂风险的加大。宝钢不断开发超高强钢新产品的同时，也注重材料硬化与损失表征技术的研究。通过先进试验技术，并结合仿真对标，提出了应变硬化普适表征模型并开发了面向碰撞工况的材料损伤模型关键参数确定流程。以QP1180-EL为例展示LS-DYNA GISSMO失效卡片开发，为行业用户实现超高强钢碰撞断裂失效的精确预测提供参考。



演讲人简介

连昌伟　宝山钢铁股份有限公司 中央研究院主任研究员

连昌伟，宝钢股份中央研究院主任研究员，任汽车板材料表征技术领域负责人。2006年毕业于上海交通大学，获硕士学位，现攻读同济大学博士学位。负责国家重点实验室研发课题、国际合作和公司年度计划等项目8项，负责与国内外汽车主机及零部件公司的技术合作项目10余项，并推动了与主流软件公司的材料库合作。在国内外发表学术论文20余篇，负责和参与发明专利申请4项，负责编制和修订行业标准2项，牵头完成译著1部，参与编写专著2部。获得冶金科学技术奖特等奖、冶金青年创意奖、中国宝武技术创新重大成果特等奖等奖项。

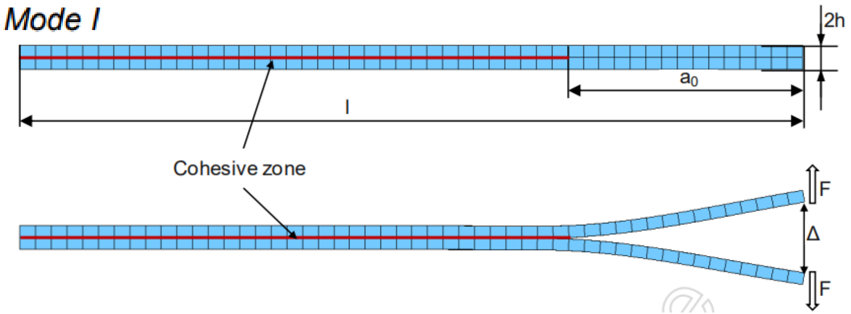
视频回看链接　https://v.ansys.com.cn/live/e04a5b5e7d9747abb53f5e2160d8d053

LS-DYNA缠绕复合材料失效模拟

德国亚琛汽车研究有限公司

- 可考虑复材的剪切非线性

*MAT_LAMINATED_FRACTURE_DAIMLER_ CAMANHO (*MAT_262)



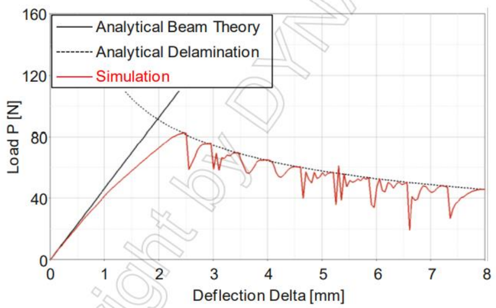


Fig.13: Simulation result of DCB test of CFRP with an element size of 3.0 mm

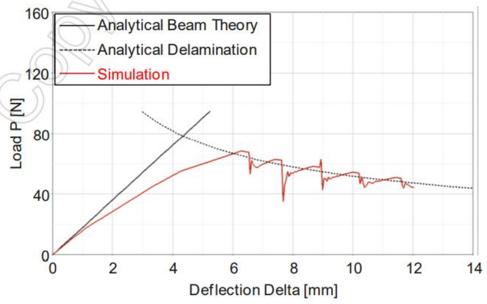
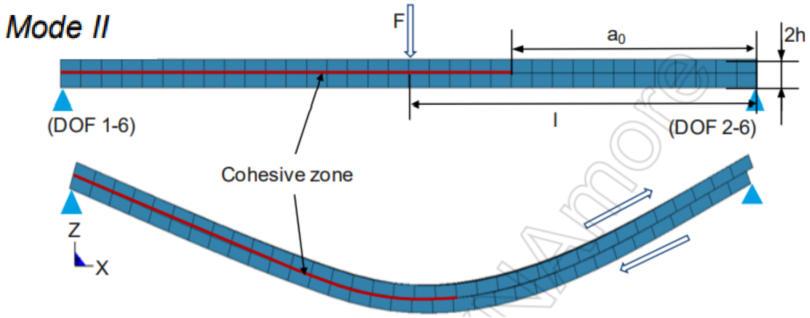


Fig.14: Simulation result of DCB test of GFRP with an element size of 3.0 mm



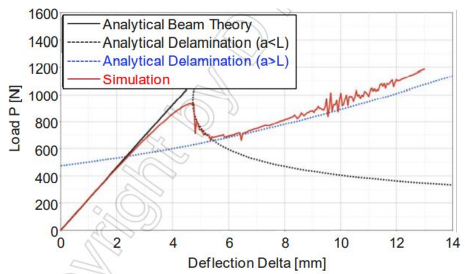


Fig.16: Simulation result of ENF test of CFRP with an element of 3.0 mm

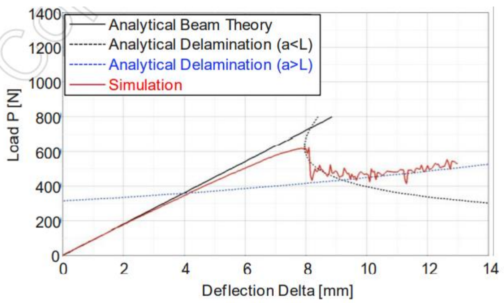
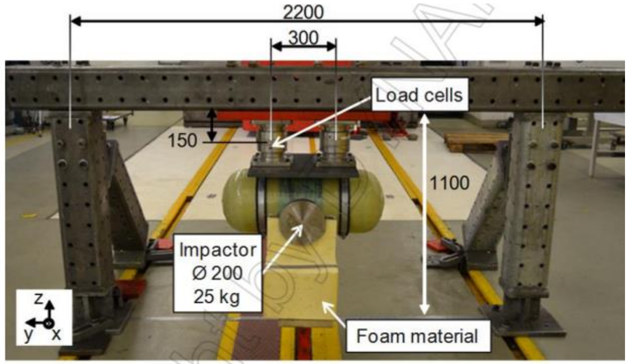
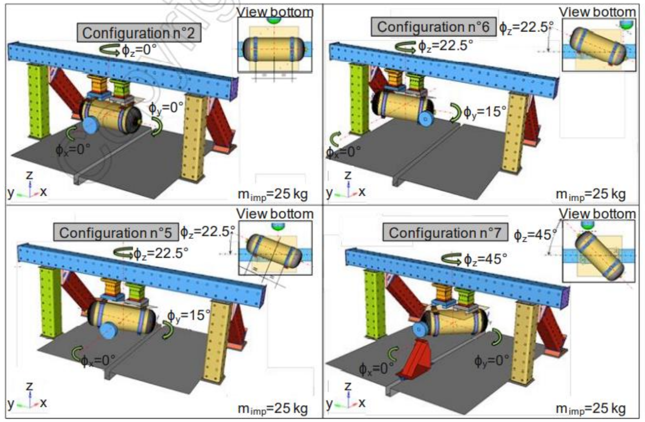
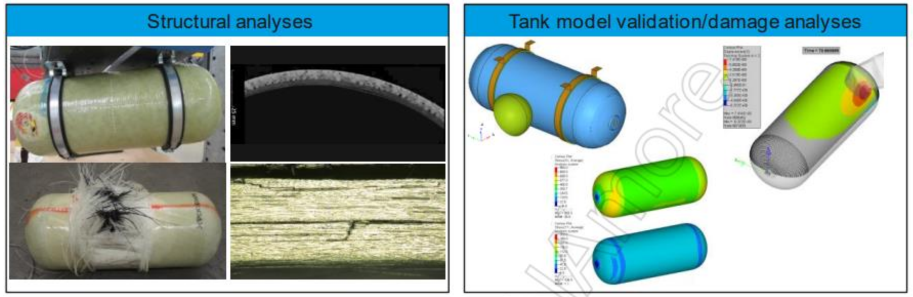


Fig.17: Simulation result of ENF test of GFRP with an element size of 3.0 mm



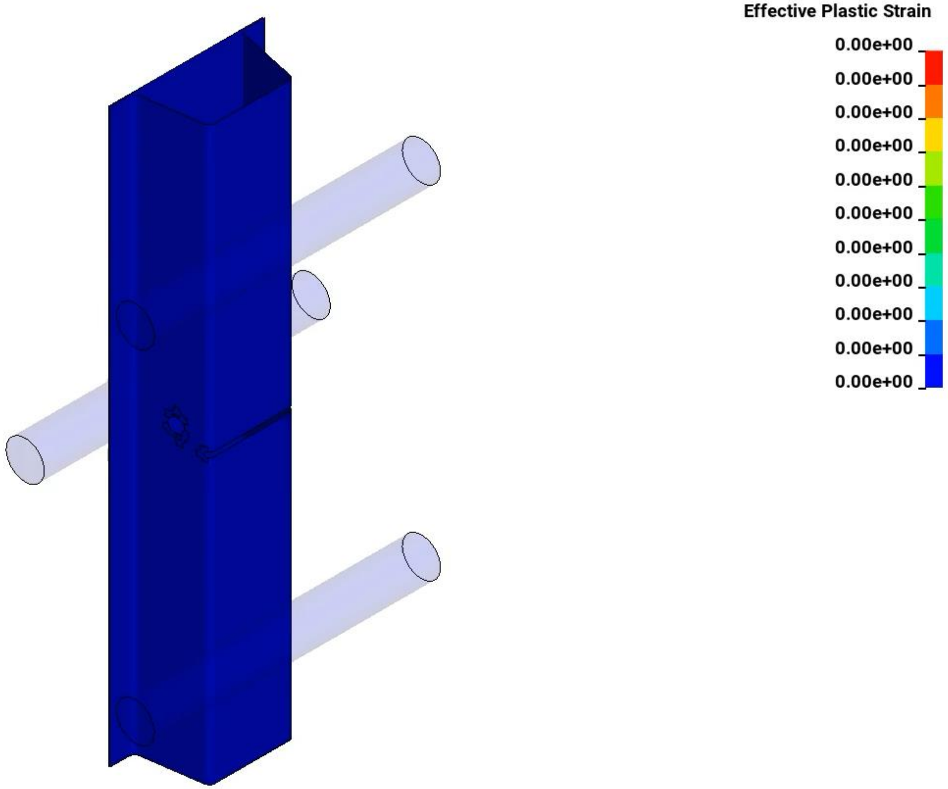




Modelling of thick UD composites for Type IV pressure vessels， 10th European LS-DYNA Conference 2015, Würzburg, Germany

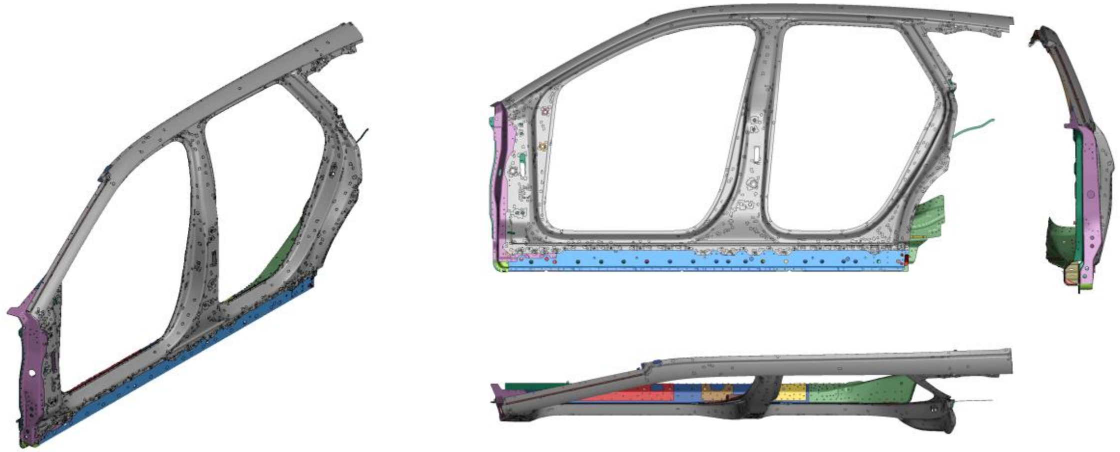
电池相关先进模拟方法

等几何建模Revision of IGA Element Erosion (R15)

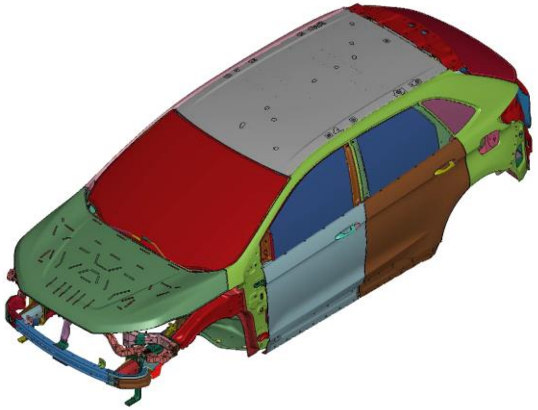


General scheme applicable to (un)structured shells and solids.

Hybrid assemblies

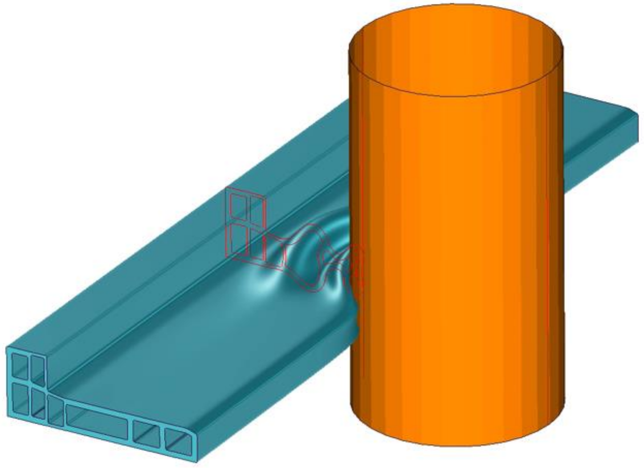


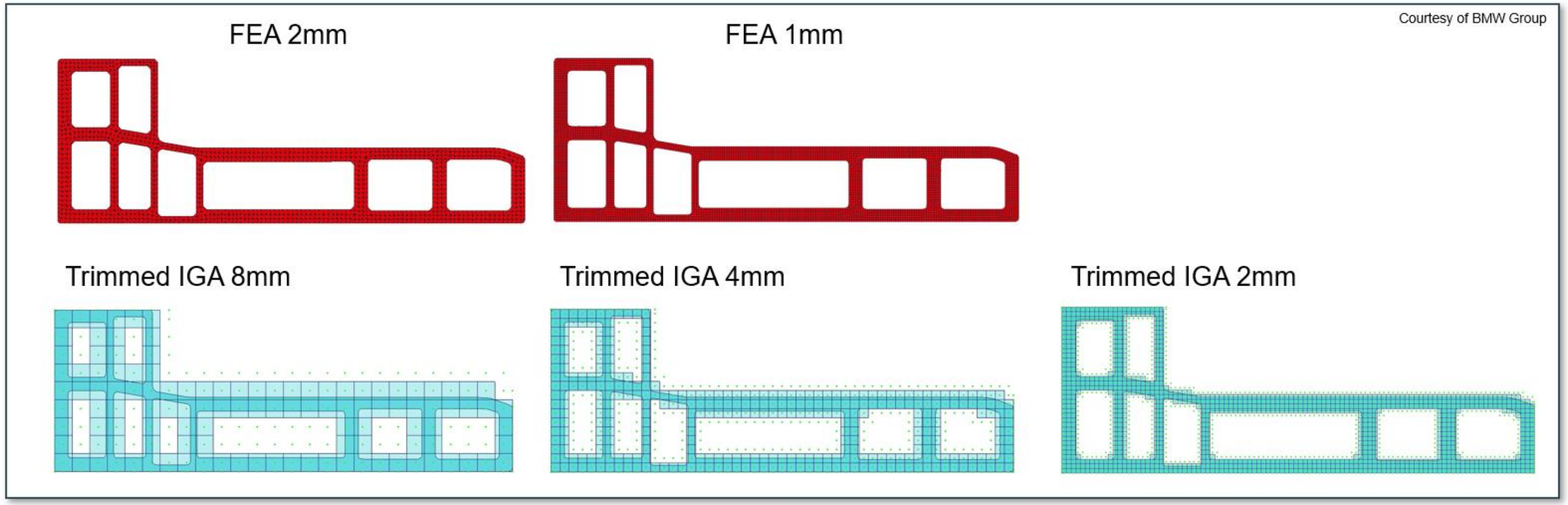
courtesy of General Motors

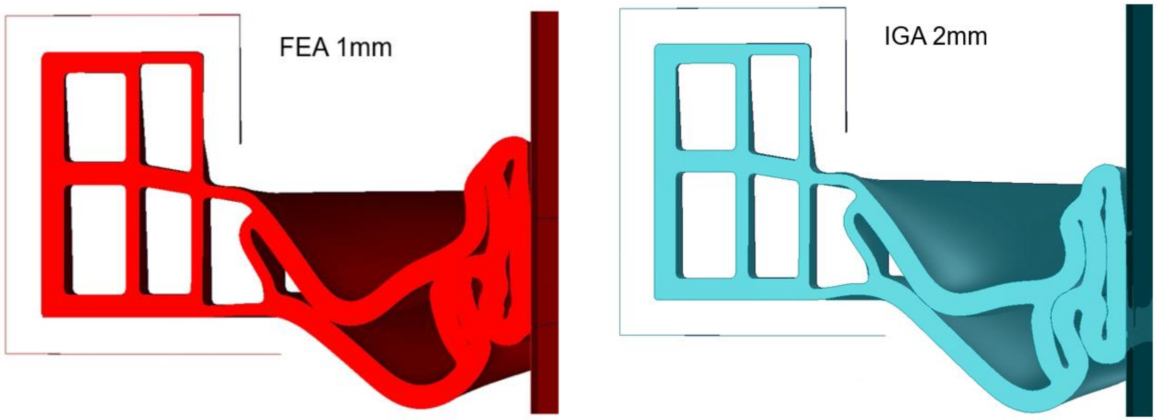


courtesy of Ford Motor Company

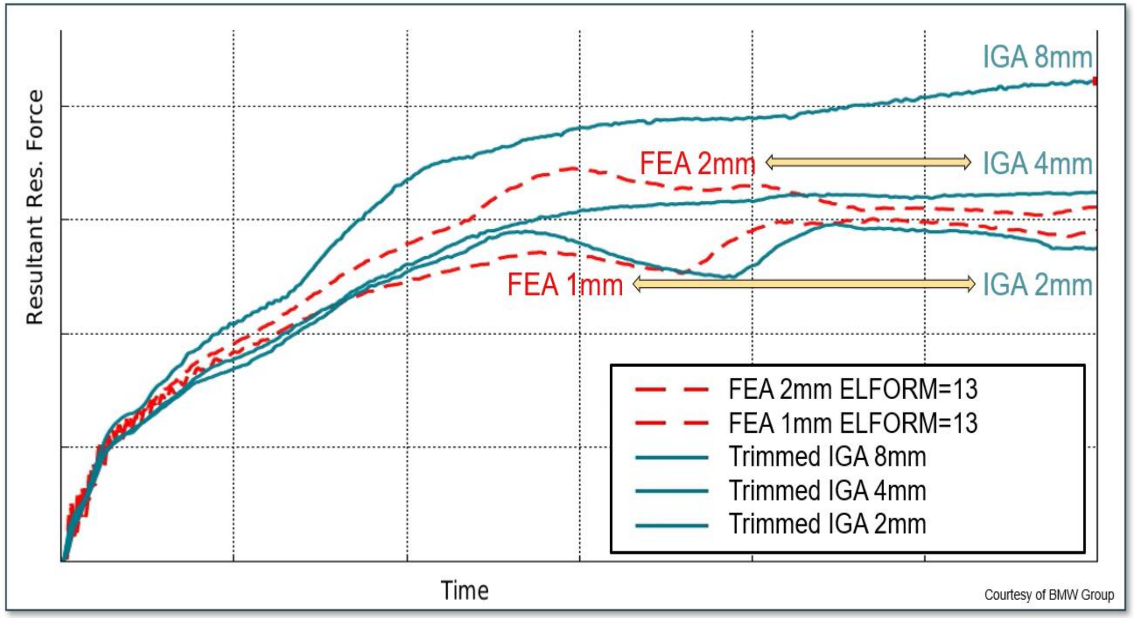
IGA挤压铝案例







变形形态对比



挤压力对比

Research on front anti-collision system using IGA method

Customer Goals

- Reduce labor costs by reducing modeling workload of crash safety.
- Find a method with higher accuracy than traditional finite element methods to reduce the number of experiments and accelerate research and development progress.

Solution

- LS-DYNA IGA is based on the description of B-spline curve, which is consistent with the description method adopted in CAD.
- IGA can be mixed with FEA model, simplifying the modeling process and improving the modeling efficiency and computing efficiency.
- It is highly compatible with FEA models, and can build hybrid models of FEA and IGA rapidly.

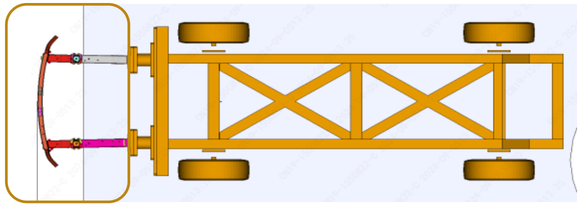
Outcome

- Good feedback from the customer:
  - Computing speed increased by about 40% (64 cores, from 5H to 3H),
  - No need to take effort on meshing works to save labor costs in the research project.
- Ansys got real IGA experience on practical customer project, strengthen relationship with CATL.

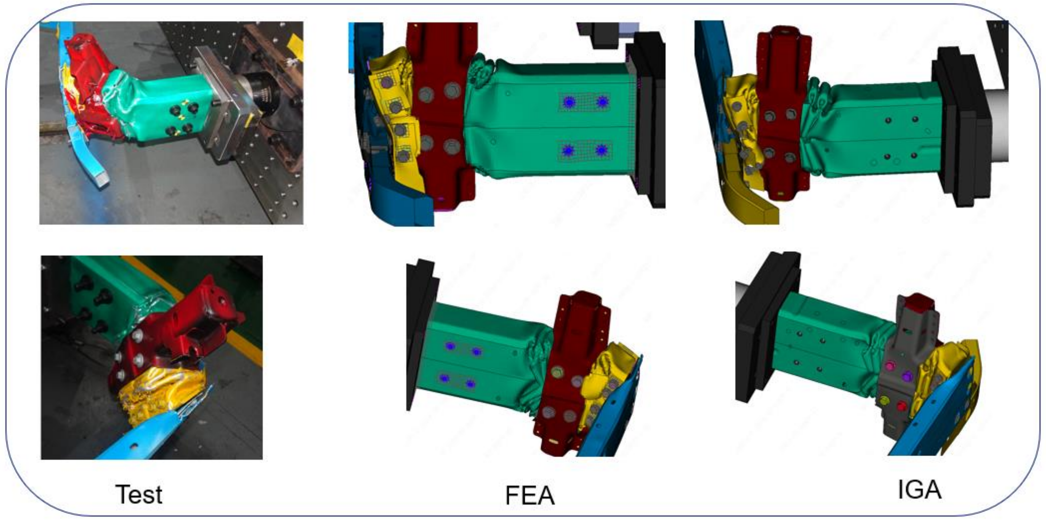
Ansys Technology	LS-DYNA

Status - Finished

Skateboard chassis



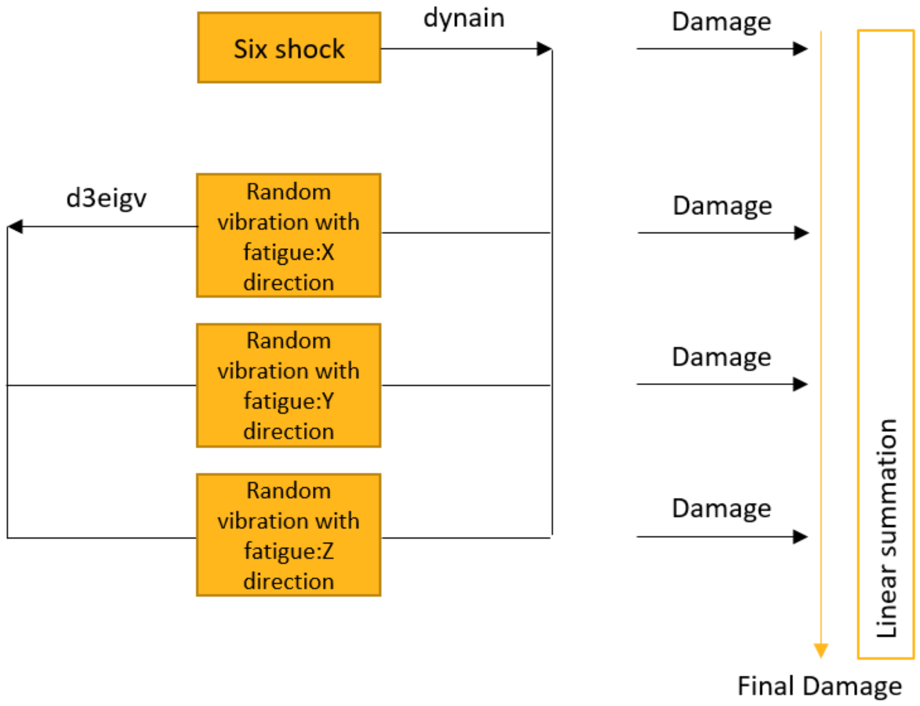
front anti-collision system



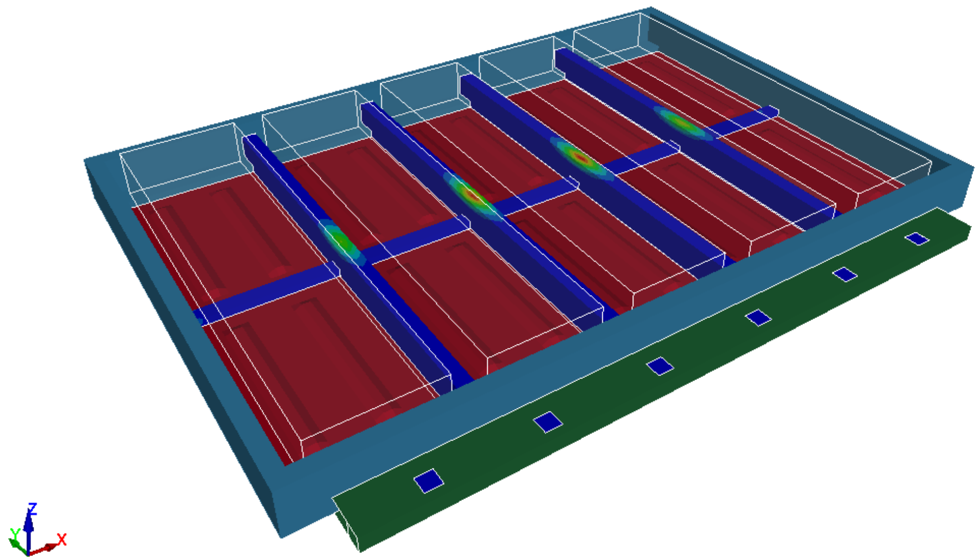
Local comparison on final deformation

Impact customers	CAERI (C-IASI)
Advantage	Fast modelling, more accuracy, speed up computation, no other software has the feature.
Competition	Pamcrash
Account Mgr.	Tao Lin
ACE Eng.	Daniel Wang

连续冲击后进行随机振动疲劳



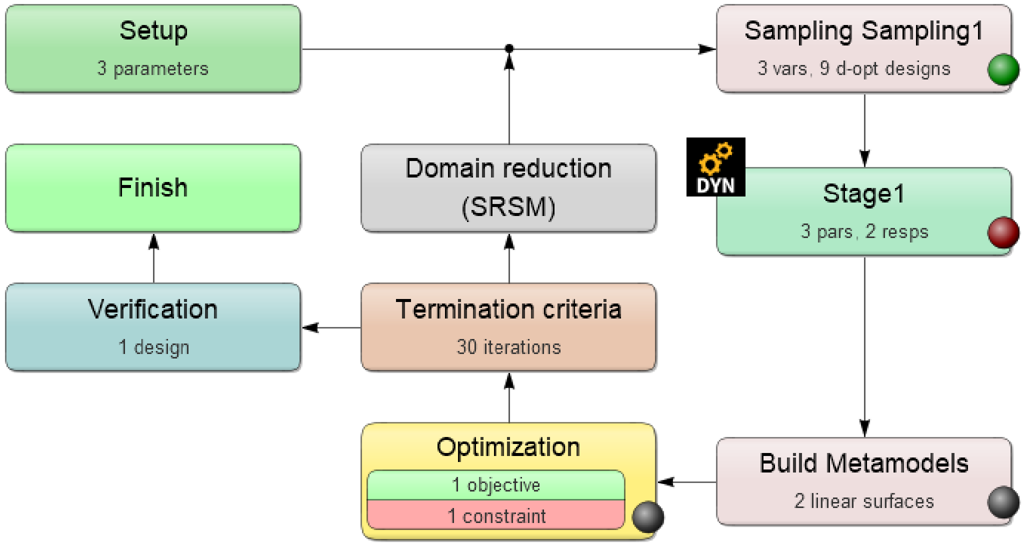
F1.Sicematic diagram of workflow

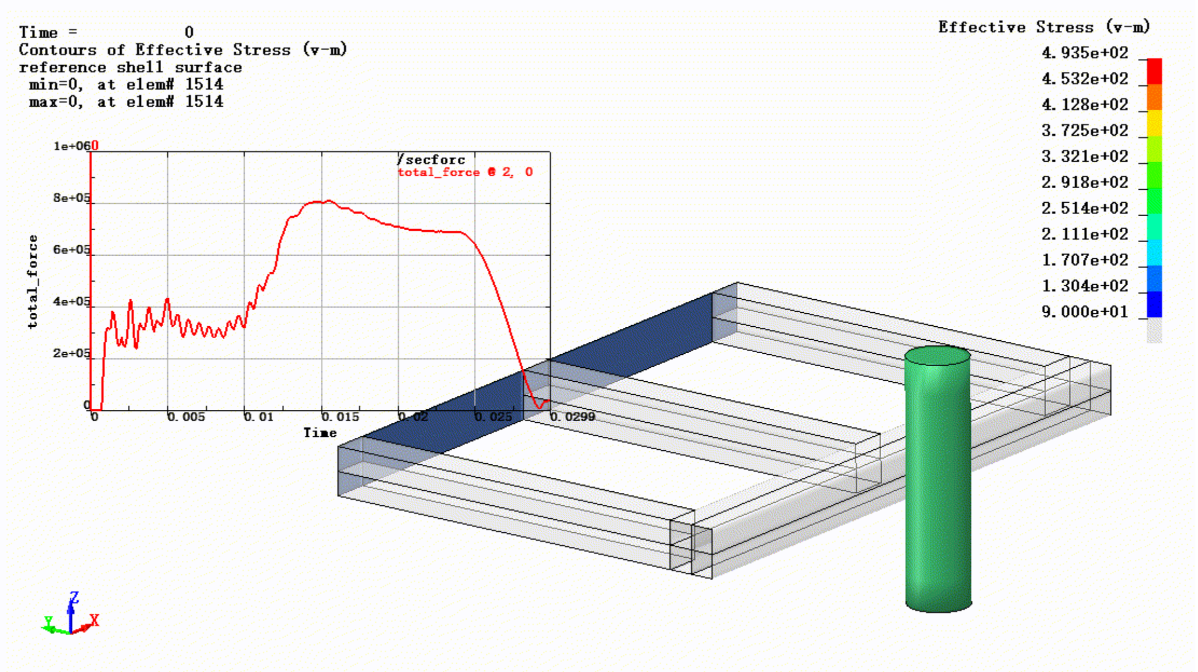


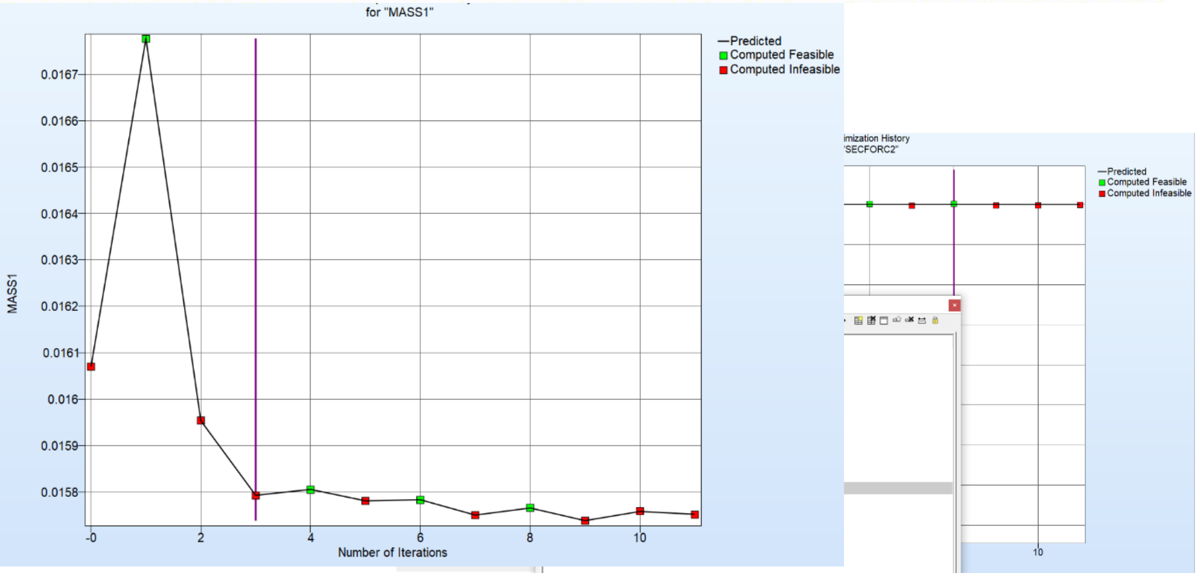
F2.Final damage with impact and random vibration

LS-OPT PACK边框挤压铝厚度优化

三个变量：零件的厚度变化
约束:截面力最大值≥800000
目标：质量最小







每个case用1个核，计算2分钟，
整个优化工程使用8个核，共花费2个小时
最终减重约2kg

焊缝案例(Mig weld)

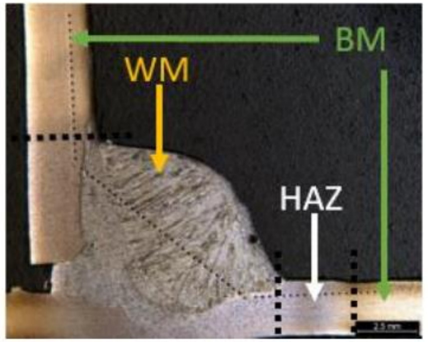


Fig. 1. Weld Zones

BM:Base Metal
WM:Weld Metal
HAZ:Heat Affected Zone

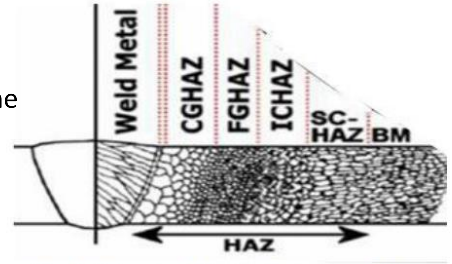


Fig. 2. Sub sets of Heat-affected zone [3]

热影响区的实际尺寸3~5mm(可用3mm网格)
硬度（Hardness）与材料强度相关
使用壳单元对母材和热影响区进行模拟
一般需要测热影响区的硬度和母材的硬度，通过对母材的gissmo进行相应的缩放得到热影响区的强度

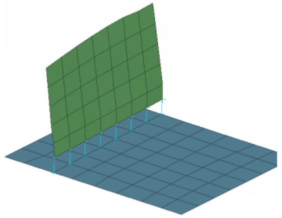


Fig. 3: MIG welds using NRBs & Beams

梁单元建模

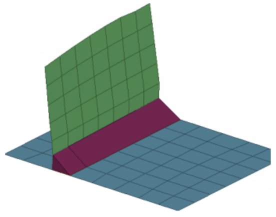


Fig. 4: MIG welds using solid elements

实体单元建模
（适合局部分析）

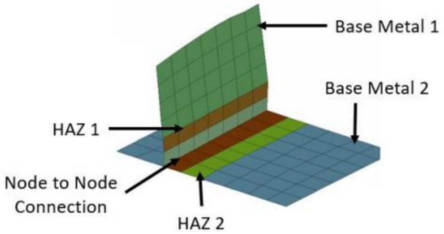


Fig. 5: Welding with HAZ representation using shell elements

壳单元建模
（适合模组或整包分析）
Weld metal设置为两倍的BM厚度

硬度与拉伸强度、屈服强度的经验公式

$$TS = \left(\frac{H}{2.9}\right)\left(\frac{n}{0.217}\right)^2$$

$$YS = \left(\frac{H}{3}\right)(0.1)^n$$

TS: Tensile strength
YS: Yield strength
H: Hardness
n: strain hardening exponent

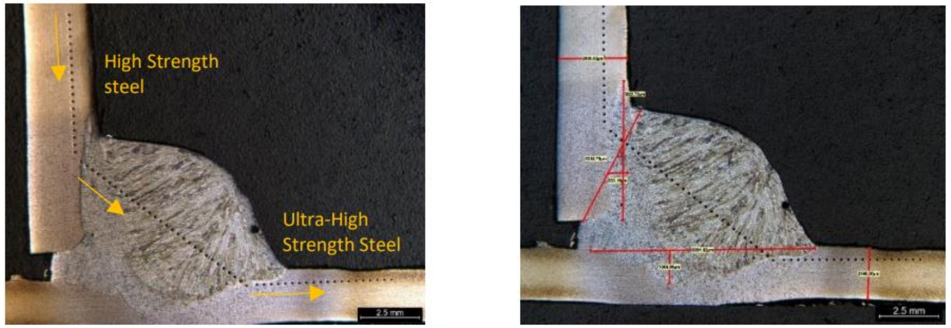


Fig. 6: Micro-Hardness Experiment at the weld joint area cross section

黑点代表硬度测试点

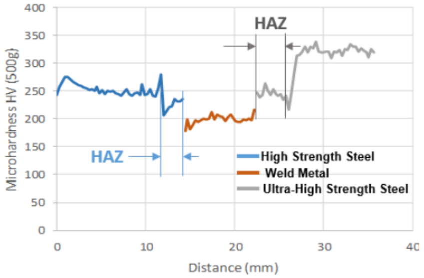


Fig. 7: Micro Hardness vs length of specimen

	Microhardness Relative to Base Metal
Material	HAZ Softening
High Strength Steel	-22%
Ultra-High Strength Steel	-33%

Table 1: HAZ Hardness relative to Base Metal

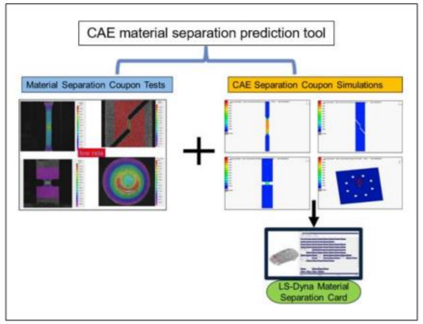
E.g.DP800,下降到70%

Emphasis on Heat Affected Zone (HAZ) Modeling Around MIG Welded Joints in Crash CAE Virtual Predictive Full Vehicle Models, 13th European LS-DYNA conference 2021

焊缝案例(Mig weld)

材料参数缩放

使用与硬度测试一致的下降比例对**应力应变曲线**（*MAT_24），**失效应变曲线**和**失稳曲线**(Gissmo)进行缩放



*MAT_24 + *MAT_ADD_EROSION(Gissmo)

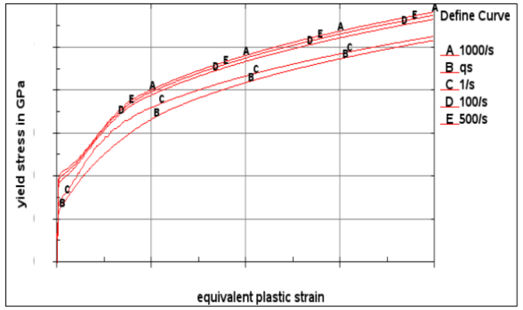


Fig.8: Typical stress-strain curve

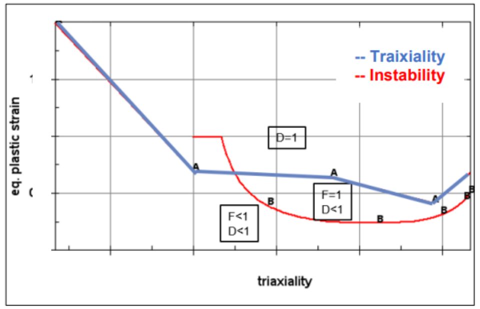
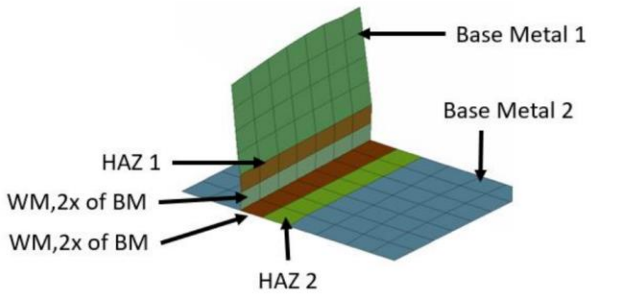
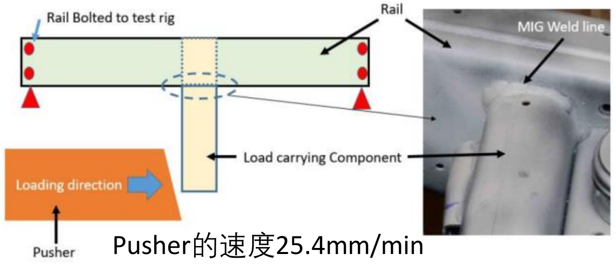


Fig.9: Typical triaxiality & instability curve .



Weld Metal(WM), HAZ and Base Metal(BM) representation using shell method

部件级验证



Pusher的速度25.4mm/min

Fig. 10: Subsystem level test set-up at FCA.

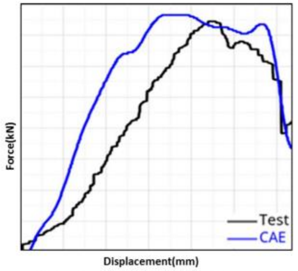
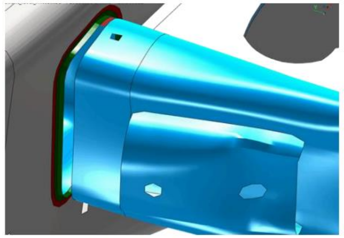


Fig.12: Test vs. CAE Prediction FD

Test



CAE Prediction

Fig.13: Component fracture at near HAZ

整车级验证（IIHS small overlap）

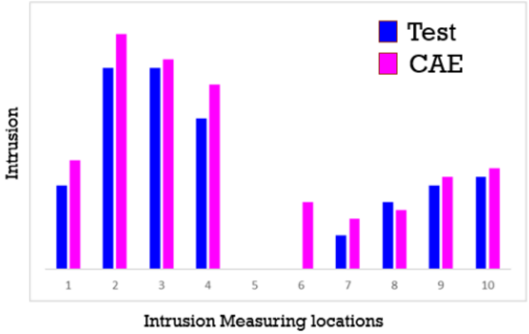


Fig.13: IIHS Structural intrusion Test vs. CAE

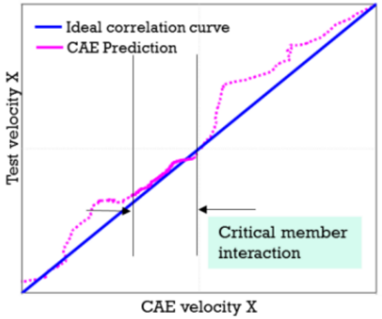


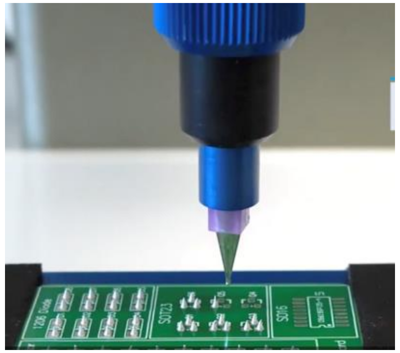
Fig. 14: Test vs CAE Velocity

Emphasis on Heat Affected Zone (HAZ) Modeling Around MIG Welded Joints in Crash CAE Virtual Predictive Full Vehicle Models, 13th European LS-DYNA conference 2021

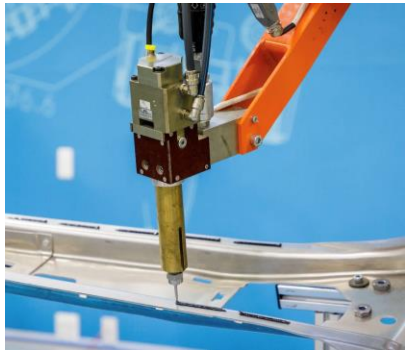
ISPG for Adhesive Fluid Dispensing and Dispersing

- 点胶技术广泛应用于汽车、电子、高科技、生物医药等行业。
- R16 full-implicit high-viscous non-Newtonian ISPG fluid can be used to model this process
  - R16中一种新的自适应细化方案来处理流体变薄效应。
  - 包括化学试剂、生物流体和工业粘合剂流体，如环氧树脂、硅树脂、锡膏和密封剂。

Adhesive dispensing examples

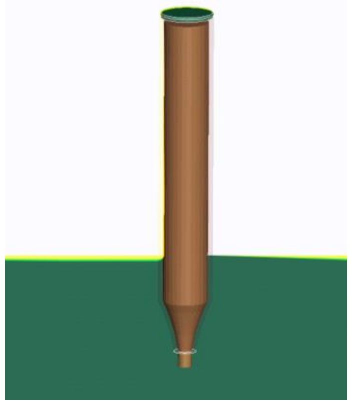


电子用导热胶
Preeflow.com



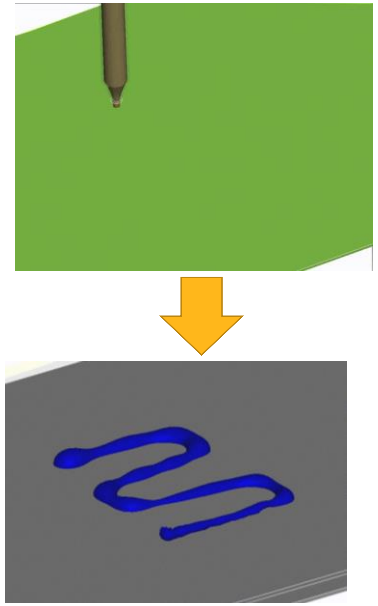
车身结构胶
Structural adhesive on car body
Henkel.com

Dispensing for
droplet deposition



Collaboration with
Ansys Pre-Sale (Ayush Kumar)

Cell side and wall bonding for EV battery packaging



AtlasCopco.com

Collaboration with ACE (Daniel Wang)

https://catalog.ansys.com/product/66e3395bdb0b6971719cb286/adaptive-ispg-act Training material of ISPG ACT

胶的流动的模拟方法开发

GOTION HIGH-TECH 国轩高科

Customer Goals

- Save money on the use of adhesive, since the amount of adhesive used is relatively large and expensive.
- Find a method with higher accuracy to reduce the number of experiments and accelerate research and development progress.
- By combining simulation technology, formulate a reasonable gluing process.

Solution

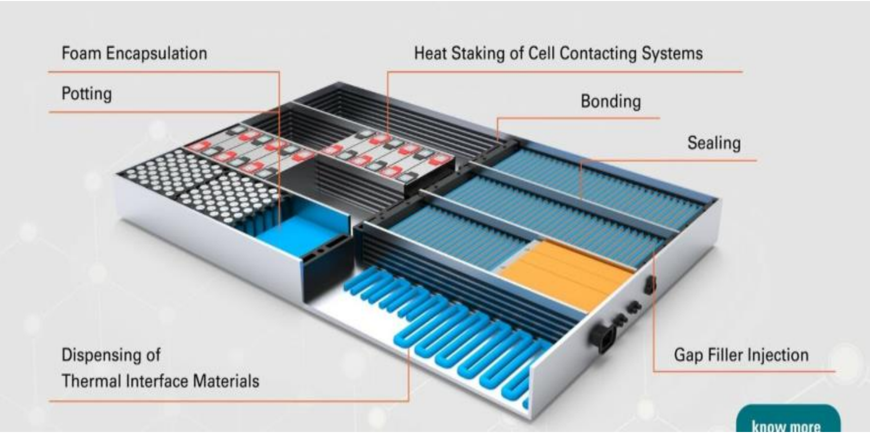
- LS-DYNA implemented the incompressible smoothed particle Galerkin method ISPG as a fluid solver,ISPG is a completely implicit calculation method,effectively solve free surface flow problems involving strong surface tension, which can accurately maintain the fluid volume.
- It could be used to solve adhesive flow well.
- Three-weekly meeting with Gotion and developer to keep closely touch with each other.

Outcome

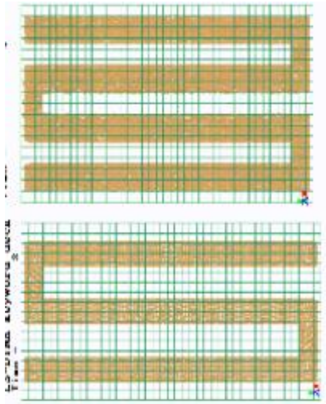
- Gotion has conducted simulation of dispensing and compressing process,and has big willing to keep making the method mature with us.
- Enhance relevant features from develops' side.
- Ansys got real adhesive simulation experience on practical customer project, strengthen relationship with Gotion.

Ansys Technology	LS-DYNA

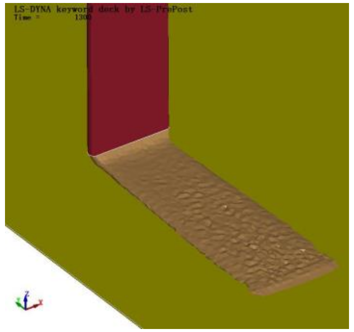
Status - Ongoing



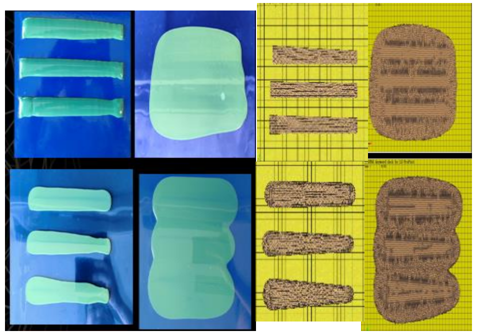
Picture from:https://www.emobility-engineering.com/battery-sealing/



compressing



dispensing



test vs simulation

Impact customers	
Account Mgr.	Yawei He
ACE Eng.	Daniel Wang
Developer	Xiaofei Pan, Jingxiao Xu

ISPG Keyword

❑ Contents in fluid.k

fluid.k   main.k   solid.k   control_implicit.k

The following keywords should be defined in fluid.k

- ✓ *ELEMENT, defines all the fluid elements (tetrahedrons)
- ✓ *NODE, define all the fluid nodes
- ✓ *PART, define fluid part
- ✓ *SECTION_ISPG, defines ISPG section
- ✓ *ISPG_MAT, defines fluid material
- ✓ *ISPG_CONTROL_ADAPTIVITY, defines adaptivity parameters for ISPG
- ✓ *ISPG_CONTROL_IMPLICIT, defines implicit parameters for ISPG
- ✓ *ISPG_BOUNDARY_SUMMETRY, for pseudo 2D (2.5D) ISPG simulation. If 3D simulation is deployed, no need to define this keyword

fluid.k

```
$# LS-DYNA Keyword file created by LS-PrePost(R) V4.10 (Beta)-30Dec2022
$# Created on Jan-24-2023 (22:33:59)
*KEYWORD
*ELEMENT
$#   eid     pid      n1      n2      n3      n4      n5      n6      n7      n8
    6507       3   70748   70754   70747   70752   70752   70752   70752   70752
    6508       3   74518   74512   74511   74514   74514   74514   74514   74514
    6510       3   75094   75087   75088   75092   75092   75092   75092   75092
```

```
*NODE
$#   nid               x               y               z      tc      rc
   69547            0.55    1.200000e-04   -1.200000e-04       0       0
   69548       0.5501397    1.200000e-04   -1.200000e-04       0       0
   69549            0.55    1.200000e-04             0.0       0       0
   69550       0.5501397    1.200000e-04             0.0       0       0
   69551            0.55             0.0   -1.200000e-04       0       0
   69552       0.5501397             0.0   -1.200000e-04       0       0
   69553            0.55             0.0             0.0       0       0
```

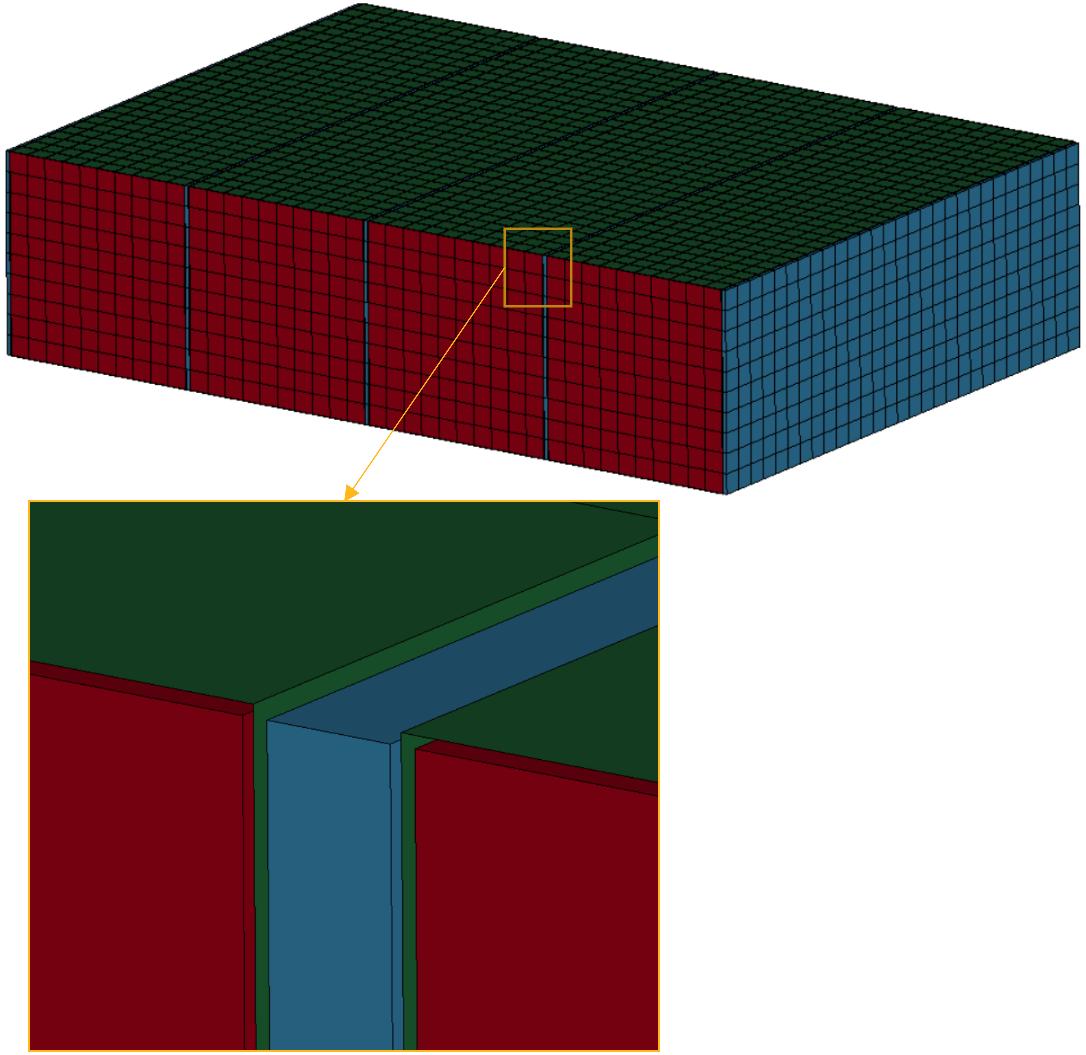
```
*PART
$#                                                                         title

$#     pid     secid       mid     eosid      hgid      grav    adpopt      tmid
         3         7         7         0         0         0         0         0
*SECTION_ISPG
$    SECID    ELFORM
         7        49         0
*ISPG_MAT_ISO_NEWTONIAN
$      MID        RO    DYNVIS     SFTEN
         7 9.9800E-7  1.15E-08  2.905E-8
*ISPG_CONTROL_ADAPTIVITY
$    align       mov    ra_scl    rd_scl  crit_anl  hard_anl   ndivmin       opt
                   2                          0.26
$     hmin     hcont

*ISPG_CONTROL_IMPLICIT
$     BETA      GAMA       CFL   MX_SUBS  MX_ITERS

*ISPG_BOUNDARY_SYMMETRY
$      dof    coord1    coord2
```

电芯间泡棉初始应力



*INITIAL_FOAM_REFERENCE_GEOMETRY
NID , X,Y,Z

*MAT_LOW_DENSITY_FOAM -> REF=1

INITIAL_FOAM_REFERENCE_GEOMETRY_*{OPTION}

Available options include:

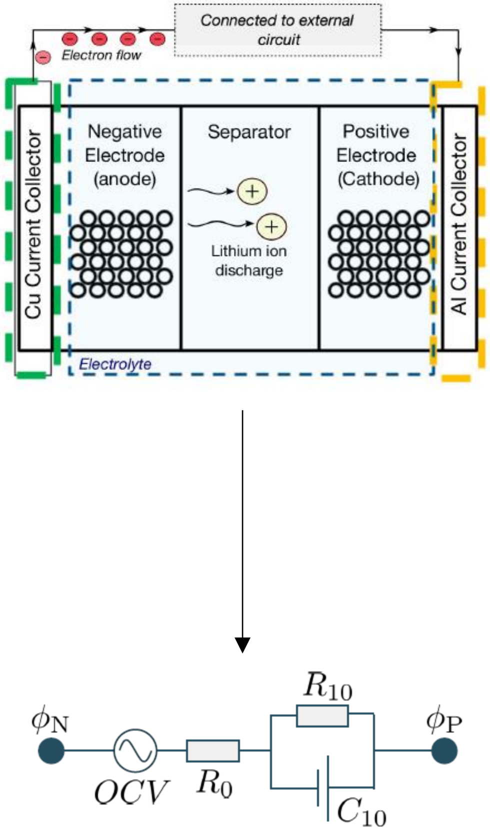
<BLANK>

RAMP

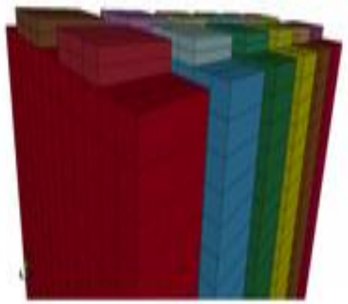
Purpose: Define the reference geometry of a foam for stress initialization. LS-DYNA initializes the stresses using the reference geometry when the REF flag is turned on in the *MAT input for the following hyperelastic material models: 2, 5, 7, 21, 23, 27, 31, 38, 57, 73, 77, 83, 132, 179, 181, 183, and 189. Supported solid elements are the constant stress hexahedron (#1), the fully integrated S/R hexahedron (#2), the tetrahedron (#10), and the pentahedron (#15). This keyword is also supported for plane strain (shell #13) and axisymmetric solid (#14 and #15) elements. With this keyword, dynamic relaxation can be avoided once a deformed configuration is obtained, usually on the first run of a particular problem.

电芯分布式等效电路

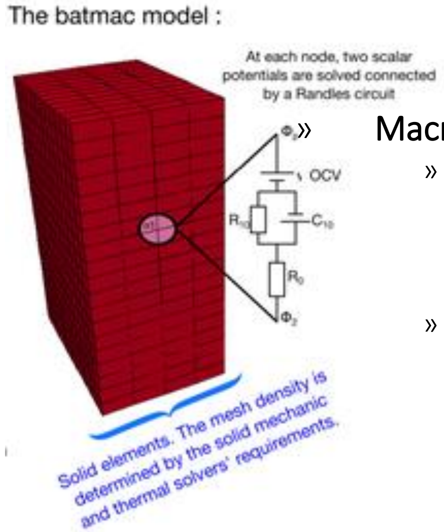
四种建模方法



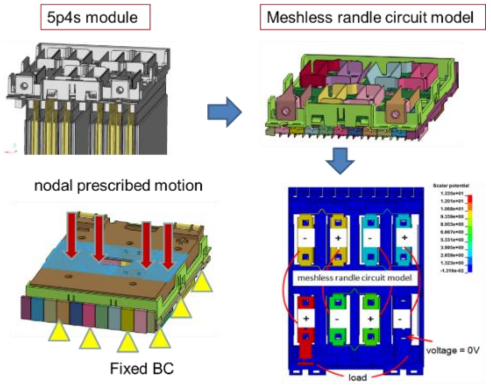
» **Solid Elements**
- » All layers are meshed as solid elements.
- » Same mesh used for Mech , EM and Thermal



» **Composite Thick Shell**
- » All layers are meshed as solid elements.
- » Same mesh used for Mech , EM and Thermal



» **Macro-model (BatMac)**
- » One (or a few) solid elements through thickness for mechanics, EM and thermal
- » 2 fields at each node (positive and negative current collectors)

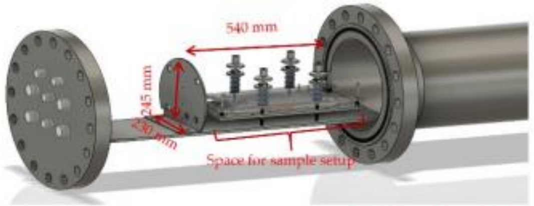


» **Meshless**
- » One single equivalent circuit for the whole cell (lumped model)

热失控实验

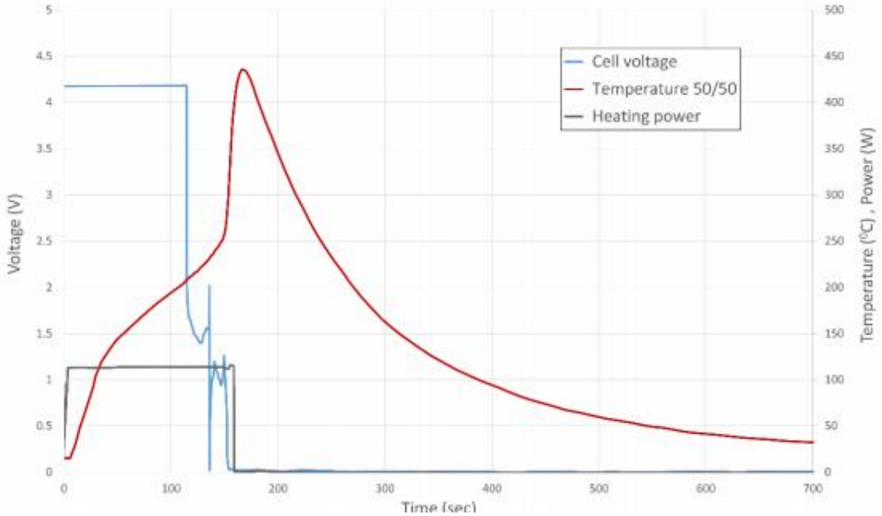
Proof of Concept

- Experimental setup
  - Heating wire is wrapped around the battery and
    - Heating power of 114 W is applied until onset of thermal runaway
  - Measurements
    - Temperature at 4 points on battery surface
      - Only point at the center of the battery is used for comparison
    - Voltage drop in battery after short

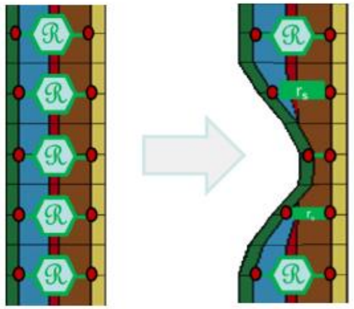


[Essl et al. 2018]

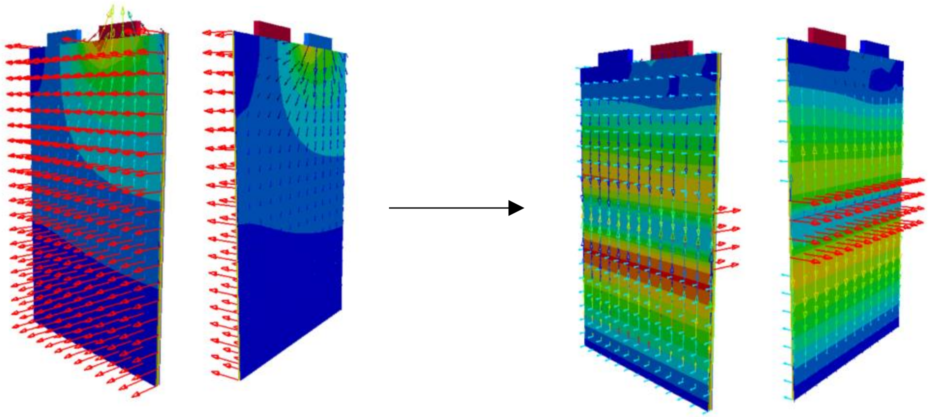
[Golubkov et al. 2018]



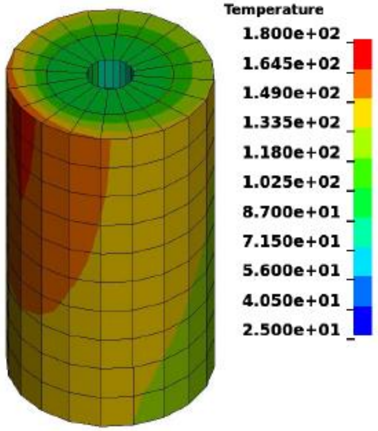
短路自定义

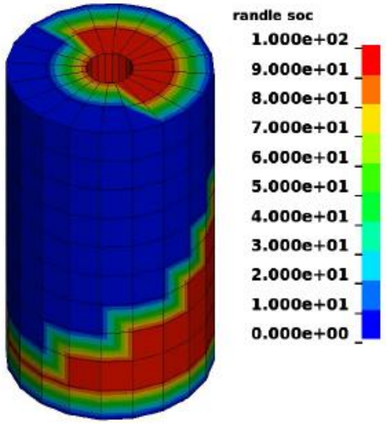


```
*EM_RANDLES_SHORT
2,501
*DEFINE_FUNCTION
501
float resistance_short_randle(float time,
                  float x_sep, float y_sep, float z_sep,
                  float x_sen, float y_sen, float z_sen,
                  float x_ccp, float y_ccp, float z_ccp,
                  float x_ccn, float y_ccn, float z_ccn)
{
 if (time > 600.) {
  if (y_sep < 0.12) {
   if (y_sep > 0.08) {
   return 0.002 ;
              }
   else {
    return -1.;
```

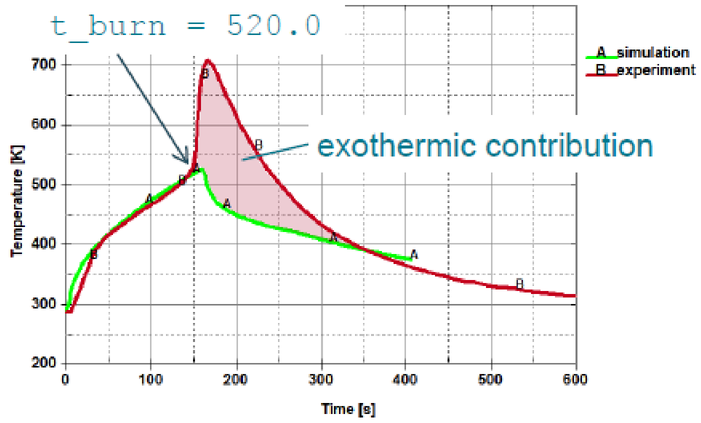


```
*EM_RANDLES_SHORT
$#areaType    functId
         3        501
*DEFINE_FUNCTION
$#      fid                   heading
        501
float resistance_short_randle(float time,
                              float temp)  {
  if (temp >= 273.0 + 180.0)  {
    return 0.1;
  }else {
    return -0.1;
  }
}
```





热失控自定义




```
*EM_RANDLES_EXOTHERMIC_REACTION
$#areaType   functId
         2       511
*DEFINE_FUNCTION
$#      fid                    heading
        511
float exothermic_reaction_randle(float time,
                                 float temp,
                                 float H_ex) {
  float t_burn = 273.0 + 247.0;
  float H_max  = 2.4;
  if (temp > t_burn && H_ex < H_max) {
    return &hexo*H_releaseVsT(temp-t_burn+offset);
  } else {
    return 0.0;
}}
*DEFINE_FUNCTION_TABULATED
$#      fid
        512
$# title
H_releaseVsT
$#       Temperature          H_release
               0.000             0.0010
               7.198             0.0057
               14.89             0.0194
                 …                  …
```

definition of exothermic release rate

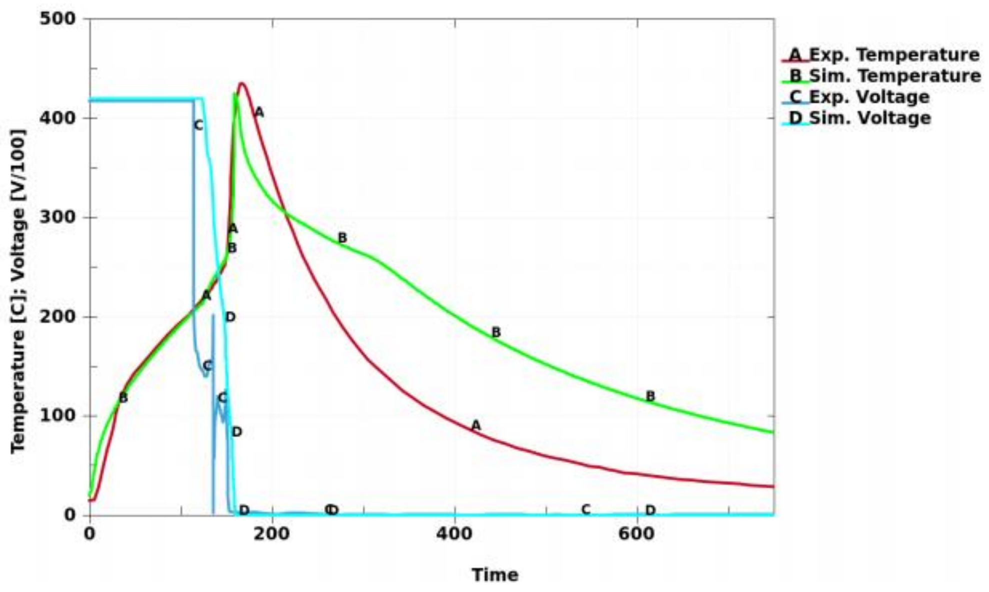
ignition temperature

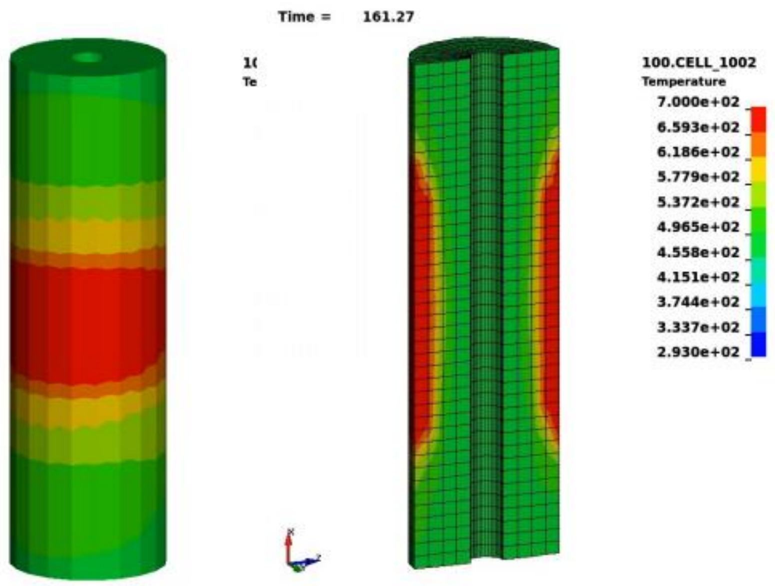
max. accumulated energy

burn only if ignition temp. t_burn is reached and not fully decomposed yet

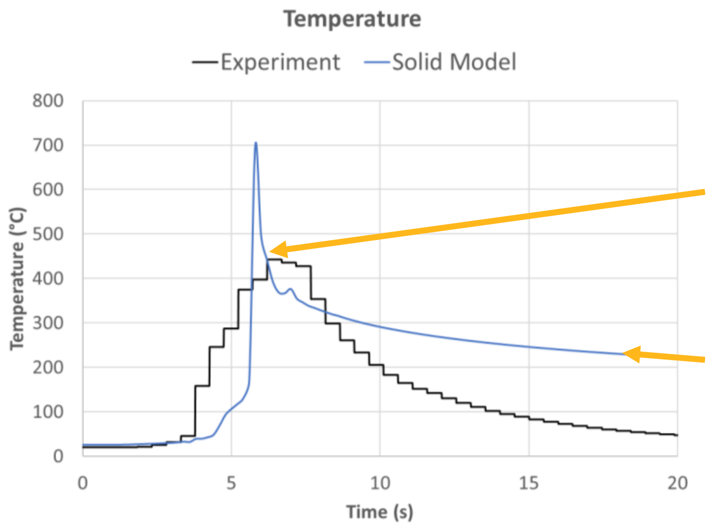
activation offset

tune T_burn, H_max, &hexo, offset to match experimental results



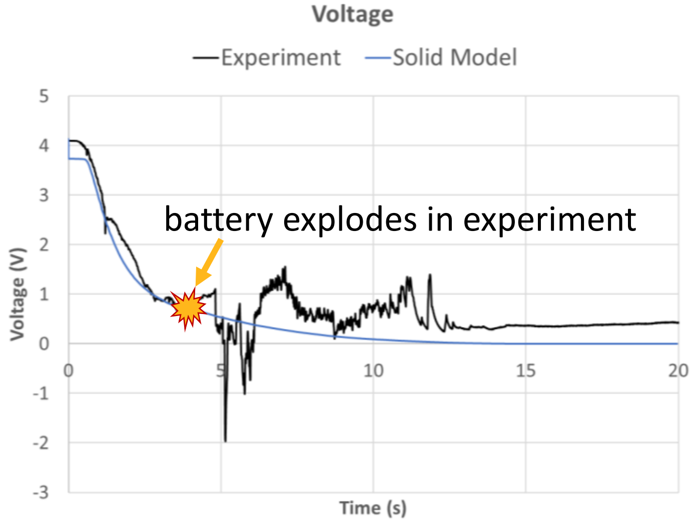


微观模型验证

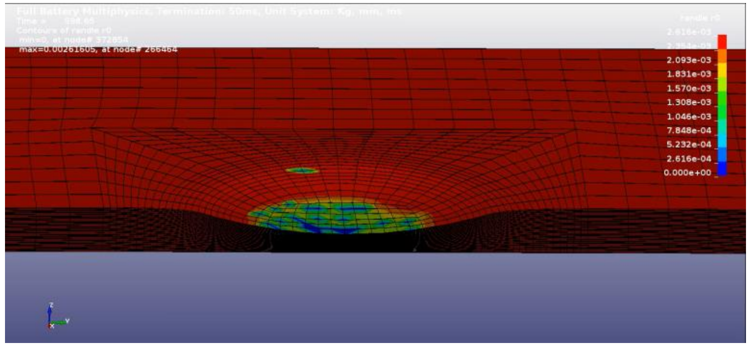


Correctly predicted the thermal runaway timing. Lack of combustion modelling and thermal BCs could explain the difference in slope.

Hard to capture thermal BCs



Runtime- 11hrs 50 minutes (224CPUs)



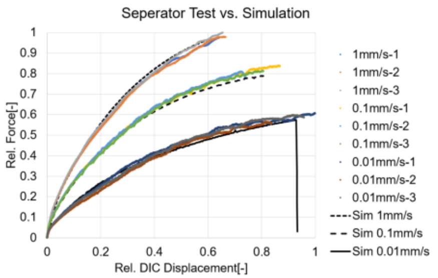
Battery short

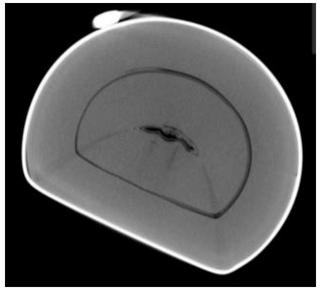
COMET-Project

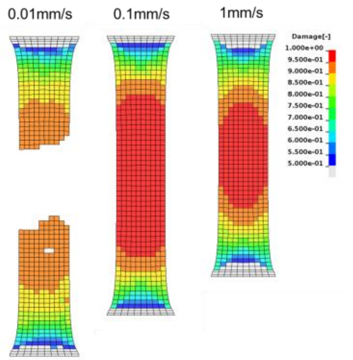
Structural only

Single component

Full cell







The research work was performed within the framework of the COMET-project "Ensuring System Reliability via Battery Cell Simulation" (Project no.: VII-3.04a) at the Polymer Competence Center Leoben GmbH (PCCL, Austria) within the framework of the COMET-program of the Federal Ministry for Transport, Innovation and Technology and the Federal Ministry of Digital and Economic Affairs with contributions by Hilti AG, 4a Engineering GmbH, Dynamore GmbH and Montanuniversität Leoben. The PCCL is funded by the Austrian Government and the State Governments of Styria, Lower Austria and Upper Austria.

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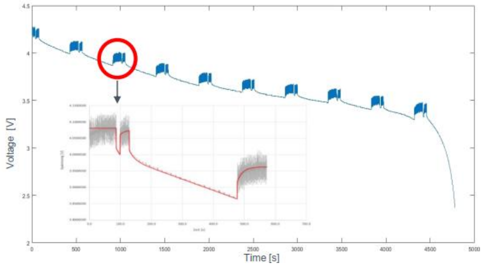
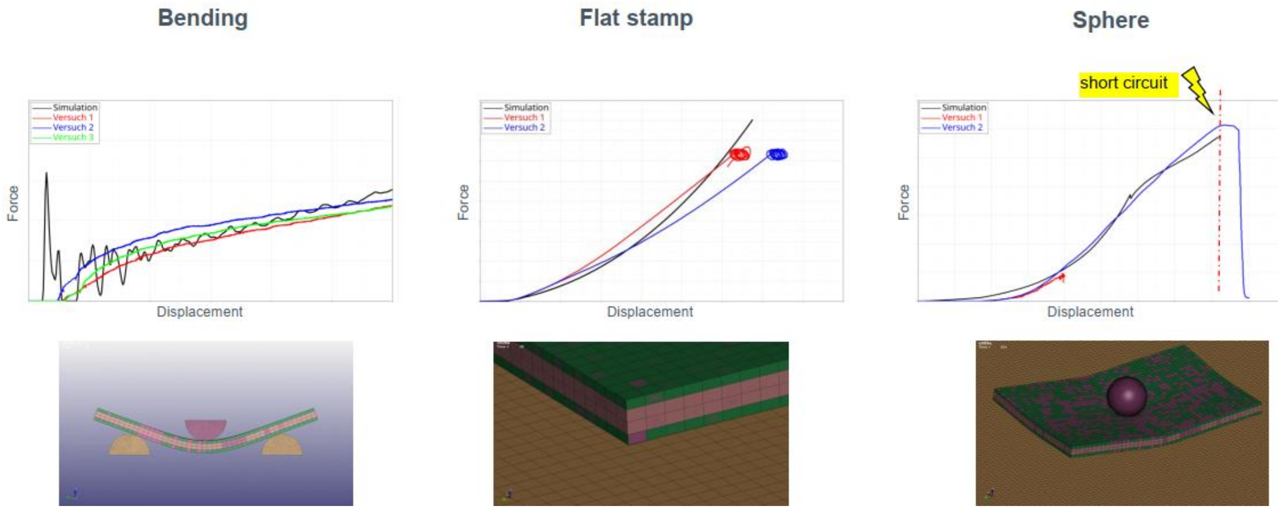
多物理场挤压国外其他案例

BATTERYMODEL FOR FULL VEHICLE SIMULATION
ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

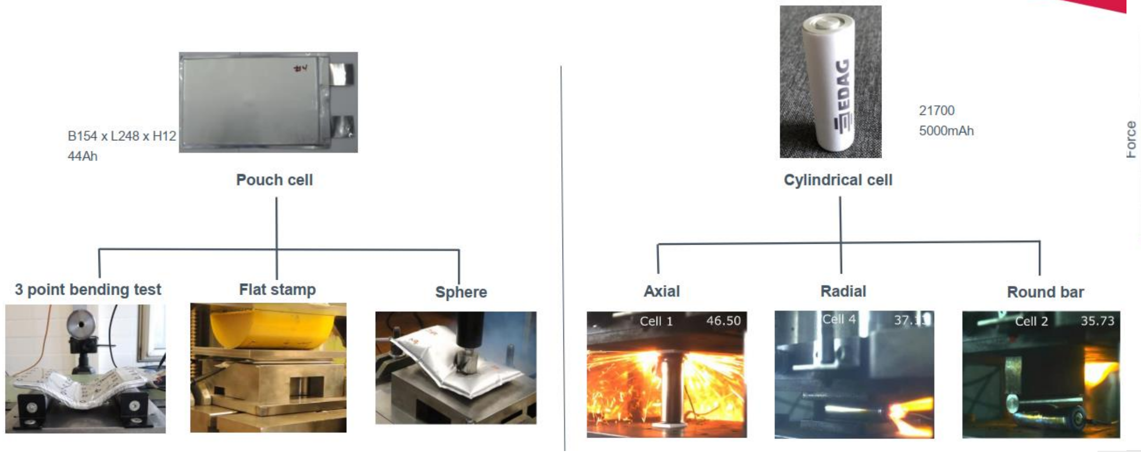
B154 x L248 x H12
44Ah

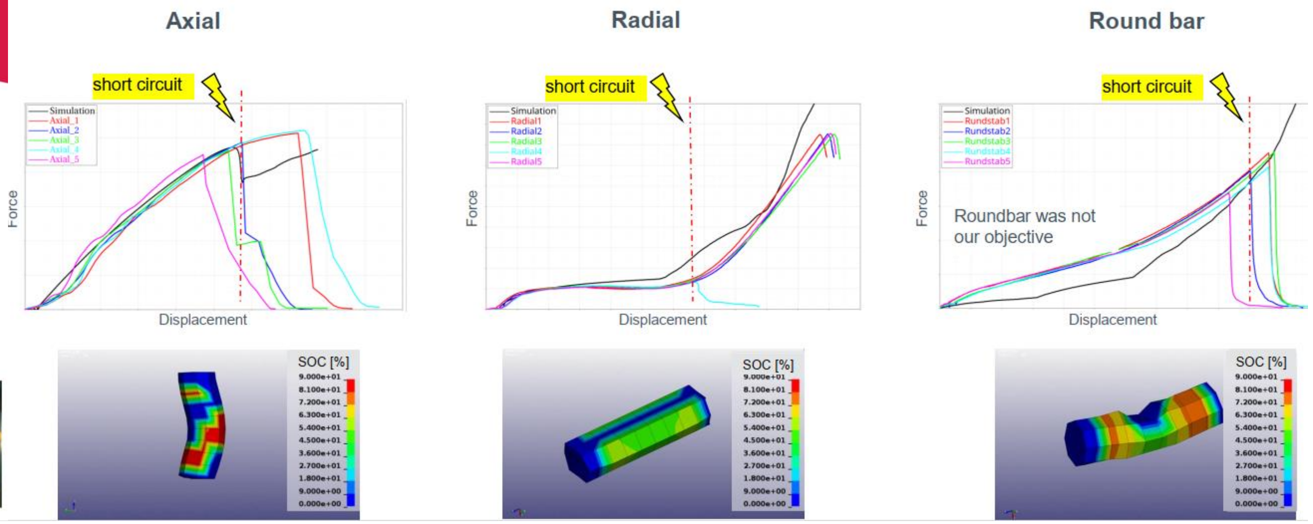
- Cell model: LC-44 Litacell
- Electrochemical impedance spectroscopy every 10% State of Charge (SoC)
  - Test sequence of discharge cycles (from 100% to 10%) and rest phases
- Determination of the characteristic values for the equivalent circuit diagram
  - Characteristic values were subsequently adjusted using a curve fitting method in Matlab





BATTERYMODEL FOR FULL VEHICLE SIMULATION
TESTS FOR VALIDATION





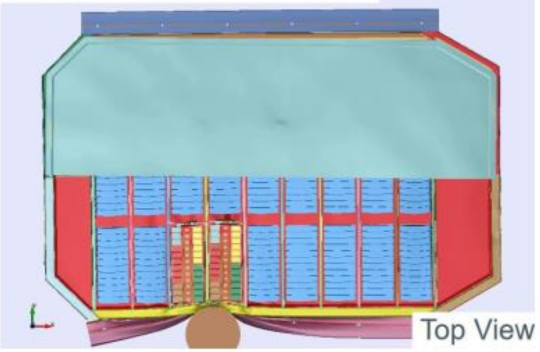
多物理场挤压国外其他案例

BATTERYMODEL FOR FULL VEHICLE SIMULATION
EM SIMULATION OF BATTERY PACK

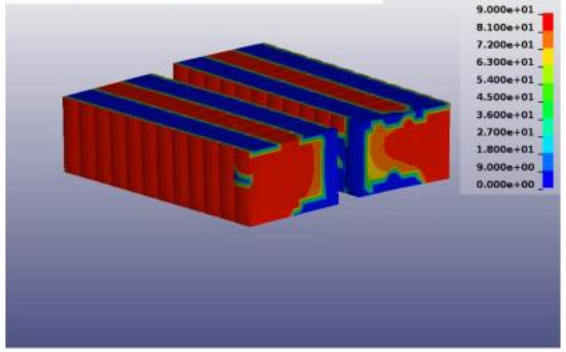
- Design of a battery with 100 electrically simulated prismatic cells
- Use of the Randles Batmac Model
- Model size ~1,500,000 elements for the electrical cells
- Parameters determined by electrochemical impedance spectroscopy
- Mechanical behavior from an adapted pouch cell model
- Computing time ~ 10h for 80ms on 96 CPU strongly dependent on EM time step

➢ Successful detection of the short circuit

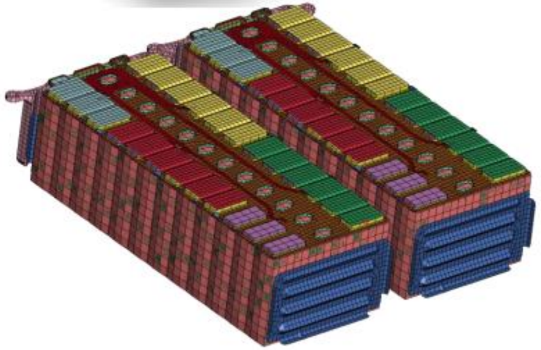
Example from EDAG SCALEbat



Example from EDAG SCALEbat



EDAG SCALEbat



电芯部分：150万单元
仿真时间：80ms
使用96cores用时10hours

Benefits in the Project for a B-Segment car:

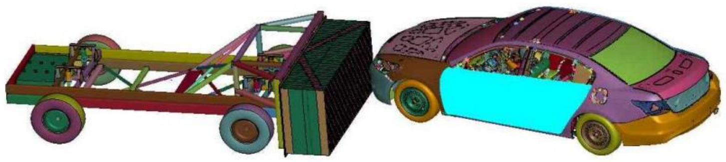
➢ Increase Vehicle Range:
  ➢ + 50km WLTP (13%)
➢ Reduce Frame Weight:
  ➢ - 20kg (-33%) on the crash parts of battery frame

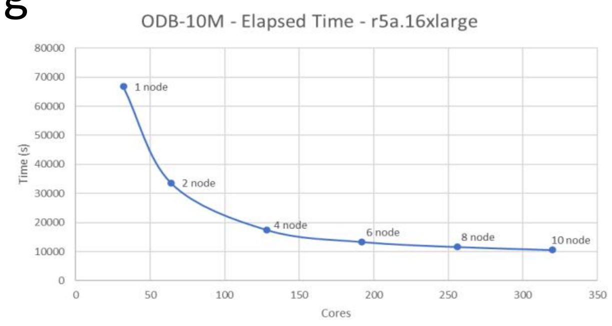
并行计算

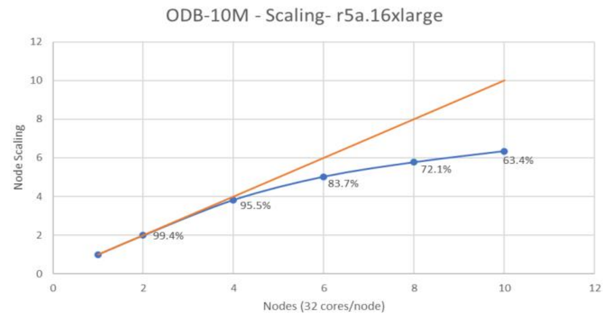
LS-DYNA AWS Cluster Benchmarking

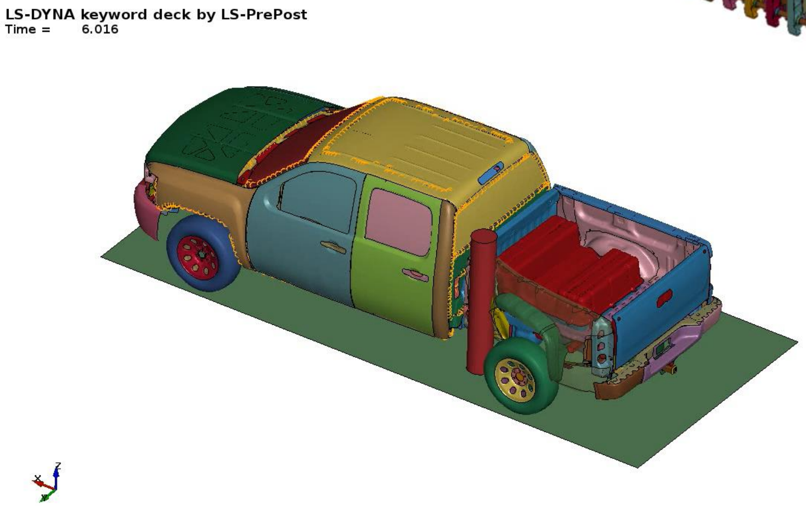
- Benchmarking example: ODB-10M – 10 million elements
- AWS instance: r5a.16xlarge (32 core/node) - AMD EPYC 7571
- Good Performance with unideal (temporary) Cluster settings
  - EFA: **no** Fabric: **tcp** Hyperthreading: **on**
- Performance expected to improve once EFA is live on Ansys Gateway
  - EFA: **yes** Fabric: **ofi** Hyperthreading: **off**

nodes	cores	elapsed time	speedup	efficiency
1	32	18 hrs 33 min 23 sec	1	1
2	64	9 hours 20 min 12 sec	1.987474711	0.993737356
4	128	4 hrs 51 min 20 sec	3.821681922	0.955420481
6	192	3 hours 41 min 38 sec	5.023537374	0.837256229
8	256	3 hours 12 min 56 sec	5.770818936	0.721352367
10	320	2 hours 55 mins 31 sec	6.343462159	0.634346216





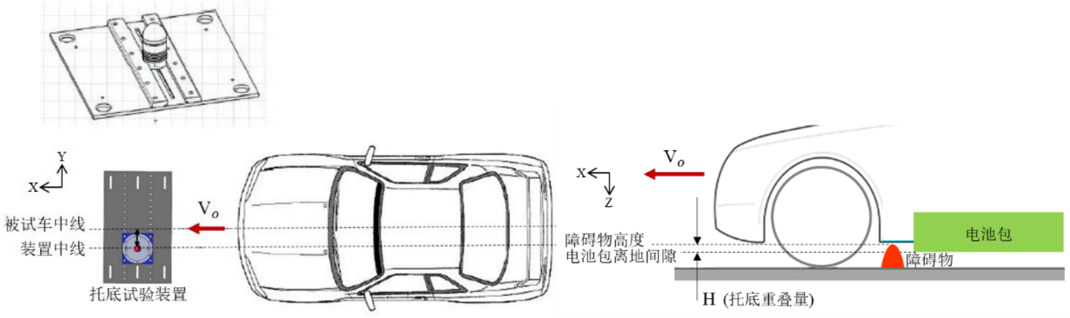




- 柱碰 56 kph
- Open-Source Vehicle model from NHTSA
- Battery integration made by Ansys
- 计算时间 – 5 hours (224 CPUs)
- 物理时间: 6秒

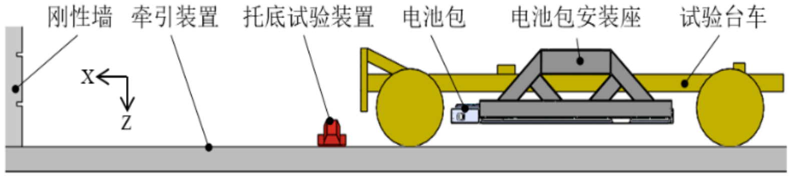
Ansys

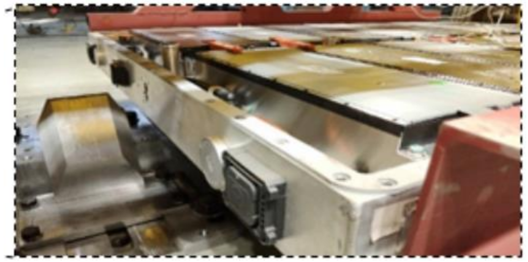
刮底

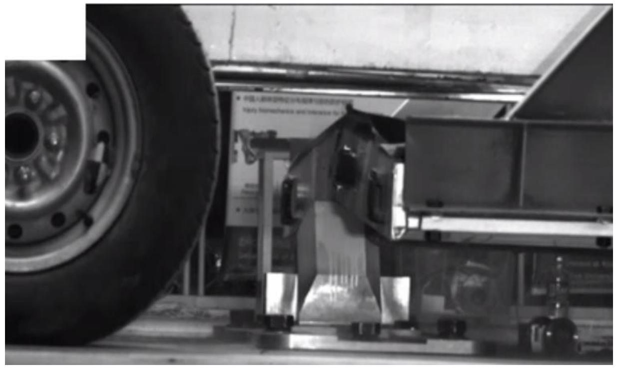


测试介绍

C-NAP2024
半球形障碍物
直径：150mm，45号钢
重叠量：30mm
前进：30km/h
后退：5km/h

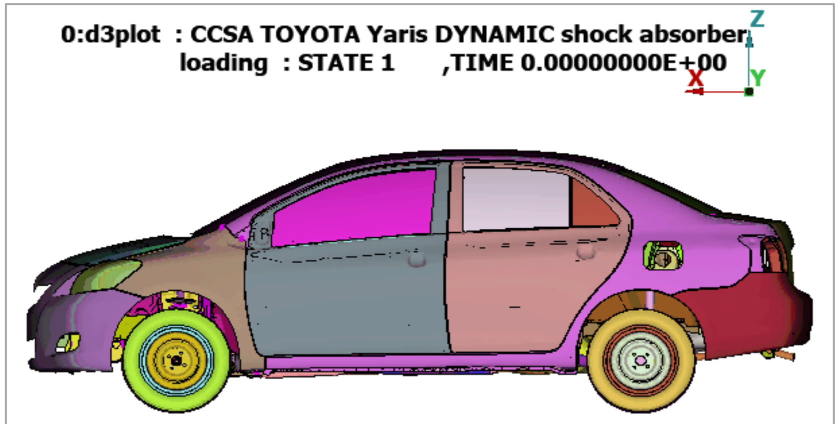






仿真评价标准

1. 液冷板不向内破裂
2. 电芯不变形 或 变形量小于某个值
3. 箱体的密封面完好



整车静态平衡仿真

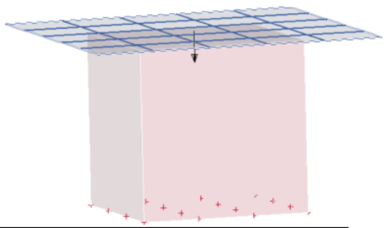
https://www.auto-testing.net/news/show-114952.html

Ansys

电池包仿真中的接触经验

使用挤压力作为终止计算条件

Crush_contact_force_as_termination.k
对接触力进行光滑过滤处理



```
*CONTROL_TERMINATION
$       0.1          0        0.0        0.0        0.0
$#   endtim     endcyc      dtmin     endeng     endmas      nosol
       0.05          0        0.0       0.01.000000E8          0
```

需要定义一个接触力传感器

```
*CONTACT_FORCE_TRANSDUCER_PENALTY_ID
$#      cid
        101
```

定义光滑或过滤
如将0.001时间段内的数据做平均

```
*DEFINE_FILTER
$#       id
         10
$#     type     data1     data2     data3     data4     data5
CONTINUOUSAVG       0.001
```

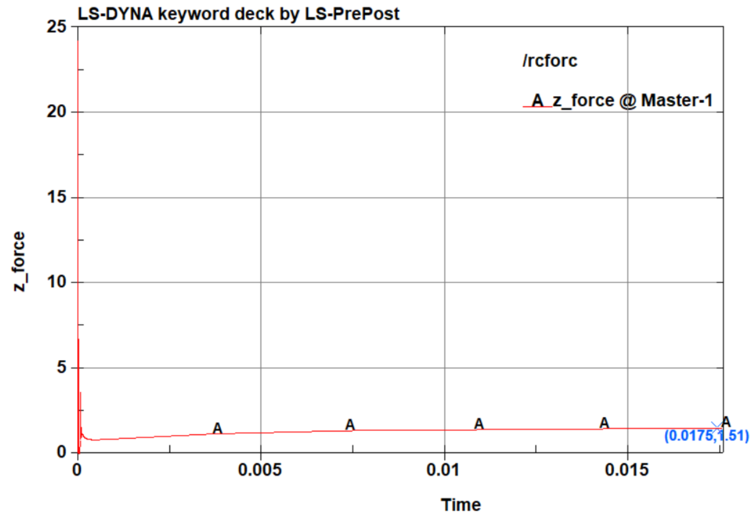
定义接触力检测

```
*SENSOR_DEFINE_FORCE
$#   sensid     ftype     typeid        vid        crd
          1CONTACT           101Z                    0
```

接触力大于1.5开始切换

```
*SENSOR_SWITCH
$#   switid      type     sensid      logic      value    filtrid
          1SENSOR          1GT                     1.5         10
```

```
*TERMINATION_SENSOR
$#     swid
          1
```




```
estimated total cpu time          =         0 sec (       0 hrs  0 mins)
estimated cpu time to complete    =         0 sec (       0 hrs  0 mins)
estimated total clock time        =        54 sec (       0 hrs  0 mins)
estimated clock time to complete  =        54 sec (       0 hrs  0 mins)
termination time                  = 5.000E-02
    1625 t 3.9976E-03 dt 2.43E-06 write d3plot file          07/18/23 12:09:01
    3297 t 7.9999E-03 dt 2.36E-06 write d3plot file          07/18/23 12:09:02
    5000 t 1.1957E-02 dt 2.29E-06 flush i/o buffers          07/18/23 12:09:02
    5018 t 1.1998E-02 dt 2.29E-06 write d3plot file          07/18/23 12:09:02
    6796 t 1.6000E-02 dt 2.21E-06 write d3plot file          07/18/23 12:09:02

*** termination due to sensor_switch 1 ***
    7526 t 1.7607E-02 dt 2.18E-06 write d3dump01 file        07/18/23 12:09:02
    7526 t 1.7607E-02 dt 2.18E-06 flush i/o buffers          07/18/23 12:09:02
    7526 t 1.7607E-02 dt 2.18E-06 write d3plot file          07/18/23 12:09:02

N o r m a l    t e r m i n a t i o n                         07/18/23 12:09:02

Memory required to complete solution (memory=    273K memory2=     4582)
          Minimum     4582 on processor      0
          Maximum     4582 on processor      0
          Average     4582
```

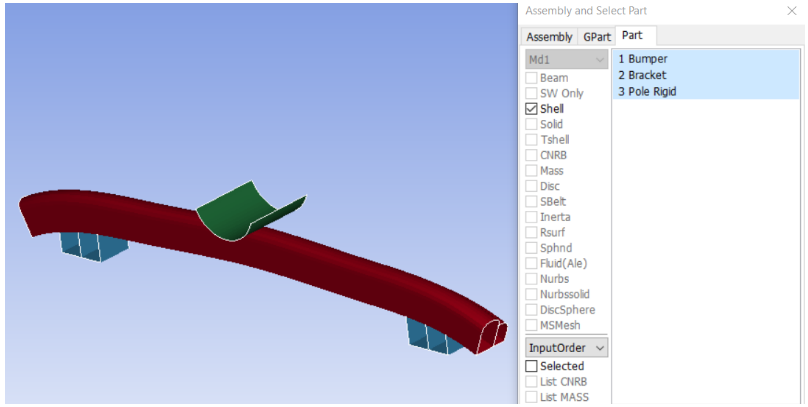
电池包仿真中的部分接触调试经验

- *PART_CONTACT->SFT=0.95
- TIE接触与Automatic Single Surface
  （接触定义不重复或改成有个0.1mm的间隙）
- 对于软材料，Tie推荐用constrained_offset_MPP
- VDC=20
- Automatic_single_surface ->soft=2 depth=5 sbopt=3

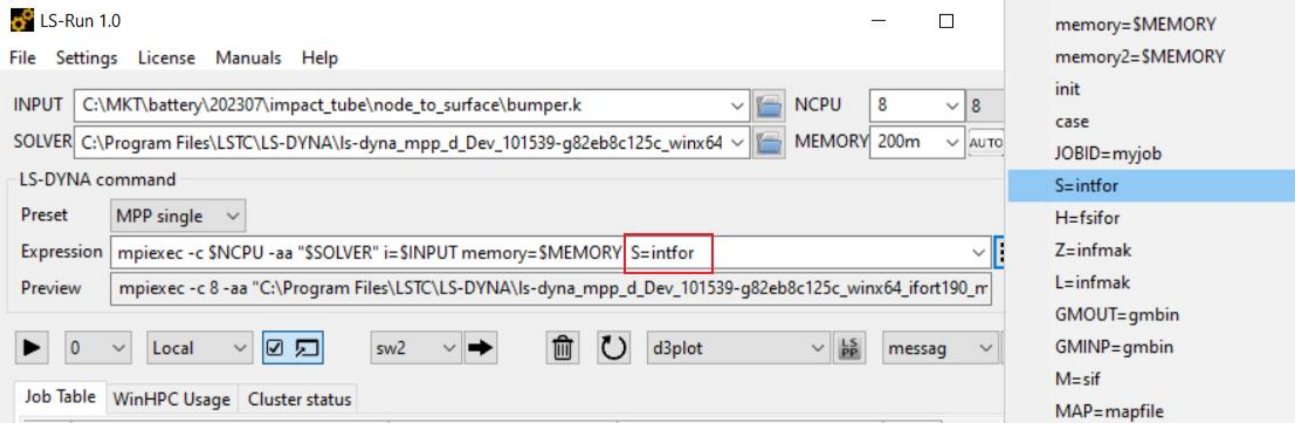
图片来源：新能源汽车动力电池的发展趋势_搜狐汽车_搜狐网

接触节点力前处理输出设置

```
*CONTACT_AUTOMATIC_NODES_TO_SURFACE
$#     cid                                                                 title
$#   surfa     surfb  surfatyp  surfbtyp   saboxid   sbboxid      sapr      sbpr
         1         3         3         3         0         0         1         1
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
     0.1       0.1       0.0       0.0       0.0         0       0.01.00000E20
$#    sfsa      sfsb      sast      sbst     sfsat     sfsbt       fsf       vsf
     1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         0       0.1         0     1.025         0         2         0         1
$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
     0.0         0         0         1         0         0       0.0       0.0
```



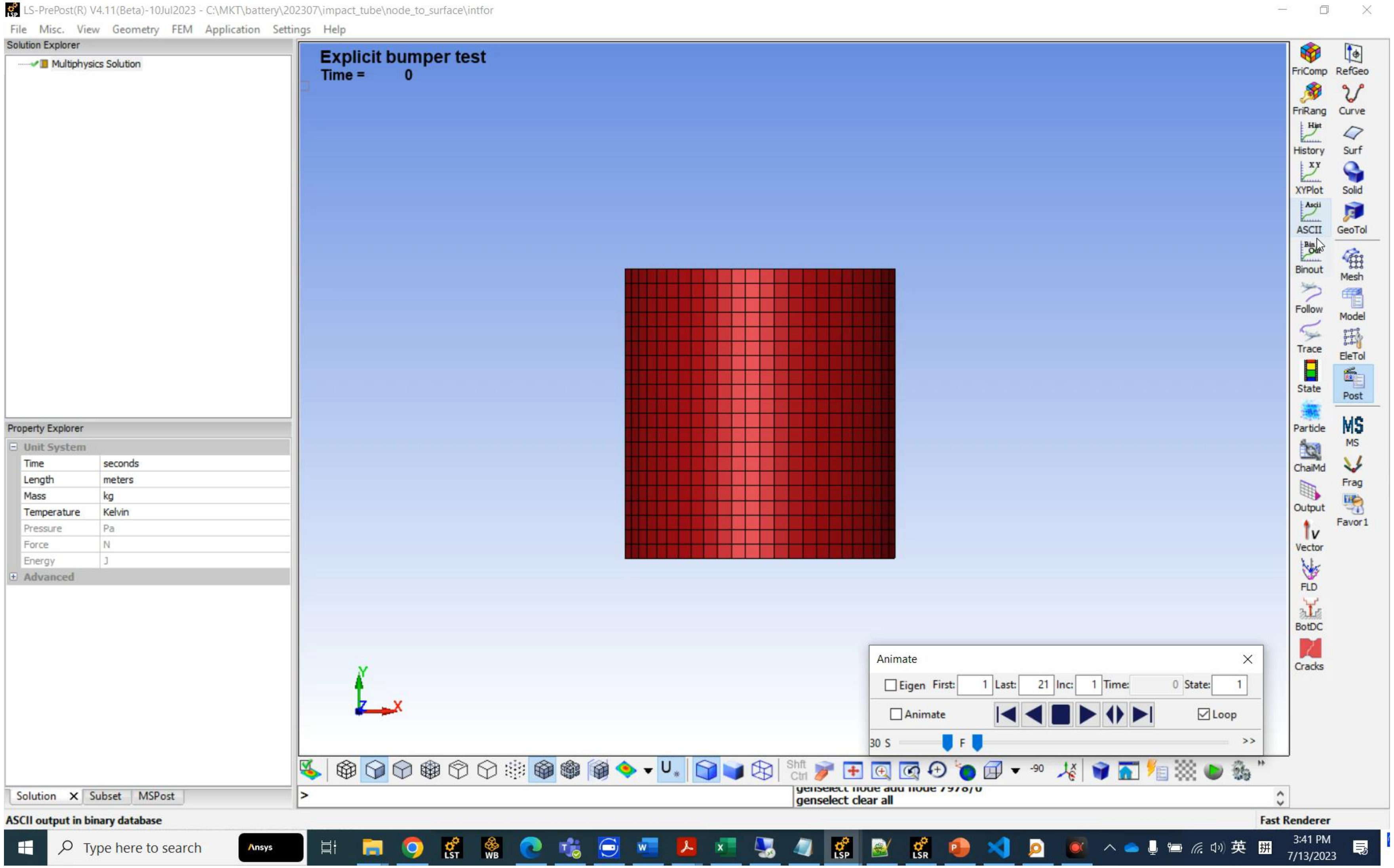

```
*DATABASE_BINARY_INTFOR
$#      dt      lcdt      beam     npltc    psetid
       1.0         0         0         0         0
```



适用的接触类型:

- Surface to surface
- Node to surface
- Single surface
- General
- Tied

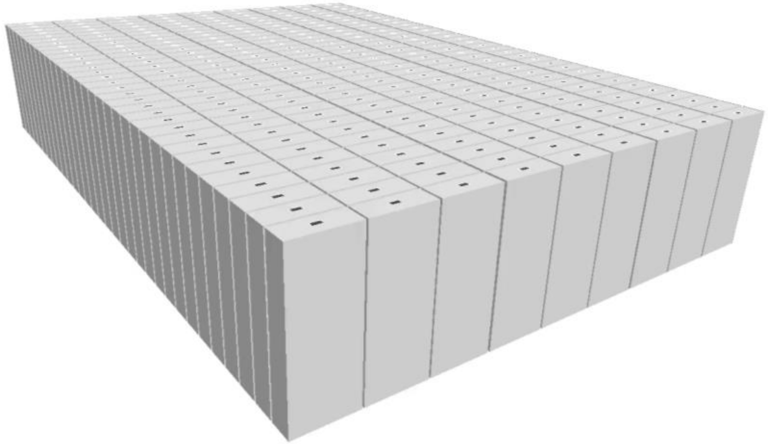
接触节点力后处理过程

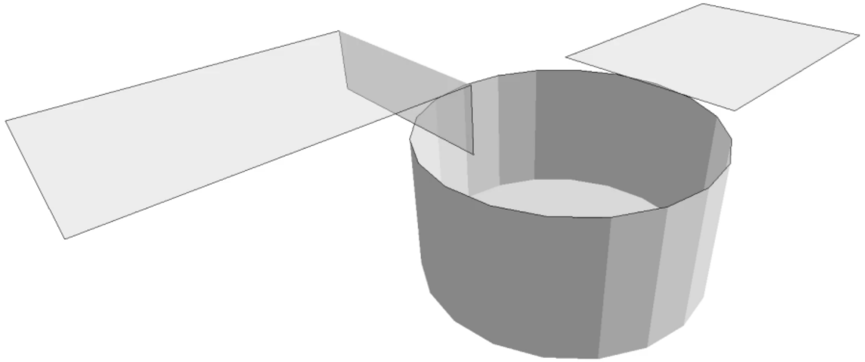


LS-PrePost(R) V4.11(Beta)-10Jul2023 - C:\MKT\battery\202307\impact_tube\node_to_surface\intfor
File Misc. View Geometry FEM Application Settings Help
Solution Explorer
Multiphysics Solution
Explicit bumper test
Time = 0
Property Explorer
Unit System
Time seconds
Length meters
Mass kg
Temperature Kelvin
Pressure Pa
Force N
Energy J
Advanced
Animate
Eigen First: 1 Last: 21 Inc: 1 Time: 0 State: 1
Animate
Loop
FriComp RefGeo FriRang Curve History Surf XYPlot Solid ASCII GeoTol Binout Mesh Follow Model Trace EleTol State Post Particle MS ChaiMd Frag Output Favor1 Vector FLD BotDC Cracks
genselect clear all
ASCII output in binary database
Fast Renderer
Solution Subset MSPost
Type here to search
3:41 PM
7/13/2023

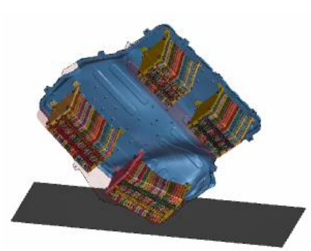
热接触功能增强(R16)

- Single surface接触定义可用于简化定义步骤
  - 可用于电池包热失控
  - 1 个Single surface接触就足够了， 而不是 ~100 个Surface to Surface接触
- 支持热的边接触
  - 可用于Single surface接触
  - 可用于电池包的接触

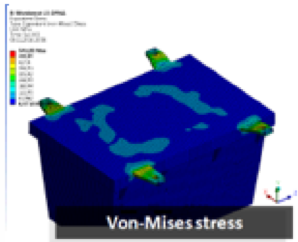




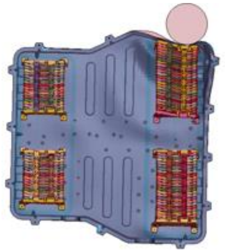
总结：LS-DYNA锂电池应用



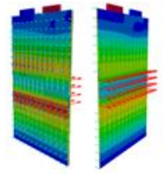
跌落分析



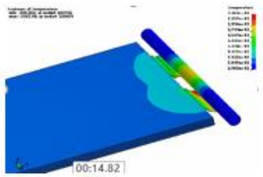
冲击分析



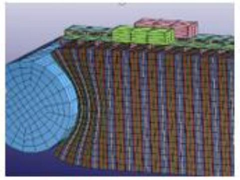
挤压分析



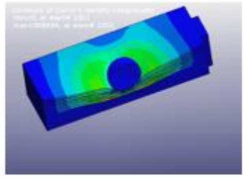
内短路电流云图



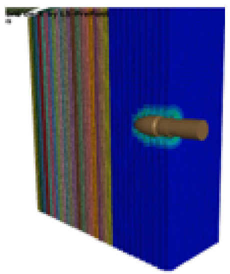
外短路温度云图

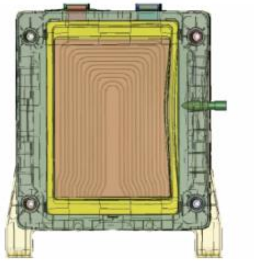


挤压多物理场分析

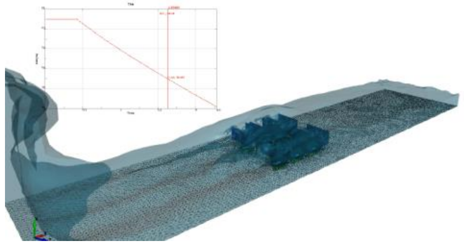


球击电流密度云图





针刺电流密度云图



水中短路SOC变化

可以应用在

- 电芯\模组\电池包级别的冲击、跌落、挤压等大变形工况
- 多次冲击、多次跌落损伤累计
- 橡胶大变形、胶粘大变形
- 多物理场挤压、针刺、水中短路
- 冲击后的残余应力和损伤对随机振动的影响
- 卷绕分析

优势

- LS-DYNA使用一个模型可以同时求解结构-热-电磁（EM）等多方面的多物理场问题，可以应用在锂电池的挤压、针刺、球击、遇水短路等工况，可一次性得到结构变形信息、热信息、电流电压及SOC剩余载荷等信息；
- 开放接触电阻、短路机制、热失控机制等接口，用户在模型中使用C语言方便自定义模型；
- 完善的断裂仿真方案：材料应变率效应、gissmo断裂损伤模型、断裂参数优化方法、SPG高精度不删网格的伽辽金断裂模拟方法；
- 集成短纤维材料映射到碰撞模型；
- 具有EFG算法可以模拟橡胶等柔性物体的极度大变形，易于收敛；
- 锂电池行业LS-DYNA用户众多，便于经验交流。

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