# METAL FORMING AND TEXTURE EVOLUTION MODELLING

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*Summary* A description of plastic anisotropy evolution due to texture development during metal forming processes is presented. It bases on the model of single crystal with the regularized Schmid law. The single crystal model is used to description of polycrystal behaviour basing on the Taylor assumption. The approach makes possible to predict a texture development in plastically deformed elements during the metal forming processes. The associated evolution of plastic anisotropy in drawing wires, rolled or sheared sheets is discussed.

## INTRODUCTION

In the metal forming processes, the crystals of deformed elements are seldom oriented completely at random. At first, during the casting process, due to solidification, grains are formed along a specific crystallographic direction. Next, through subsequent plastic deformations, the crystals rotate to certain stable orientations. Finally, upon the recrystallization process, new crystals are formed. All these processes lead to the development of non-random grain orientations, known as textures. It is commonly known, that many of the physical, mechanical and chemical properties of single crystals vary with the crystallographic directions and planes. Thus, a textured polycrystalline material usually exhibits anisotropic properties. Depending on the texture and the use of the material, the property of anisotropy may or may not be a desirable feature from the practical point of view. This is the reason that much research on the texture development and the principles governing such development has been conducted recently. Below, it is presented a model of polycrystal plastic behaviour observed during metal forming processes. It is a generalization of the model of a single crystal behaviour proposed in the papers [1-3] and described in the book [4].

## SINGLE CRYSTAL BEHAVIOUR

At first, recall the model of single crystal behaviour introduced independently by Arminjon [1] and by Gambin [2]. Consider a single metallic grain with $M$ slip systems $\{\boldsymbol{m}^{(r)}, \boldsymbol{n}^{(r)}\}$, for $r = 1,..., M$, where $\boldsymbol{m}^{(r)}$ is the unit vector of slip direction, and $\boldsymbol{n}^{(r)}$ — the unit vector orthogonal to the slip plane of the $r$-th slip system. The orientation of crystallographic lattice is described by 3 Euler angles $(\varphi_1, \Phi, \varphi_2)$. For a given stress tensor $\boldsymbol{\sigma}$, one can introduce the resolved shear stress $\tau^{(r)} = \boldsymbol{m}^{(r)} \boldsymbol{\sigma}\, \boldsymbol{n}^{(r)}$ on the slip plane prescribed by the unite vector $\boldsymbol{n}^{(r)}$ and in the slip direction given by the unite vector $\boldsymbol{m}^{(r)}$. A glide of the on the $r$-th slip system appears when $\tau^{(r)}$ reaches its critical value $\tau_{cr}^{(r)}$. As the yield condition for single metallic grain, the following $2n$-th order polynomial is assumed:

$$\sum_{r=1}^{M} \left( \frac{\tau^{(r)}}{\tau_{cr}^{(r)}} \right)^{2n} - m = 0 , \tag{1}$$

where $m > 0$ and $1 \le n \le 20$ are non-dimensional material constants of the considered grain. The above polynomial describes a smooth, but strongly non-linear yield surface with rounded-off corners [2]. Denote by $\boldsymbol{D}^p$ the strain rate tensor, and by $\boldsymbol{\Omega}^p$, the plastic spin tensor. The assumed smooth yield condition generates the conjugate flow rule and the plastic spin rule, respectively:

$$\boldsymbol{D}^p = \frac{1}{2} \lambda \sum_{r=1}^{M} \frac{1}{\tau_{cr}^{(r)}} \left( \frac{\tau^{(r)}}{\tau_{cr}^{(r)}} \right)^{2n-1} \left( \boldsymbol{m}^{(r)} \boldsymbol{n}^{(r)} + \boldsymbol{n}^{(r)} \boldsymbol{m}^{(r)} \right), \quad \boldsymbol{\Omega}^p = \frac{1}{2} \lambda \sum_{r=1}^{M} \frac{1}{\tau_{cr}^{(r)}} \left( \frac{\tau^{(r)}}{\tau_{cr}^{(r)}} \right)^{2n-1} \left( \boldsymbol{m}^{(r)} \boldsymbol{n}^{(r)} - \boldsymbol{n}^{(r)} \boldsymbol{m}^{(r)} \right) \tag{2}$$

where the coefficient $\lambda > 0$ is the same for all slip systems. The above relations may be used to formulation of rigid-plastic [2] or elastic-plastic [3] model of single crystal behaviour. In both cases, for a given stress given stress $\boldsymbol{\sigma}$ acting on the crystal, one can find an adequate velocity field $\boldsymbol{v}$ and the total spin of the crystal $\boldsymbol{\Omega}$. On the other hand, the lattice spin of the crystal is given by the rule $\boldsymbol{\Omega}^* = \boldsymbol{\Omega} - \boldsymbol{\Omega}^p$. Because, the lattice spin $\boldsymbol{\Omega}^*$ is described by time derivatives of the Euler angles $(\dot{\varphi}_1, \dot{\Phi}, \dot{\varphi}_2)$, one can determine the increments $(\Delta\varphi_1, \Delta\Phi, \Delta\varphi_2)$ uniquely describing grain reorientations at each step of the considered deformation process [4].

## MODEL OF CRYSTAL AGGREGATE

Assume that polycrystalline element contains grains with the same kind of the crystallographic lattice. Let the element consists of $N$ groups of grains with the same lattice orientation. Denote by $\kappa^{(g)}$ the volume ratio of grains with the orientation $g$ ($g$ = 1,…, $N$) to all grains of the element. For each group of grains the material constants $m^{(g)}$ in Eq. 1 are prescribed. If a stress tensor $\boldsymbol{\sigma}$ is applied to the element, we have the same resolved shear stress $\tau^{(r,g)}$ and the critical shear stress $\tau_{cr}^{(r,g)}$ in all grains of the $g$-th group. It is convenient to introduce the reference critical shear stress $\tau_{cr}$, which is the critical shear stress for a fixed group of grains and a fixed slip system. Denote by $\bar{\tau}^{(r,g)}$ the ratio $\tau^{(r,g)} / \tau_{cr}$. Then the yield surface for polycrystalline element will be described by the following $(2\bar{n})$-th order polynomial [5]:

$$\sum_{g=1}^{N} \kappa^{(g)} \frac{1}{m^{(g)}} \sum_{r=1}^{M} \left( \frac{\tau^{(r,g)}}{\bar{\tau}_{cr}^{(r,g)}} \right)^{2\bar{n}} = \tau_{cr}^{2\bar{n}} , \tag{3}$$

where exponent $\bar{n}$ belongs to the interval $1 < \bar{n} < 8$. Then, the plastic corners of polycrystalline yield surface are more rounded than the yield surface of single crystal ($0 < n < 20$). The plastic flow rule (2) and the plastic spin rule (3) for single crystals are conjugated with the polycrystalline yield surface (4). Consider a polycrystalline element under a plastic deformation. Assuming the Taylor model of polycrystal behaviour, that the plastic strain rate $\boldsymbol{D}^p$ in each of the grains is the same, one can calculate lattice reorientations caused by the given deformation. The above reorientations will change the directions of vectors $\boldsymbol{m}^{(r,g)}$ and $\boldsymbol{n}^{(r,g)}$, and then the quantity $\tau^{(r,g)} = \boldsymbol{m}^{(r,g)} \boldsymbol{\sigma} \boldsymbol{n}^{(r,g)}$. We may observe the *texture development* caused by plastic deformation of the polycrystalline element. On the other hand, we have to do with change of a shape of the yield surface. It leads to generation of plastic anisotropy in the element.

## TEXTURE DEVELOPMENT SIMULATION

To describe the texture development, changes of pole figures for drawing of wires with diameter diminishing 2, 5 and 10 times are shown. The same results are given for rolling of sheets with thickness diminishing 2, 5, and 10 times and for pure shear of a metal sheet. Next, the associated evolution of plastic anisotropy in the drawn wires, the rolled sheets and the sheets under pure shear, are analysed. To do it, changes of shape of the plastic yield surfaces are discussed. On the above surfaces, we may observe a shift of plastic corners causing a change of plastic flow direction. Independently, an influence of texture development in the rolled sheets on variations of the Lankford coefficient is shown. Its distribution on the sheet plane, that enables to predict a form and place of strain localization, is discussed in details.

## CONCLUSIONS

The presented models of single grain and polycrystalline element based on the concept of yield surfaces with rounded corners are good tools for prediction of texture development in plastically deformed metals. Within the rate-independent plasticity, the single grain model overcomes the problem of non-uniqueness in the choice of active slip systems. Although this problem may be solved with the help of rate-dependent approach, the proposed formulation eliminates influence of viscous effects. It allows the use of standard FEM procedures in numerical analysis of polycrystals.

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