

MATERIAL MODELLING AND PHYSICAL BASED MODELS WITH PARTICULAR EMPHASIS ON HIGH STRAIN RATES

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ABSTRACT- The problem of calibrating material models with tests in a limited range of conditions and then applying outside this range is discussed. This is the case when machining simulations are performed where very high strain rates ($>50000\text{s}^{-1}$) can be obtained. The paper discusses the Johnson-Cook model, an empirical model that is common for high strain rate applications and a physical based dislocation density model. Test data for AISI 316L ranging from 0.001 to 10s^{-1} and room temperature up to 1300°C are used for calibration of the models and thereafter additional tests up to 9000s^{-1} at varying initial temperatures are compared with the model predictions.

INTRODUCTION: The description of material behaviour is crucial for all simulations of material deformation processes. Simulation of machining [Vaz jr et al. 2007] has several numerical as well as modelling complications. One problem is to obtain test data for the material at high strain rates. Thus it is always necessary to extrapolate the material model outside the range of calibration. This paper illustrates the complexity of the mentioned problem for two different types of material models describing the mechanical behaviour of AISI 316L.

PROCEDURES, RESULTS AND DISCUSSION: A dislocation density model and the Johnson-Cook model are used as examples when discussion extrapolation of models to high strain rates.

Empirical and physical based models: Physical based models are models where the physical mechanisms are underlying the deformation in contrast to empirical models which are of a more curve-fitting nature. However, due to the need for averaging and also limited knowledge about some of the relations making up the model, physical based models need also be calibrated. Two different types of physical based models exist. One option is to explicitly include variables from physics as internal state variables. The other possibility is to determine the format of the constitutive equation based on knowledge about the physical mechanisms causing the deformation. The latter is a so-called “model-based-phenomenology” [Frost and Ashby 1982]. Some advantages of physical based models are that they may have links, via parameters like grain size etc, to models for microstructure evolution [Kocks & Mecking 2003] and may have a larger domain of validity. It is also hoped that they can be extrapolated outside their range of calibration. This requires that the physical mechanisms implemented in the models still dominate the deformation in the extended range.

Scope of study: A dislocation density model is compared with the classical Johnson-Cook model [Johnson and Cook 1983]. Previous model development [Lindgren et al. 2008] has been based on a strain range up to 0.6, strain rate up to 10s^{-1} , and temperatures up to 1300°C . In this paper the previously calibrated dislocation density model and the Johnson-Cook model are compared with the new data for high strain rates obtained via split Hopkinson pressure bar tests (SHPB).

Numerical procedure: A toolbox has been implemented in MatlabTM where parameter calibration can be done. A constrained gradient method was used in the minimization algorithm and the radial return stress-strain algorithm was used in order to be able to apply varying strain and temperature paths to the model. The temperatures were measured during the tests at low strain rates and computed assuming adiabatic heating for the tests in the high strain rate. The data for the Johnson-Cook model that is used to generate the results shown below are given in Table 1. The model is written as

$$\sigma_y = \left(A + B \bar{\epsilon}^{p^n} \right) \left(1 + C \ln \left(\frac{\dot{\bar{\epsilon}}}{\dot{\bar{\epsilon}}_{ref}} \right) \right) \left(1 + \left(\frac{T - T_{room}}{T_{melt} - T_{room}} \right)^m \right) \quad (1)$$

where $\bar{\epsilon}^p$ is the effective plastic strain and T is the temperature.

Table 1: Material Parameters for Johnson-Cook Model.

Case	A	B	n	C	$\dot{\bar{\epsilon}}_{ref}$	m
Low	248 MPa	1007 MPa	0.452	0.0727	1 s^{-1}	0.259
High	245 MPa	580 MPa	0.587	0.117	1 s^{-1}	0.733

Results: Some examples of measured stress-strain curves compared with the dislocation density model are shown to the left in Fig. 1, from Lindgren et al. [2008]. The model gives an overall good agreement in the range from 0.001 to 10s^{-1} and room temperature up to 1300°C . The Johnson-Cook model does not give any good results when subjected to the entire test data in Lindgren et al. [2008] due to its simple form. Therefore only the curves, shown in the right part of Fig. 1, were used to calibrate it. The obtained parameters are called ‘Low’ in Table 1. These two models were then used to model the response in the high strain rate range and the results are shown in Fig. 2. The Johnson-Cook model can be re-calibrated to fit the high strain rate data well (not shown in paper) and the parameters denoted ‘High’ in Table 1 are obtained but then the fit to the low strain rate range will be poor.

CONCLUSIONS: Re-calibration is not a consistent approach using a physical based model. Rather, the discrepancy indicates that new physics are entering during the deformation at these high strain rates. The correct approach will be to determine the underlying physics, implement it into the model and then re-calibrate. The possible phenomena for deviation may be martensite formation, twinning, a more even structure of immobile dislocation or drag forces on moving dislocations.

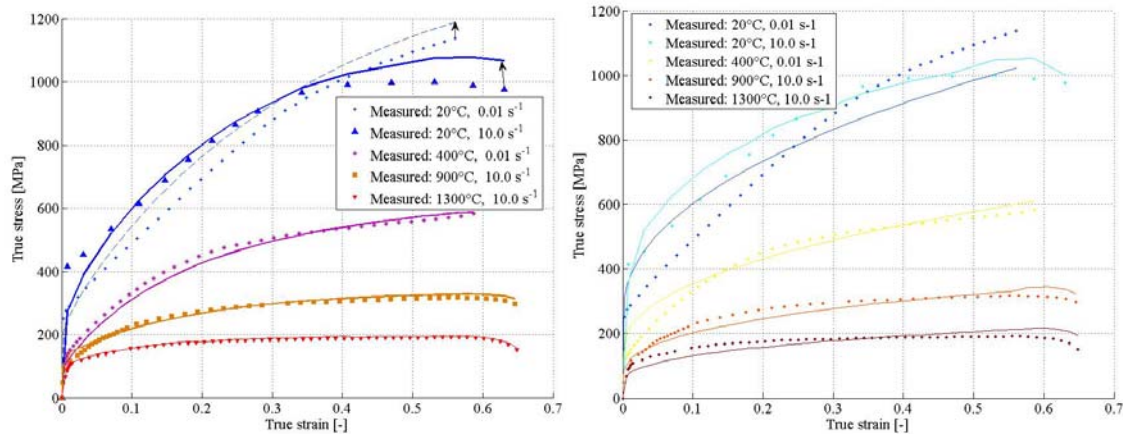


Fig. 1. Flow stress curves for dislocation density model, left, calibrated for strain rates up to 10s^{-1} , and temperatures up to 1300°C [Lindgren et al. 2008] and, right, for Johnson-Cook model calibrated using the shown curves. The lines are computed values.

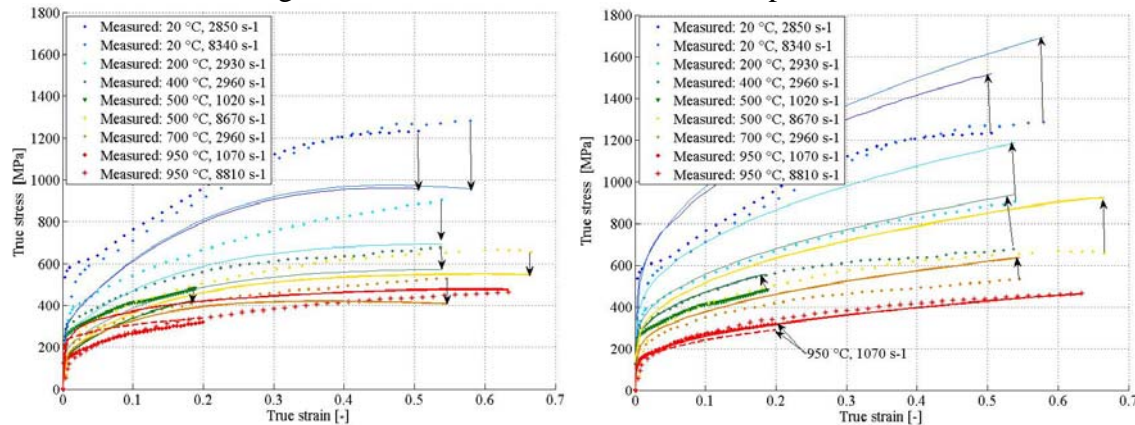


Fig. 2. Flow stress curves for dislocation density model, left, and for Johnson-Cook model, right, extrapolated to high strain rates. The lines are computed values.

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