A Multiscale Simulation Framework of the Accumulative Roll Bonding Process Accounting for Texture Evolution

A. Prakash[1], W.G. Nöhring[1,3], R.A. Lebensohn[2], H.W. Höppel[1], E. Bitzek[1]

[1]Materials Science & Engineering, Institute I, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

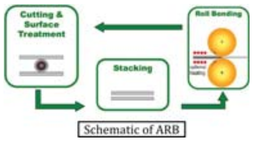
[2]Los Alamos National Laboratory, Los Alamos, NM 87545, USA

[3]currently at: Laboratory for Multiscale Mechanics Modeling, École Polytechnique Fédérale de Lausanne, Switzerland

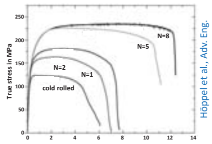
A. Prakash et al., Mater. Sci. & Eng. A 631 (2015)

Motivation

Accumulative Roll Bonding (ARB) is a promising severe plastic deformation process for achieving materials with enhanced properties. Due to repeated stacking and roll bonding, a large amount of plastic deformation is accumulated, resulting in an ultra-fine-grained (UFG) microstructure, and consequently, high strength.



Hausöl et al., Adv. Eng. Mater. 12 (2010)

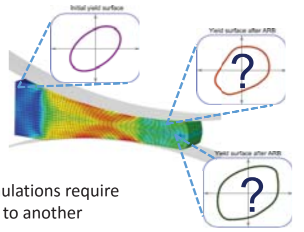


Höppel et al., Adv. Eng. Mater. 6 (2004)

- Currently, no comprehensive simulation framework available for ARB
- Adoption of new materials, however, hinges on the possibility to reliably model the deformation behavior and failure of the material during processing and *in-use* conditions

Challenges

- Conventional rolling simulations are insufficient - anisotropy in yield surface depends on the number of ARB passes
- Mesh distortion due to large amount of thickness reduction (50%)
- Doubling of number of elements in each ARB pass due to stacking of sheets
- Multiscale approach needed to incorporate a microstructural model
- Memory of solution state → multiple pass simulations require the carry-over of material state from one pass to another
- Computationally intensive → development and implementation of efficient numerical algorithms required for simulations in realistic time frames



Methods and simulations details

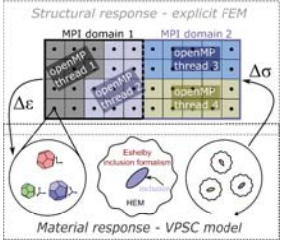
Elements of the multiscale framework:

- Structural response – explicit FEM
- Material response – visco-plastic selfconsistent (VPSC) model

➢ Multi-level parallelization: MPI based domain decomposition of the structural response + openMP based thread parallelization of the material response

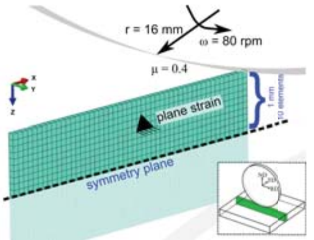
➢ Selective probing: linear stress update performed when VPSC is not called

Schematic of the multiscale framework with multi-level parallelization



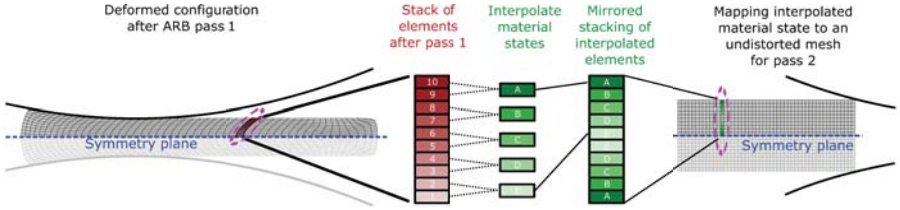
Simulation details:

- Plane strain rolling, roller φ = 32 mm
- Feedstock – two AA5754 Al alloy sheets
- Mesh – 500 brick elements (C3D8R)
- Random texture with 250 grains per integration point



Novel solution mapping scheme

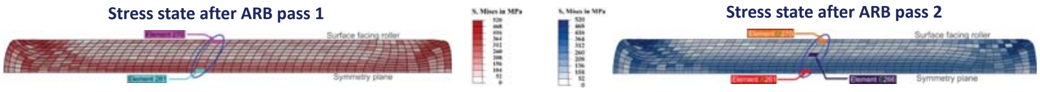
- Transfers complete material state from one pass to another
- Material state mapped onto a completely new mesh → No mesh distortion problems
- Only microscopic variables used for mapping → CRSS $g^{(\alpha)}$, cumulative shear Γ, grain shape $\boldsymbol{F}^c$, grain orientation $\boldsymbol{g}^c$



Results*

Stress state after ARB pass 1

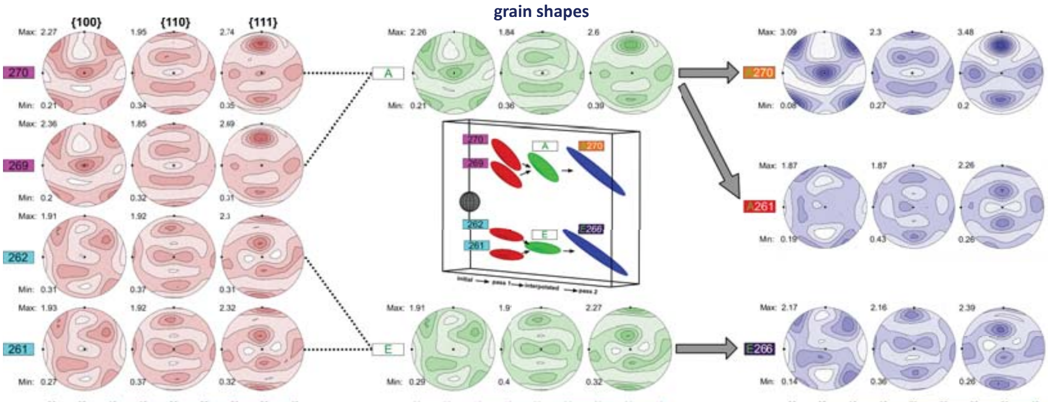
Stress state after ARB pass 2



Textures after ARB pass 1

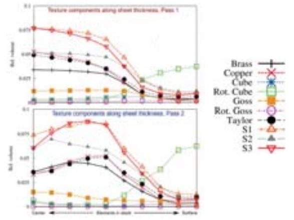
Interpolated textures and grain shapes

Textures after ARB pass 2



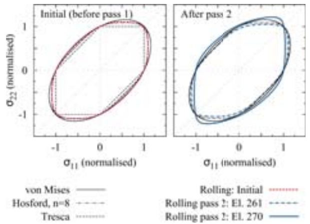
Through-thickness-gradient of texture

(All texture dependent properties are critically influenced by this gradient)



Yield surfaces after ARB pass 2

(Due to mirrored stacking, elements 261 and 270 have the same yield surfaces before pass 2)



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Conclusions

- Proposed multiscale framework able to capture evolution of texture and resulting anisotropy during ARB
- Novel solution mapping scheme enables simulation of multiple ARB passes and facilitates usage of constant number of elements in each pass
- Material state mapped onto a completely new mesh → mesh distortion problems circumvented
- Multilevel parallelization (MPI+openMP) helps reduce simulation times by up to 70%
- Through-thickness-gradient of material properties → yield behavior of surface elements differs from those in the center → must be accounted for in subsequent simulations like e.g. deep drawing
- Effect of stacking of sheets → gradient of texture depends on number of ARB passes
  → shear experienced by elements in lower surface is reduced in subsequent pass
  → yield behavior significantly different when compared to conventional rolling
- Proposed framework not restricted to ARB alone; can be used for other forming processes like conventional rolling, deep drawling etc.