# Coupled elasto-plastic self-consistent and finite element crystal plasticity modeling: Applications to sheet metal forming processes


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## Introduction

Sheet metal forming simulations are usually performed with shell finite elements. We investigate differences in cup drawing predictions between conventional and continuum shell elements while using an elasto-plastic self-consistent (**EPSC**) model as a constitutive relation **[1]**.

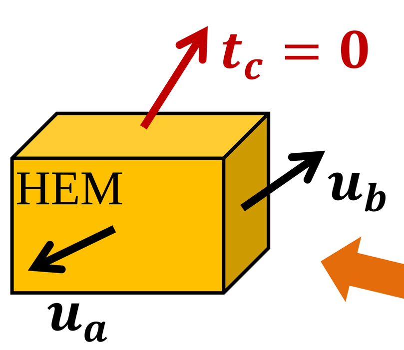
## EPSC

The EPSC model is capable of predicting the response of the heterogeneous representative volume element (**RVE**) to applied displacement and traction boundary conditions by replacing it with homogenous effective medium (**HEM**). Constitutive relation is:

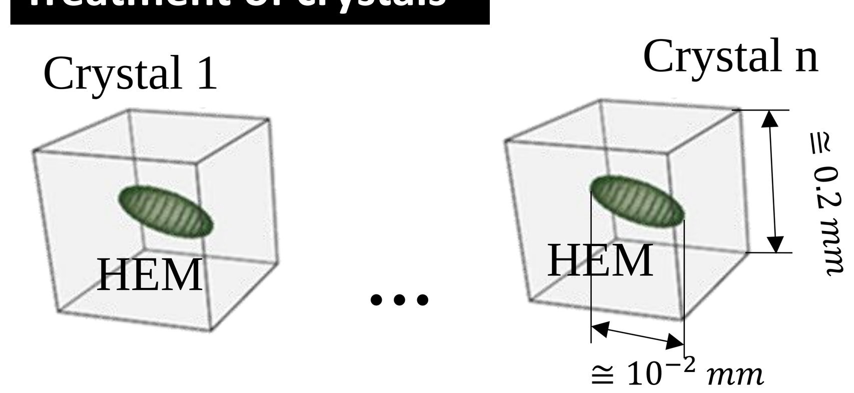
$$\dot{\boldsymbol{\sigma}} = \mathbf{L}(\dot{\boldsymbol{\varepsilon}}, \boldsymbol{\sigma})\dot{\boldsymbol{\varepsilon}}$$

where $\mathbf{L}$ is the tangent stiffness of HEM.

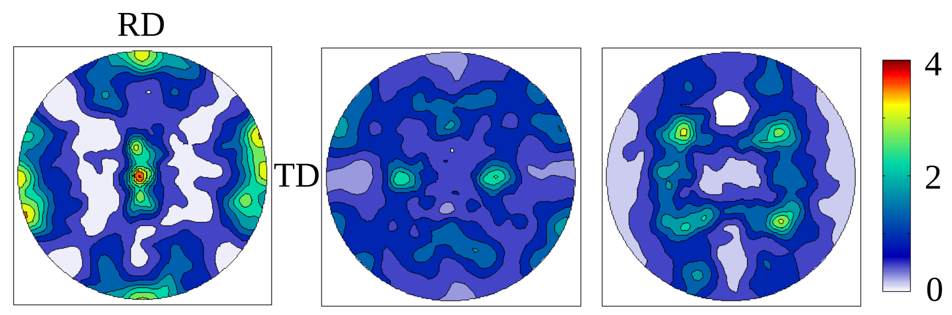
Stress in each crystal is found by assuming that crystal is an ellipsoidal inclusion inside HEM.



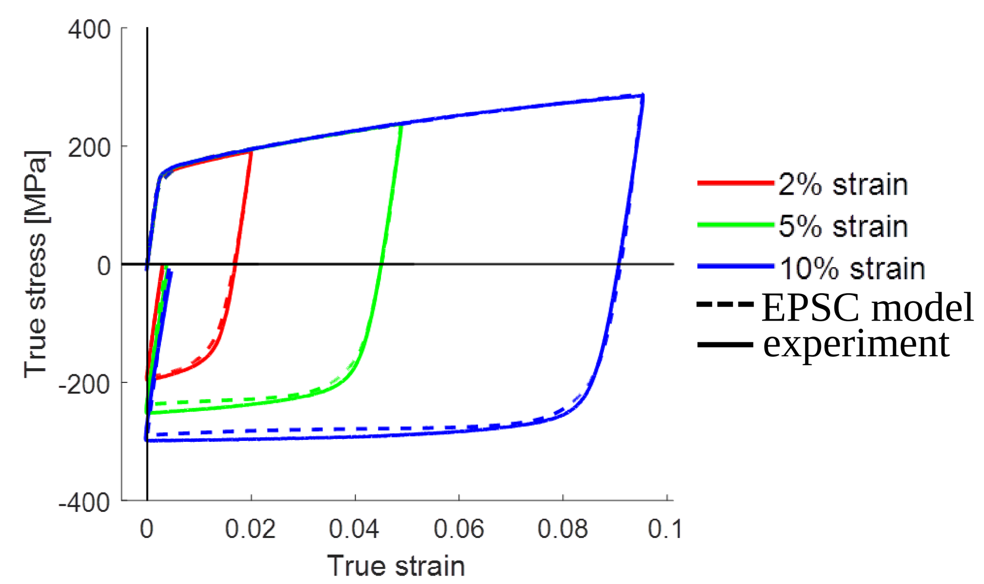

### Treatment of crystals




## Material

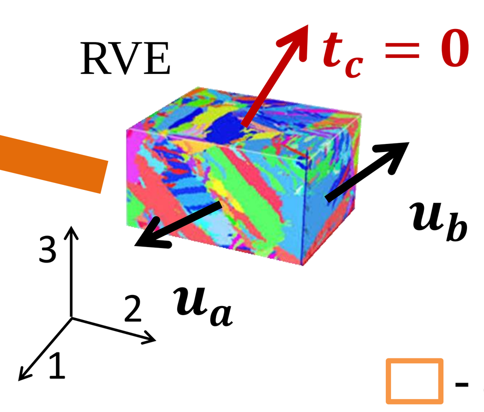



Measured texture of aluminum alloy AA6022-T4.




Calibration of hardening parameters.

## EPSC input




$$\boldsymbol{\sigma} = \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ 0 \\ 0 \\ 0 \\ \sigma_{12} \end{Bmatrix} \qquad \Delta\boldsymbol{\varepsilon} = \begin{Bmatrix} \Delta\varepsilon_{11} \\ \Delta\varepsilon_{22} \\ \Delta\varepsilon_{33} \\ \Delta\varepsilon_{23} \\ \Delta\varepsilon_{13} \\ \Delta\varepsilon_{12} \end{Bmatrix}$$

□ - applied components

Mixed boundary conditions are applied to enforce plane stress state present at integration points in shell finite elements **[3]**.

EPSC is used to calculate stress in finite elements, $\boldsymbol{\sigma}^m$, [2].

## Results

Deep drawing simulation of AA6022-T4 sheet is performed with conventional and continuum shell elements. The results are compared after forming and after springback.

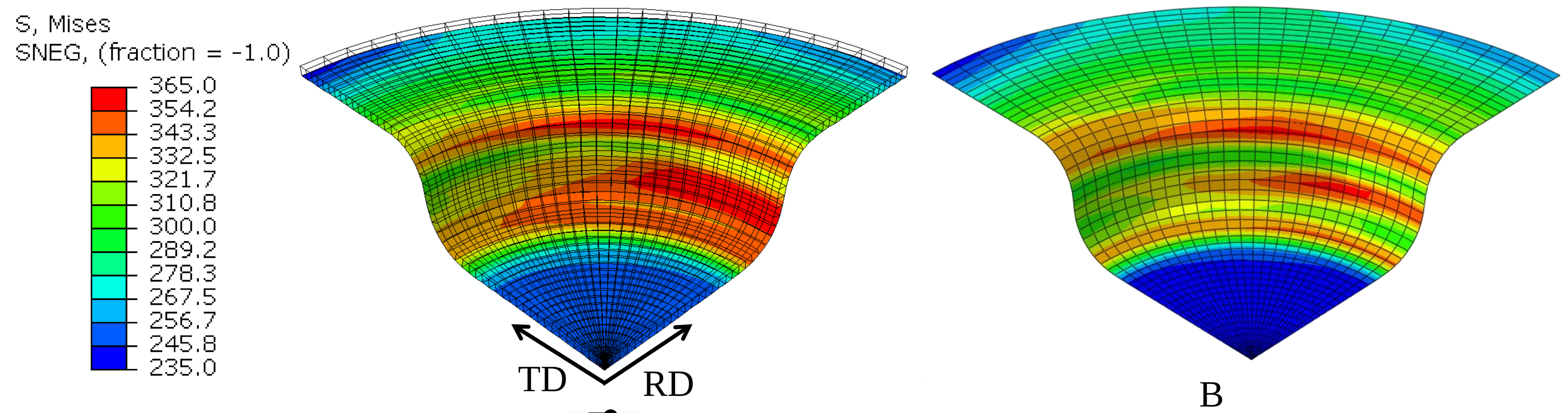
The blank holder force is set to 5000 N. The coefficient of friction is set to 0.05.

| **Shell element:** | Continuum | Conventional |
|---|---|---|
| DOFs | displacements | rotations and displacements |
| Thickness change | accounted | not accounted |
| Thickness normal stress | not zero | zero |
| Geometry | | |

Continuum shell elements | Conventional shell elements

**After forming**

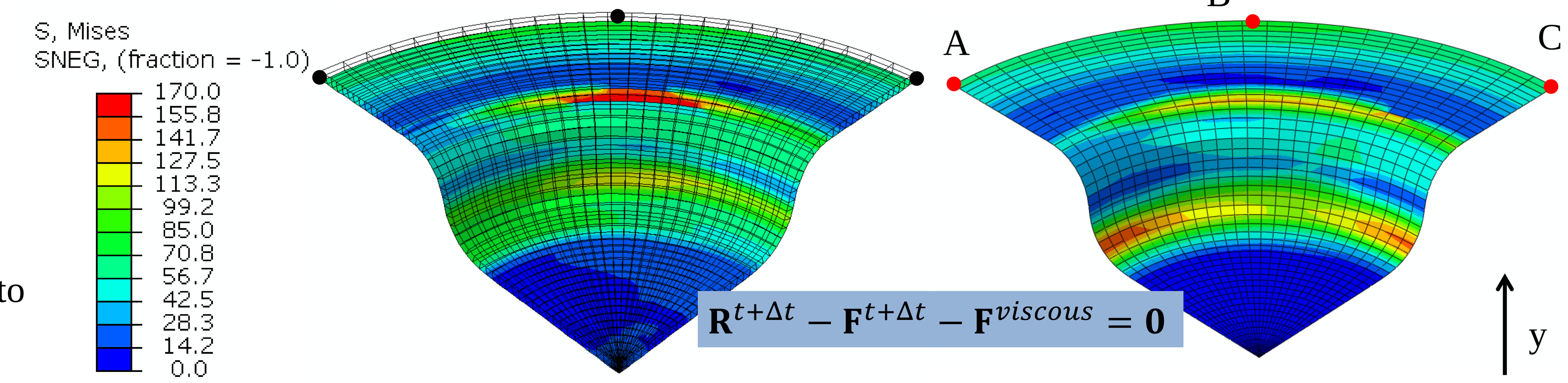
Distribution of von Mises stress on bottom surface of the formed cup.



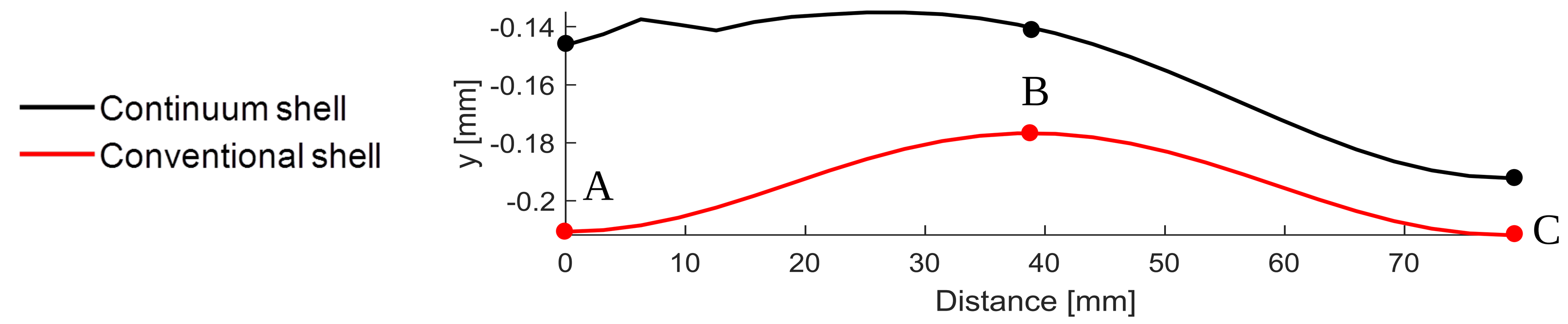

**After springback**

Distribution of von Mises stress on bottom surface of the formed cup.

Artificial viscous forces, $\mathbf{F}^{viscous}$, are added in order to suppress local instabilities.




Vertical position of mid-thickness points along the circumference of the formed cup.




## FEA equilibrium

The equilibrium statement in finite element framework is:

$$\mathbf{R}^{t+\Delta t}(\mathbf{u}^{t+\Delta t}) - \mathbf{F}^{t+\Delta t}(\mathbf{u}^{t+\Delta t}) = \mathbf{0}$$

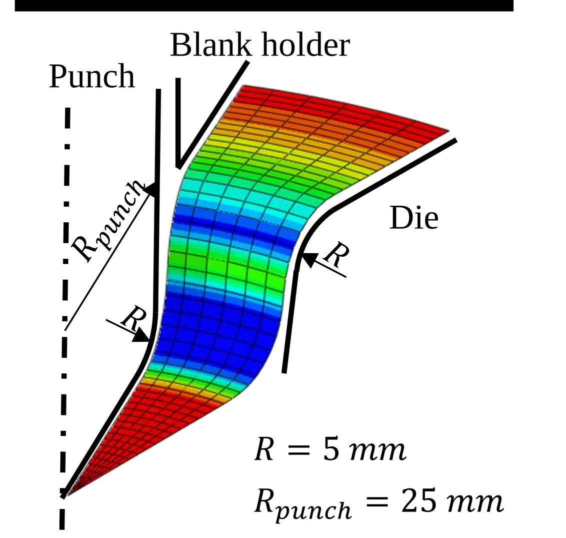
$$\mathbf{F}^{t+\Delta t} = \sum_m \int_{V^m} \mathbf{B}^{m,\mathrm{T}} \boldsymbol{\sigma}^m dV^m$$

where: $\boldsymbol{\sigma}^m$ is stress in element,

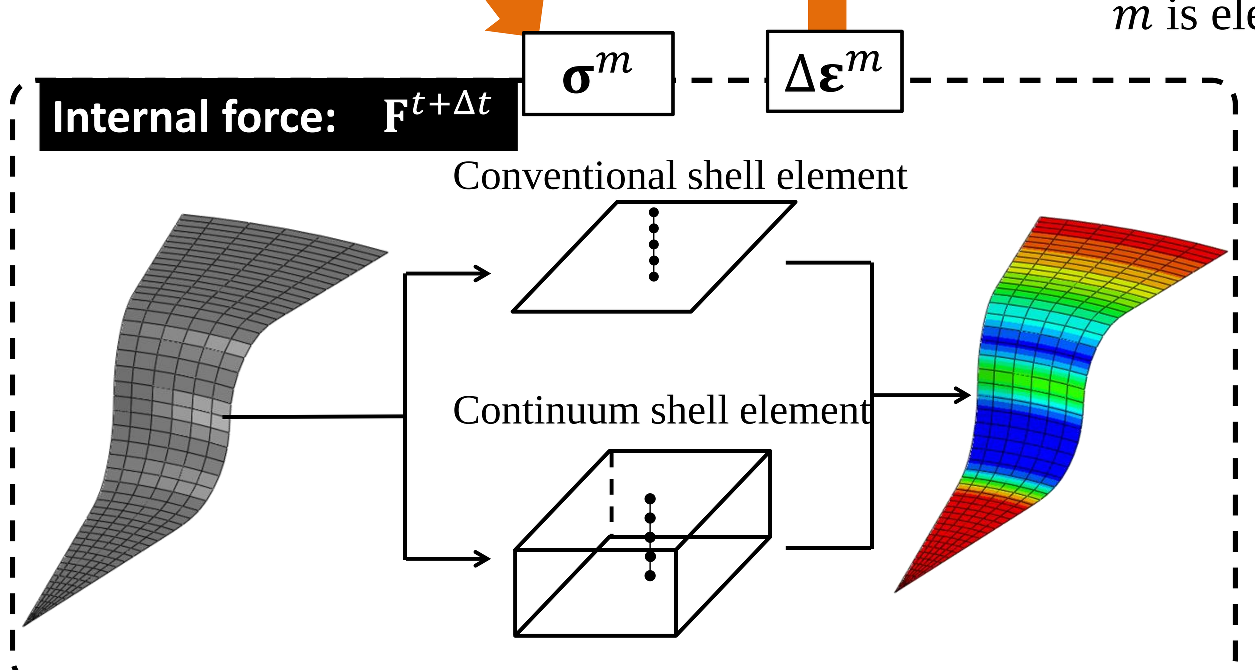
$\mathbf{B}^m$ is strain-displacement matrix,

$m$ is element number.

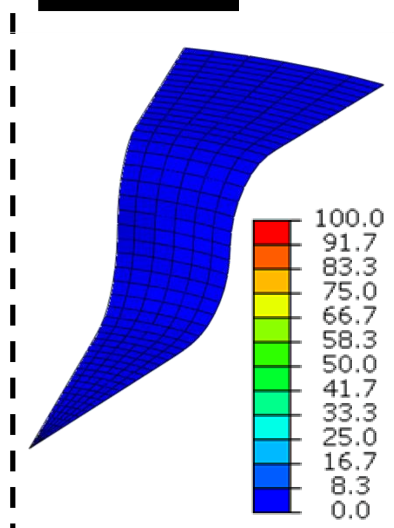
**External force:** $\mathbf{R}^{t+\Delta t}$




**Internal force:** $\mathbf{F}^{t+\Delta t}$




**Residual**




## Conclusion

The coupling of EPSC model with shell finite elements was successfully performed. Both continuum and conventional shell elements predicted similar stress levels and stress distribution after forming, while the cup shape and residual stress after springback exhibited differences.

## Acknowledgments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## References


[1] Turner, P.A., Tomé, C.N., 1994. Acta Metallurgica et Materialia 42, 4143-4153.

[2] Zecevic, M., Beyerlein, I.J., Knezevic, M., 2016. International Journal of Plasticity. doi:10.1016/j.ijplas.2016.07.016.

[3] Zecevic, M., Knezevic, M., 2017. JOM, 1-8.