Plastic deformation modeling of metallic materials

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Nowadays computer modelling is commonly used for prediction of many phenomena and realistic simulation of processes e.g. weather changes, economy development and also forming processes. In all cases to obtain reasonable results proper model description of basic phenomena affecting the final result (prediction) has to be considered. For the plastic deformation this phenomena is slip on slip planes. Depending on the spatial position (orientation) of the slip planes relative to external loads the material exhibits different behaviour. Since the metallic materials commonly occurs as polycrystalline aggregates, composed of many (billions) grains differently oriented, considering each grain and slip systems in the model is difficult. The common approach for description of polycrystalline materials is to use flow curves, which describes relation of stress and strain. This description assumes that crystallites properties are statistically homogenized and depend only on the variables like strain, strain rate, temperature, etc.

On the metal forming field the aim of modelling is to predict behaviour of formed material as well as properties of final product. To obtain reliable results, several conditions have to be fulfilled. First, the process parameters have to reflect real life conditions, which are described by initial and boundary conditions. In case of simulation of metal forming processes these conditions usually are: initial temperature, initial velocity or velocity prescribed on boundary, displacement prescribed on boundary, force, friction, etc. However, most important factor is description of material behaviour. In case of metallic material the behaviour is described by, already mentioned flow curve.

Since the deformation behaviour may be affected by different factors/conditions, the flow curve also has to consider all of them. For the mathematical description of the flow curve is difficult to select the function, which describes properly the flow stress in a wide range of different conditions like temperatures, strain and strain rates. Therefore, relatively complicated functions are proposed [1]. The general classification of the flow stress functions is presented in [2].

Example of models (flow curves), in which flow stress is defined as function of the three primary variables: strain, strain rate and temperatures, are presented in (Table 1).

Table 1. Flow stress models

For cold plastic deformation			
$\sigma = \sigma_0 + a\varepsilon^n$	(1)	$\sigma = \sigma_0 + \exp(a\varepsilon)^r$	(2)
For hot plastic deformation			
$\sigma = \sigma_0 + a\varepsilon^n Z^m; \; Z = \dot{\varepsilon}\exp\left(\frac{Q}{R\ldots}\right.$	(3)	$\sigma = \sigma_0 + a\varepsilon^n \dot{\varepsilon}^m \exp\left(\frac{Q}{R\ldots}\right.$	(4)
$\sigma = \sigma_0 + a\varepsilon^n \dot{\varepsilon}^m \exp\left(\frac{Q}{RT}\right)\exp(\ldots$			(5)

where: σ_0 – stress at the beginning of plastic deformation, ε – strain, $\dot{\varepsilon}$ – strain rate, T – temperature, n, m – coefficients of sensitivity of flow stress to strain and strain rate, respectively, Q - activation energy, which represents sensitivity to temperature, R - gas constant.

It is easy to notice that in order to uniquely describe the material behaviour by flow curve the parameters of the equation have to be identify. Since the flow curve model is empirical the parameters have to be determined using experimental data. To obtain the data various test are used. They can have various forms (tension, compression, torsion) depending on further use of the flow curve. In industry tensile test is most commonly used to obtain characteristic mechanical parameters of the material (elongation, yield stress, tensile strength). However from scientific point of view applications of other tests like: plain strain compression (PSC), plain strain compression in channel die (PSCc), cylinder (UC) and ring (RC) compression tests, provides useful information about material behaviours. Advantages and disadvantages of typical tests (PSC, RC, UC) are discussed in [3,4]. These tests proved their applicability to all bulk forming processes. Particular interesting is the channel test PSCc (Fig. 1). It is often used to investigate influence of shear band formation on material flow [5, 6]. Among commonly used plastometric tests, the channel die test is the most sensitive to the strain localization phenomena. The stress state in PSCc resembles strip rolling conditions, where occurrence of shear bands is likely. Moreover, in PSCc the specimen after deformation can be rotated to simulate strain path changes. Examples of such experiment were published for different materials (copper, aluminium, …) [7, 8,9].

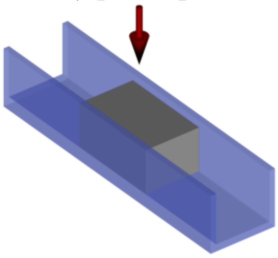

Figure 1. Scheme of plain strain compression test in channel die.

The main goal, but also problem with mentioned tests for polycrystalline materials, is to properly interpret the results, which are affected by errors caused by inhomogeneous distribution of strains, strain rates, temperatures, stresses, etc. Usually, the force and displacement obtained in the test are referenced to initial dimensions of specimen and presented in form of engineering stress and strain. The stress and strain may be used in that form to obtain equation parameters (by approximation), however obtained results are affected by the errors. In order to eliminate influence of mentioned inhomogeneities the inverse technique [10] can be used. Typically the inverse technique uses Finite Element Method (FEM) to simulate material behavioural in a given test. The FEM calculations allow simulate material behaviour taking into account all inhomogeneities. The material properties in FEM simulation are described by flow curve with some initial parameters. In inverse method the parameters are consider as unknowns, which can be found using optimization techniques (e.g. Simplex method). Typically the goal function for optimisation is error between calculated and obtained from experiment forces. Nevertheless, additional quantities may be included into goal function e.g shape of deformed specimen.

Since each plastometric test has its own sources of errors (e.g. arising from different magnitude of inhomogeneities), the inverse method by eliminating influence of the inhomogeneities allows to obtain flow curves independent of the type of the test. Subsequently, the obtained flow curves may be use to simulate (e.g. with the FEM) more complex processes of metal forming (plastic deformation) like e.g rolling, extrusion, forging, etc.

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