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The dynamic local Facet method for multiscale modeling of texture anisotropy in metal forming processes

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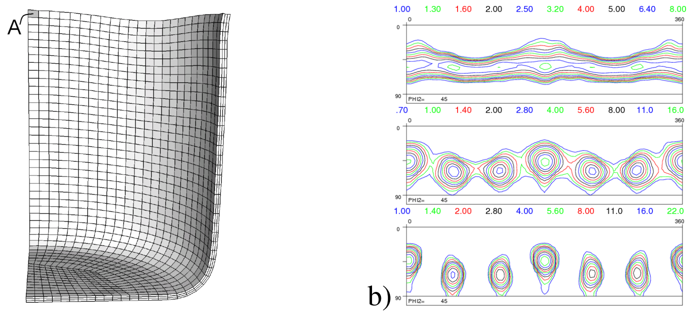
In this paper we present a new multiscale model of a deformation process in which the anisotropy of plastic properties is related to the evolution of crystallographic texture. The model spans several length scales from the macroscopic deformation of the workpiece to the microscale interactions between the grains in polycrystalline material. It includes three main constituents: (1) a Finite Element (FE) method that provides a macroscopic description of plastic deformation, (2) a constitutive law describing the plastic anisotropy, based on the concept of a plastic potential in strain rate space, and (3) a micromechanical model that predicts evolution of the texture and provides the parameters for the aforementioned constitutive equation. Mutual interactions between micro- and macro- scale are taken into account by a full bidirectional coupling introduced in the model. Therefore, the plastic deformation influences the crystallographic texture while the evolution of the texture induces changes in the anisotropy of macroscopic deformation. The presented approach enables adaptive texture and yield surface update schema with respect to the local plastic deformation in the FE integration points. The updating criterion is based on the plastic strain accumulated in a given integration point since the last texture modification. The update of texture in an integration point is triggered by exceeding a critical value ε_c. Texture evolution in the FE integration points is predicted by the ALAMEL micromechanical model [2]. The ALAMEL takes into account the stress equilibrium conditions at grain boundaries in a simulated microstructure. As a consequence, the qualitative predictions of the texture are more accurate than those obtained using the Full Constraint Taylor model.
The plastic anisotropy of textured polycrystalline material can be described by means of a plastic potential in strain rate space. Recently, Van Houtte et al. [1] proposed the Facet method that utilises the following homogeneous polynomial of degree n to describe the plastic potential:

$$G(\mathbf{D}) = \sum_{\kappa=1}^{K} \lambda_\kappa \left(S_{\kappa,p} D_p\right)^n \tag{1}$$

where $\mathbf{D}$ is five-dimensional strain rate vector, $D_p, p = 1\ldots5$ are the components of the strain rate vector, λ_κ and the components of 5D stress vectors $S_{\kappa,p}, p = 1\ldots5, \kappa = 1\ldots K$ are parameters. Provided that $\lambda_\kappa \geq 0$ and n is a positive even number, it can be shown that the equipotential surface as obtained by Eq. (1) is always convex [1], which is a clear advantage of the method. The stress vectors are obtained for the corresponding nearly equidistant strain rate modes by means of a *virtual experiment*, using the micromechanical ALAMEL model. Previous experience [1] suggests that a reasonable approximation of the equipotential surface requires at least $K = 402$ strain modes and degree $n \geq 6$. However, every update of the texture entails the update of constitutive law (1), which becomes an obstacle due to the computational cost of the micromechanical model. Moreover, the macro-scale FE model does not require the whole yield surface but only the zone which is close to the active part of yield locus. The concept of a local zone in yield locus was previously proposed by others, e.g. [3, 4]. Whereas these approaches are aimed at the local interpolation applied in a narrow zone, the current work is focused on restricting the global description of yield surface to the local zone. This can be done by reducing the number of strain modes K and a local adaptation of polynomial order n. In this paper we propose a generalisation



a) b)

Figure 1: a) Cup profile prediction obtained using the NNLS-identified Facet expression, (point A lay on the line 0° to rolling direction) b) evolution of texture in point A: initial texture (first row), and corresponding to accumulated von Mises strains: 0.4 (second row) and 0.8 (third row)

of Eq. (1) that makes use of a small number of strain modes to approximate a local part of yield surface. A set of the strain modes is selected from the regular equidistant grid. The equation (1) can be rewritten in the matrix form, suitable for determination of the parameters λ_κ:

$$[W]\{\lambda\} \cong \{C\} \tag{2}$$

where the components of the matrix $W_{i,j} = (\mathbf{D}_i \cdot \mathbf{S}_j)^n$ and the vector C selects the equipotential surface. The system (2) is solved using Non-Negative Least Squares (NNLS) algorithm [5], with respect to $\lambda \geq 0$. The NNLS algorithm is able to eliminate the equations that either violate non-negativity constraint or are superfluous because other equations provide a sufficiently accurate prediction. Degree of polynomial n is iteratively selected by minimising a residual approximation error. Since the sharpness of texture affects locally the shape of the yield surface, the degree n may vary from one FE integration point to another. This dynamic Facet formulation requires smaller number of virtual experiment evaluations, since it may cover only a part of the yield surface. If the strain path sufficiently changes, a new zone of yield surface is requested by the FE part of the model. Therefore, the matrix W has to be extended by new results of virtual experiments and a new set of λ parameters must be determined. The system given by Eq. (2) is solved using a QR decomposition method. Efficient updating techniques can be used to compute the QR decomposition for the new problem based upon the QR decomposition for the previous problem. Therefore, only the update of the texture invalidates the entire system given by Eq. (2).

Results obtained using the multiscale model outlined above will be presented. The cup drawing process simulation is considered. The investigated material is a low carbon DC01 steel. The discussion of results will include the analysis of cup profiles and the influence of complex deformation path on texture development. An example of the results obtained using the NNLS-identified Facet expression is demonstrated in Fig. 1a. Evolution of texture at selected material points is assessed as well. Texture evolution in selected element at the cup rim (0° to rolling direction) predicted by the ALAMEL model is shown in Fig. 1b.

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