Applus IDIADA

Non-Isochoric Plasticity Assessment for Accurate Crashworthiness CAE Analysis

Application to SAMP-1 and SAMP-Light

OCTOBER 2021

PUBLIC

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WHO WE ARE & WHAT WE DO

Applus IDIADA is an engineering partner to the automotive industry providing complete solutions for product development projects worldwide

OUR ASSETS

2.500
PROFESSIONALS

FIRST CLASS
STATE-OF-THE-ART
TESTING FACILITIES

22 COUNTRIES
56 LOCAL OFFICES

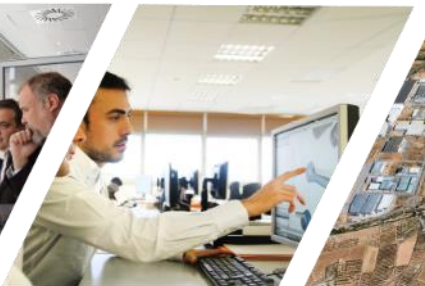
CONSTANT
INNOVATION
IN NEW SERVICES
AND TECHNOLOGIES

COMPLETE SOLUTIONS FOR AUTOMOTIVE ENGINEERING

PROJECT MANAGEMENT

KNOW-HOW IN ALL VEHICLE FUNCTIONALITIES

TESTING AND CAD & CAE TOOLS



STRENGTHENED INTERNATIONAL ORGANIZATION

A single organization able to adapt its international resources to meet each project needs

2.500
PEOPLE WORLDWIDE

USA

BRAZIL

SPAIN

GERMANY

CZECH REPUBLIC

UNITED KINGDOM

INDIA

CHINA

OTHER LOCATIONS: BELGIUM · FRANCE · ITALY · JAPAN · MALAYSIA · MEXICO · POLAND · RUSSIA · SLOVAKIA · SOUTH KOREA · SWEDEN · TAIWAN · THAILAND · TURKEY

DEVELOPMENT LED BY VEHICLE FUNCTIONALITIES

MAIN VEHICLE FUNCTIONALITIES

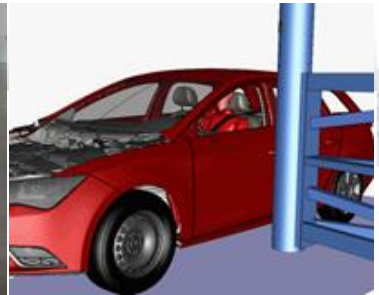
PASSIVE SAFETY · ACTIVE SAFETY · NVH · POWERTRAIN · COMFORT · RELIABILITY

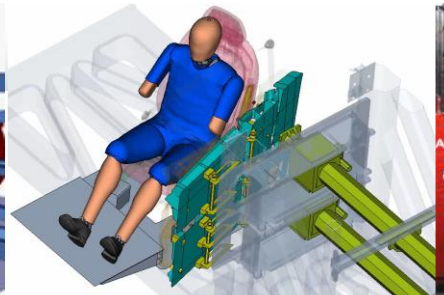
BODY + CLOSURES + TRIMS + CHASSIS + POWERTRAIN + ELECTRONICS

Body & Passive Safety

- 900+ professionals, covering CAx, functional integration & project management
- Laboratories in Europe and the USA for crash, restraint system, pedestrian protection and BiW testing (1.000 crashes/year, 650 sleds/year, 5.000 impacts/year)
- Engineering teams providing more than 1 million hours/year for design and virtual simulation

USA • Mexico • Brazil • Spain • Italy • France • UK • Belgium • Germany
Czech Republic • Russia • India • China • South Korea • Japan





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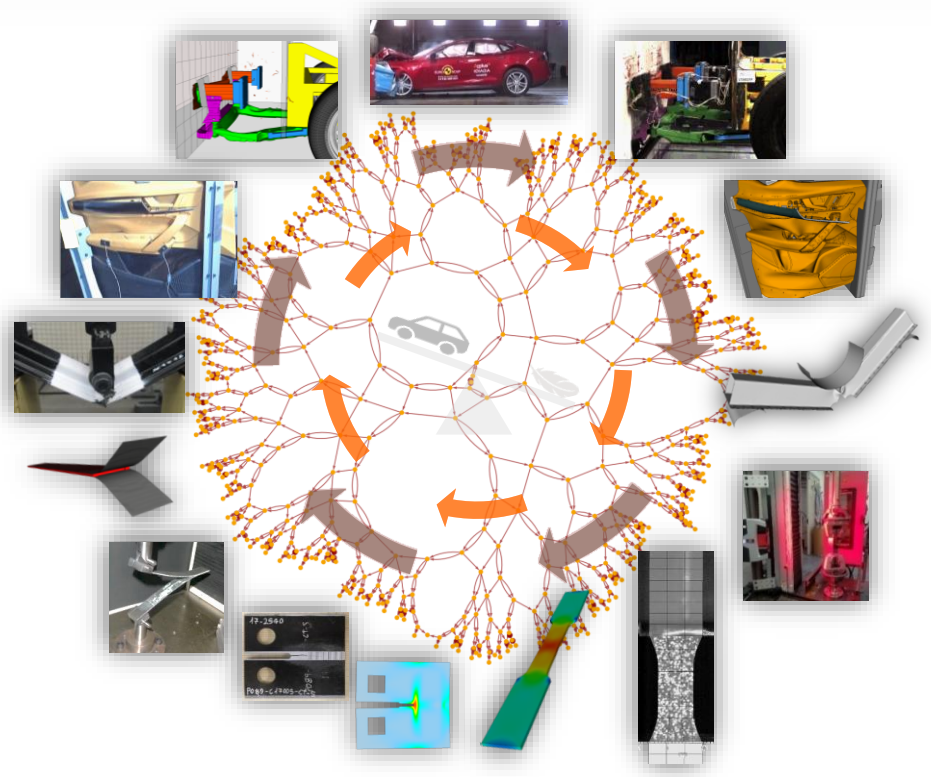
LIGHTWEIGHT MULTI-MATERIAL BODY SOLUTIONS

CORE VALUES

- Body design based on Controlled-Fracture-Driven approach. Unique know-how in applied advanced material plasticity and fracture for crashworthiness CAE analysis
- Developing innovative multi-material lightweight solutions securing body structural performance without penalizing development time-frames
- Tailored-defined Testing & CAE methods for performance validation at component, subsystem and full vehicle level applying a dynamic building block approach
- Minimizing full vehicle prototypes through clever management of the development tools



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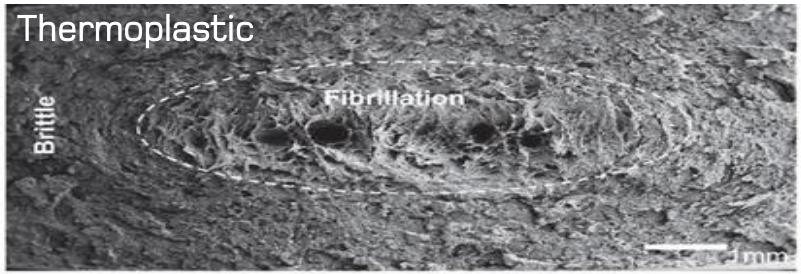
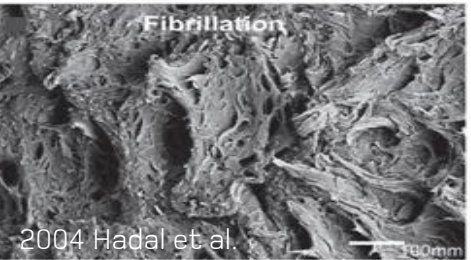
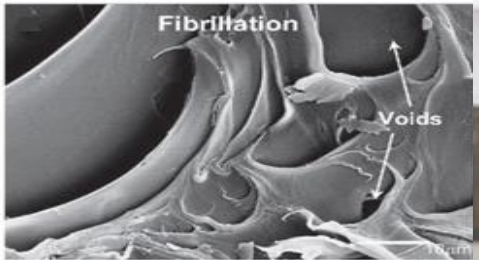
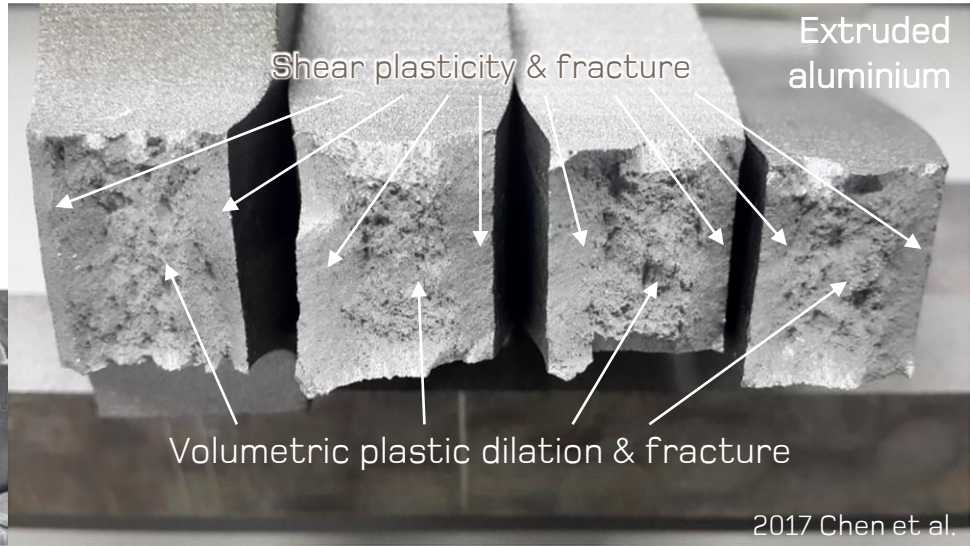
- Relevant automotive structural materials exhibit void nucleation and growth from the plasticity onset leading to the development of permanent volumetric strains while yielding (i.e. plastic dilation)
- Most of these materials also present tension-shear-compression yield stress asymmetries
- Capturing plastic dilation and yield stress asymmetries is the necessary base to develop reliable crash CAE models which properly predict the fracture behavior





2004 Hadal et al.

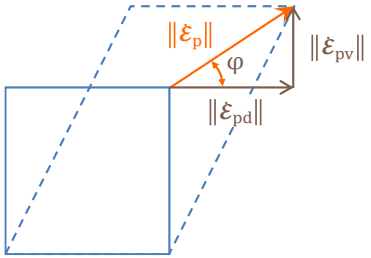




2017 Chen et al.

- The plastic Poisson's ratio is the material property that drives the material plastic dilation (i.e. dilation angle) for a given stress state :

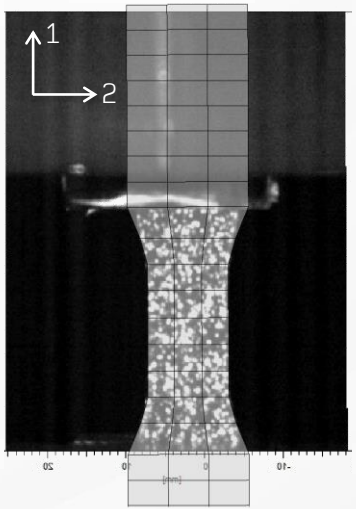
$$\mathrm{tg}\varphi = \frac{\|\dot{\varepsilon}_{pv}\|}{\|\dot{\varepsilon}_{pd}\|} = \frac{\sqrt{2}}{3}\frac{\dot{\varepsilon}_{pv}}{\dot{\varepsilon}_{peq}} = \frac{3}{\sqrt{2}}\frac{1-2\nu_p}{1+\nu_p}\eta \quad \text{with} \quad \eta = \frac{\sigma_m}{\sigma_{vm}}$$



- Plastic dilation can only be developed by stress states involving hydrostatic tension ($\sigma_m > 0 \rightarrow \eta > 0$)
- Due to the homogeneous nature of the hydrostatic stress, it is assumed that ν_p is constant for all hydrostatic tension stress states
- The plastic Poisson's ratio is experimentally measured in uniaxial tension conditions:

$$\dot{\varepsilon}_p^{ut} = \begin{bmatrix} \dot{\varepsilon}_p^{ut} & 0 & 0 \\ 0 & -\nu_p\dot{\varepsilon}_p^{ut} & 0 \\ 0 & 0 & -\nu_p\dot{\varepsilon}_p^{ut} \end{bmatrix} \Rightarrow \quad \dot{\varepsilon}_{pv}^{ut} = \mathrm{tr}\left(\dot{\varepsilon}_p^{ut}\right) = \left(1-2\nu_p\right)\dot{\varepsilon}_p^{ut} \quad \Rightarrow \quad \boxed{\nu_p = \frac{1}{2}\left(1 - \frac{\varepsilon_{pv}^{ut}}{\varepsilon_p^{ut}}\right)}$$

- NPA provides a clean engineering process based on uniaxial tension experimental results to assess when body structural materials deviate from the classic isochoric plasticity assumption
- Once NPA is applied, CAE engineers can decide which is the most appropriate material law based on an objective and consistent experimental data analysis



σ_{ut}

E $\quad \varepsilon_p^{ut} = \varepsilon_1^{ut} - \frac{\sigma_{ut}}{E}$

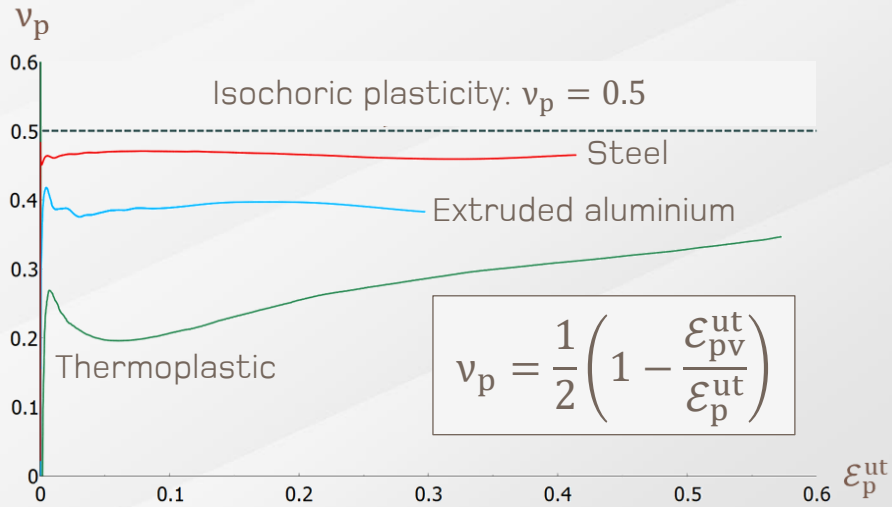
ε_{ut}

$\sigma_m^{ut} = \frac{\sigma_{ut}}{3}$

K $\quad \varepsilon_{pv}^{ut} = \varepsilon_v^{ut} - \frac{\sigma_m^{ut}}{K}$

ε_v^{ut}

$\varepsilon_v^{ut} \cong \varepsilon_1^{ut} + 2\varepsilon_2^{ut}$



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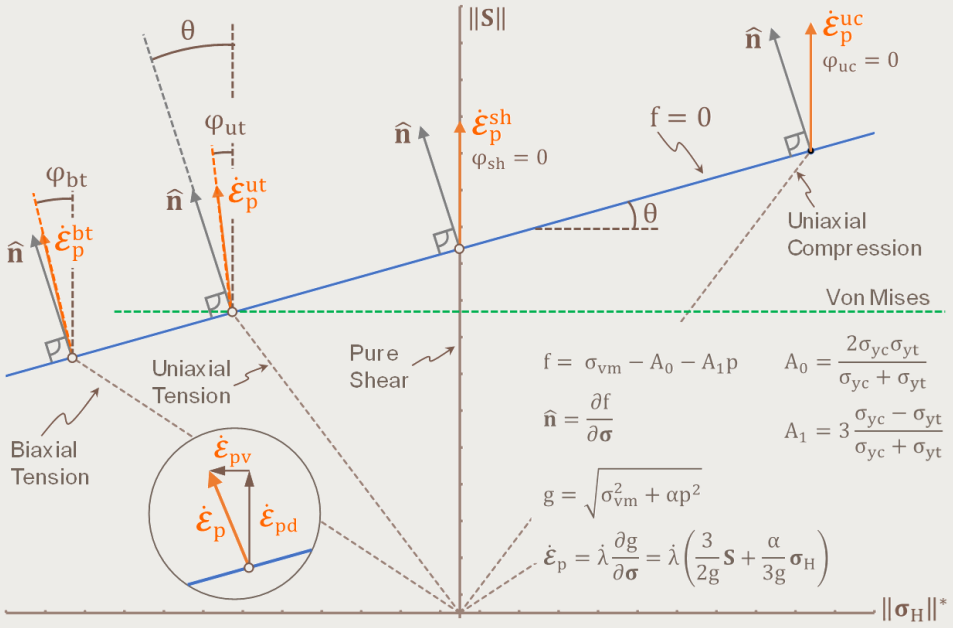
The material law needs to:

- capture the tension-shear-compression yield stress asymmetries
- develop the correct volumetric and deviatoric plastic strains for each stress state triaxiality
- and isotropically degrade the material properties due to both hydrostatic and shear plastic mechanisms

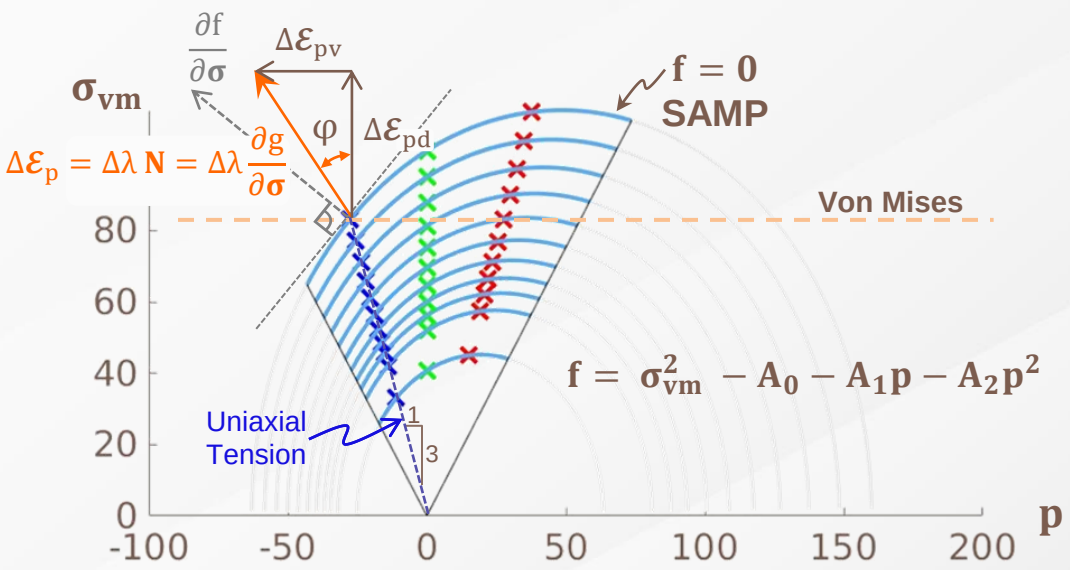


$$\mathrm{tg}\theta = \frac{\sqrt{2}}{3} A_1 = \sqrt{2}\,\frac{\sigma_{yc} - \sigma_{yt}}{\sigma_{yc} + \sigma_{yt}}$$

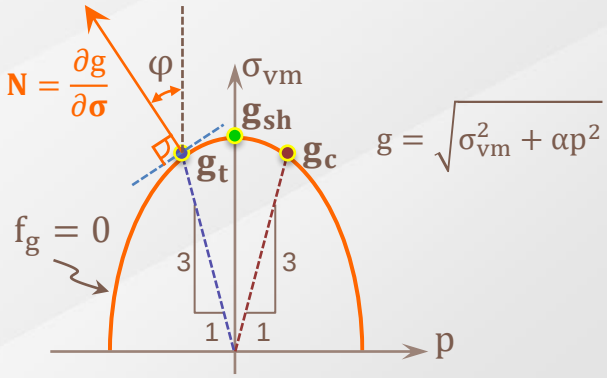
$$\mathrm{tg}\varphi = \frac{\|\dot{\varepsilon}_{pv}\|}{\|\dot{\varepsilon}_{pd}\|} = \frac{\sqrt{2}}{3}\frac{\dot{\varepsilon}_{pv}}{\dot{\varepsilon}_{peq}} = \frac{\sqrt{2}}{3}\eta\alpha \quad \Rightarrow \quad \boxed{\frac{\dot{\varepsilon}_{pv}}{\dot{\varepsilon}_{peq}} = \eta\alpha}$$

$$\text{with} \quad \alpha = \frac{9}{2}\frac{1 - 2\nu_p}{1 + \nu_p} \;;\; \eta = \frac{\sigma_m}{\sigma_{vm}} \;\&\; \nu_p = \frac{1}{2}\left(1 - \frac{\varepsilon_{pv}^{ut}}{\varepsilon_p^{ut}}\right)$$

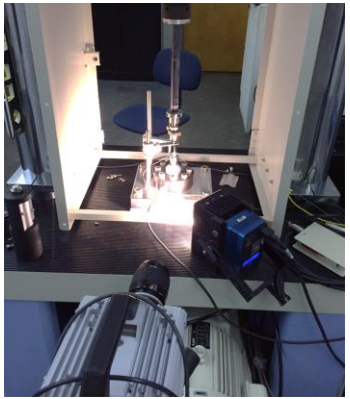
- SAMP includes all necessary features to capture the material non-isochoric plastic behavior together with a pressure-dependent yield surface able to represent tension-compression yield stress asymmetries.



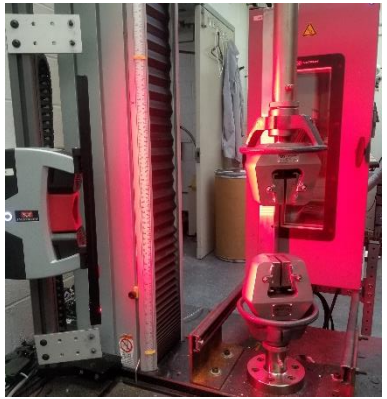
$$\frac{\dot{\varepsilon}_{pv}}{\dot{\varepsilon}_{peq}} = \eta\alpha \qquad \alpha = \frac{9}{2}\frac{1-2\nu_p}{1+\nu_p} \;;\; \eta = \frac{\sigma_m}{\sigma_{vm}}$$



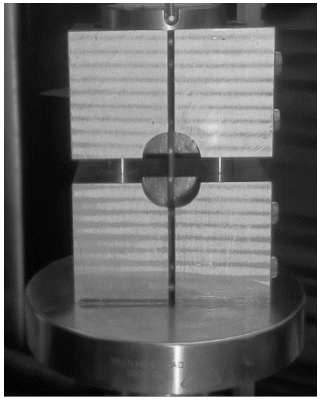
- Applus DatapointLabs & IDIADA seamless collaboration delivers state-of-art measurement of physical properties of thermoplastics required for the CAE characterization



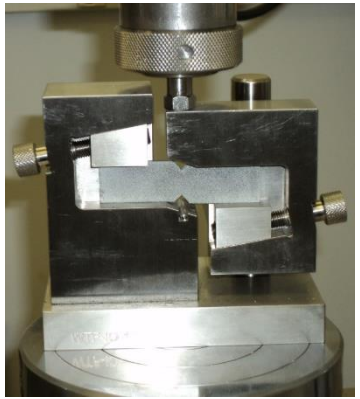
Dynamic tension tests



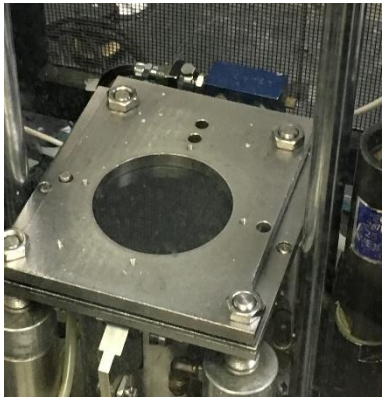
Quasi-static tension test including DIC for plastic Poisson's measurement



Quasi-static compression test

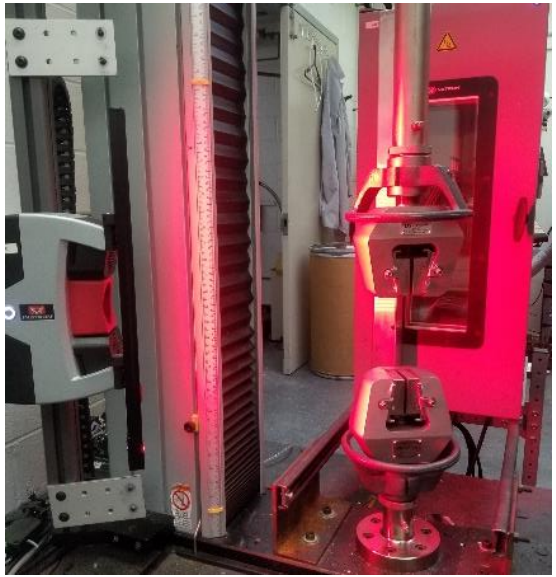


Quasi-static shear test



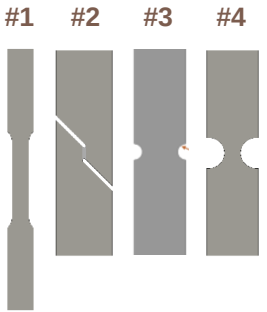
Dynamic Instrumented Dart Impact test

- Applus DatapointLabs & IDIADA seamless collaboration delivers state-of-art measurement of physical properties of extruded aluminium alloys required for the CAE characterization



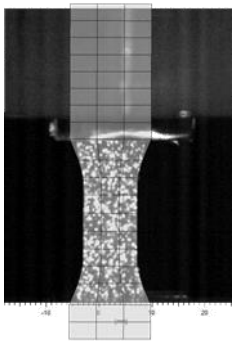
Quasi-static tests
(Incl. DIC for Plastic Poisson's ratio measurement)

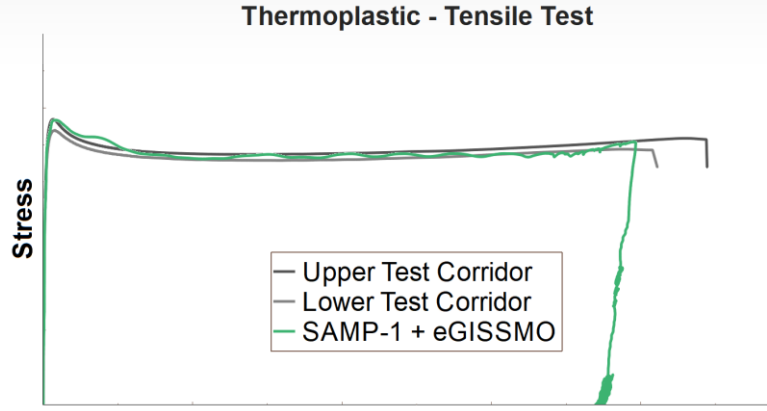
#	Coupon Test
1	Quasi-static smooth tensile ASTM E8
2	Quasi-static Shear 0º
3	Quasi-static Small notch tensile
4	Quasi-static Large notch tensile



Uniaxial tension test

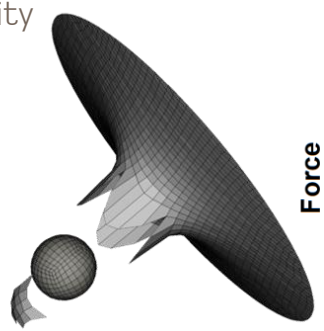
- Test data including DIC provides the necessary information to obtain the plastic Poisson's ration from experimental results

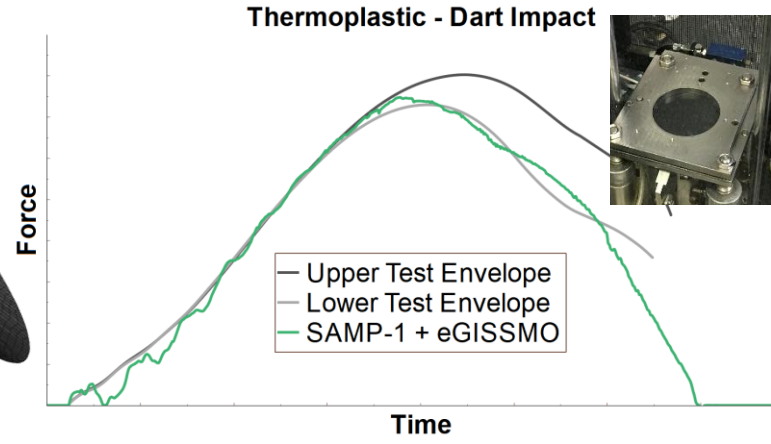




Dart Impact test (dynamic biaxial tension)

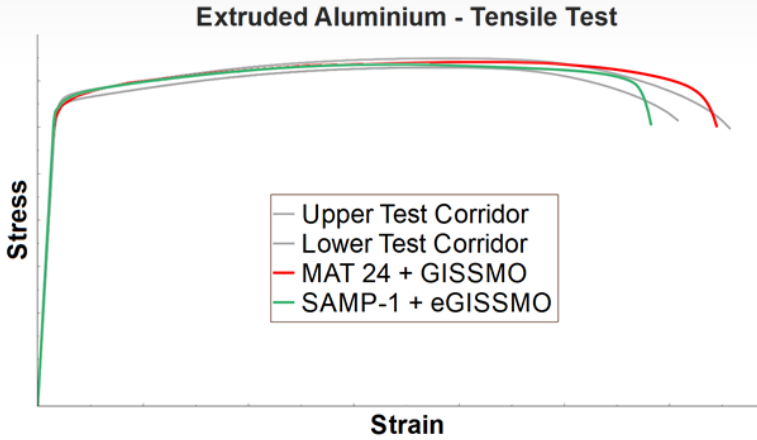
- Good correlation for both uniaxial tension and dart impact validates the plastic dilation characterization and its stress state triaxiality dependency
- Tension-shear-compression yield stress asymmetries and volumetric-shear damage need to be considered.





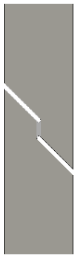
Uniaxial tension test

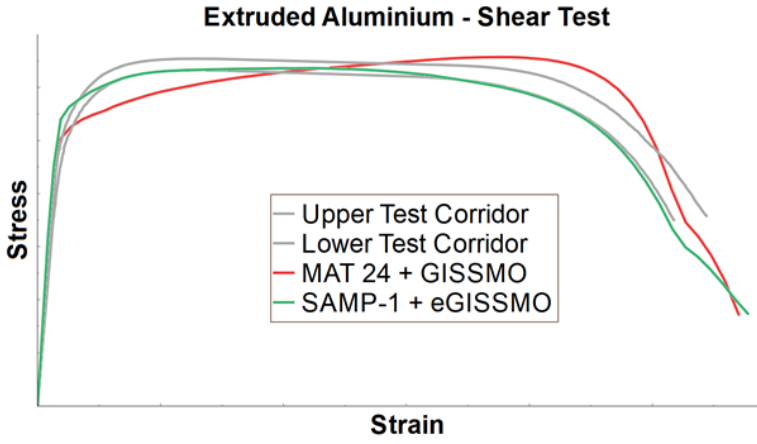
- Test data including DIC provides the necessary information to obtain the plastic Poisson's ration from experimental results



Shear test

- Pure shear plastic behavior does not respect von Mises plasticity assumptions (i.e. $\sigma_{yield}^{shear} > \sigma_{yield}^{tension}/\sqrt{3}$)
- Pressure-dependent yield surface is required
- Material degradation due to void nucleation and growth appears in the plastic region before void coalescence and shear damage dominates the final material fracture

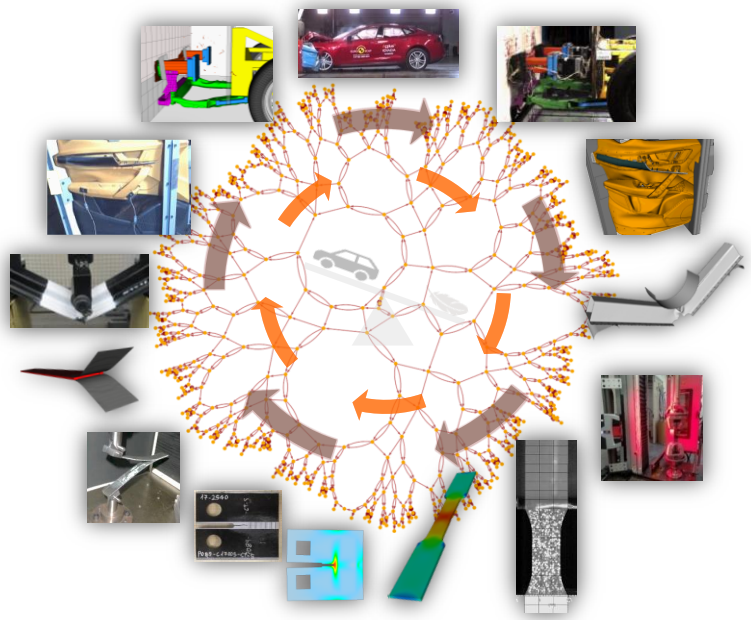




Contents

Conclusions

- NPA: Clean engineering process to assess classic isochoric plasticity assumption
- Overall approach validated for shell-based FE-models
- Accurate material laws lead to higher design lightweight efficiency
- Approach for SAMP experimental input data consistency is proposed
- Advanced plasticity is mandatory for controlled-fracture driven body designs



Applus IDIADA

THANK YOU

FOR YOUR KIND ATTENTION

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