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MatILDa®: the intelligent data base for FEM simulation

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ABSTRACT

Specific property improvements and an increase in resource efficiency are vital to optimize projects for a wide variety of production processes. A high, up to now unexploited potential is the application of realistic material parameters. The material database MatILDa® is a user-friendly and intelligent tool that provides comprehensive material properties for a wide range of plant and software solutions. Accurate, validated material data adapted to the conditions of the forming process can significantly increase the precision of simulation results, e. g. regarding temperature distribution, thermal expansion, power and work requirements, microstructure as well as phase fractions and the resulting material properties. This contribution explains the use of material data in common simulation programs.

Key words — material data base, forming and heat treatment simulation, experimental data, flow curves, microstructure / recrystallization model, CCT diagrams

1. INTRODUCTION

Simulation is widely used in the field of forming and heat treatment processes. The possibilities range from the simulation of material flow, tool load and power curves to predicting the achievable tolerances so that time-consuming trials are progressively reduced and replaced by "virtual reality" during product development. Thus, realistic simulation has been continuously optimized in recent years. Compromises are made – often unconsciously – with regard to material data. In practice, similar alloys or standard values and functions are applied without knowing the range of validity. Most important in this context, the forming process and the material behavior should be understood as one unit.

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Validated material datasets determined in practical material investigations and matched to the forming parameters and the stresses in the forming process (tension, compression, torsion) can significantly increase the accuracy of simulation results. This is the application field of the material database MatILDa® which has been proven in more than 20 years. For example, the effects of huge deformation on the dynamic and static recrystallization behavior of Inconel 718 were investigated by Borowikow et al. [1] by using flow curves from torsion experiments of this database. Significant improvements in the accuracy of simulation results can be achieved on the basis of accurate material data regarding the calculation of temperature distribution, thermal expansion, force and work requirements, microstructure as well as phase fractions and resulting final properties. To exploit this potential, a wide variety of material data and models can be incorporated in the simulation by MatILDa® (see Fig. 1).

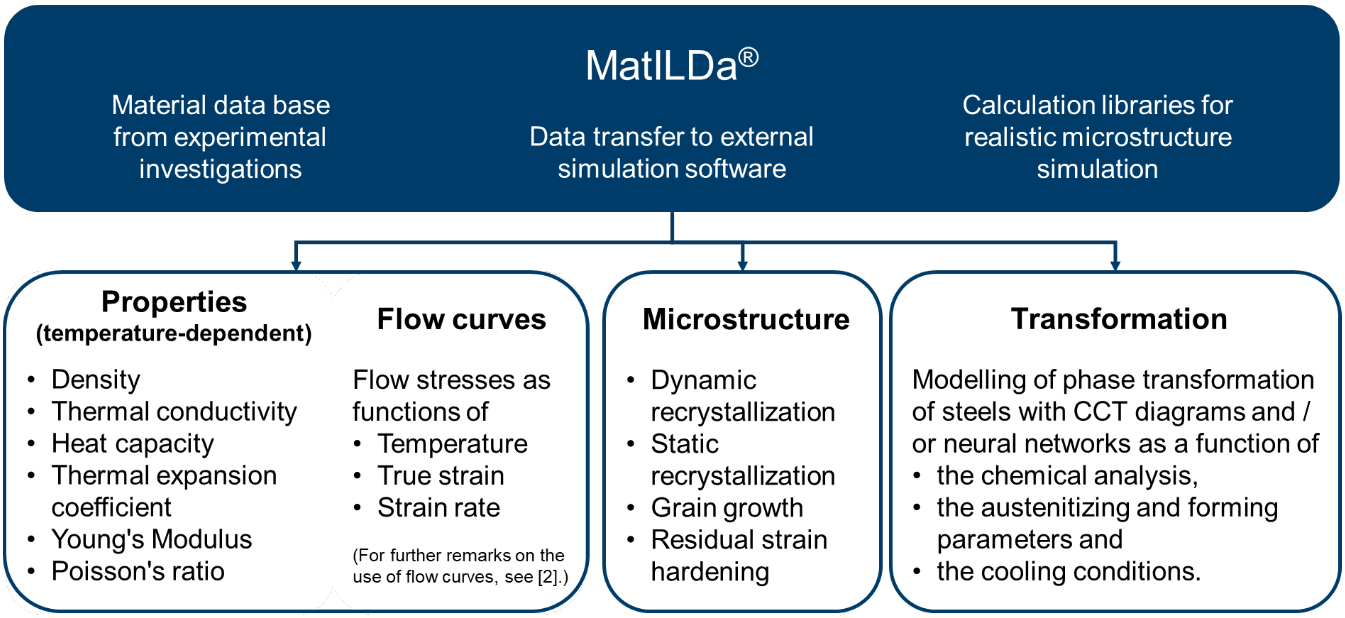

Figure 1: Scope of the material database MatILDa®.

The material database MatILDa® provides physical and mechanical material properties for a wide range of metallic materials. Furthermore, it contains functions and models to realistically calculate flow curves, grain sizes and phase transformation. These functions and models usually have a complex nature: a wide variety of mostly semi-empirical approaches are tested and matched with reality; in case of high compliance, they are included in the material database. To simulate the recrystallization behavior, a semi-empirical model based on the approaches of Sellars [3] and modifications of Lehnert/Cuong [4] is used, whose practical feasibility has been demonstrated in numerous publications [5]-[9]. These models can be imported into FEM and simulation programs either as dataset or function.

2. USE OF MATERIAL DATASETS IN WORKING PRACTICE

At best, the implementation of these material data and models in FEM programs or individual process software is carried out by direct interface: the user simply selects the alloy for the workpiece and tool in the simulation software, and the material datasets are loaded in the background from the material database. Material data for individual materials can usually also be exported in a pre-defined file format from the material database into the simulation software.

During the FEM simulation, the condition in each node is checked and the parameters from the material database are applied as required. For example, the flow stress is determined from the datasets of the flow curves according to the prevailing temperature, the true strain and the strain rate in each node. This procedure also applies to the temperature-dependent material properties as a function of the temperature, which is determined in each node. For the microstructure model, the recrystallization and grain growth processes, and the resulting grain sizes are calculated according to the conditions at the individual nodes. This procedure can also be applied to the phase transformation.

The application of material datasets can be described as follows using the simulation of temperature distribution as an example: material parameters are imported from the material database into the simulation software. The boundary conditions of the forming process are defined in the simulation software. Various models are stored in the software for the simulation, e.g. a temperature model to simulate the time-temperature curve during forming. The material database now automatically supplies the required physical properties of the forming material in the background. This ultimately results in the temperature distribution in the component or in the die. Further application examples such as the distribution of the true strain, the strain rate as well as the grain size are summarized in Fig. 2.

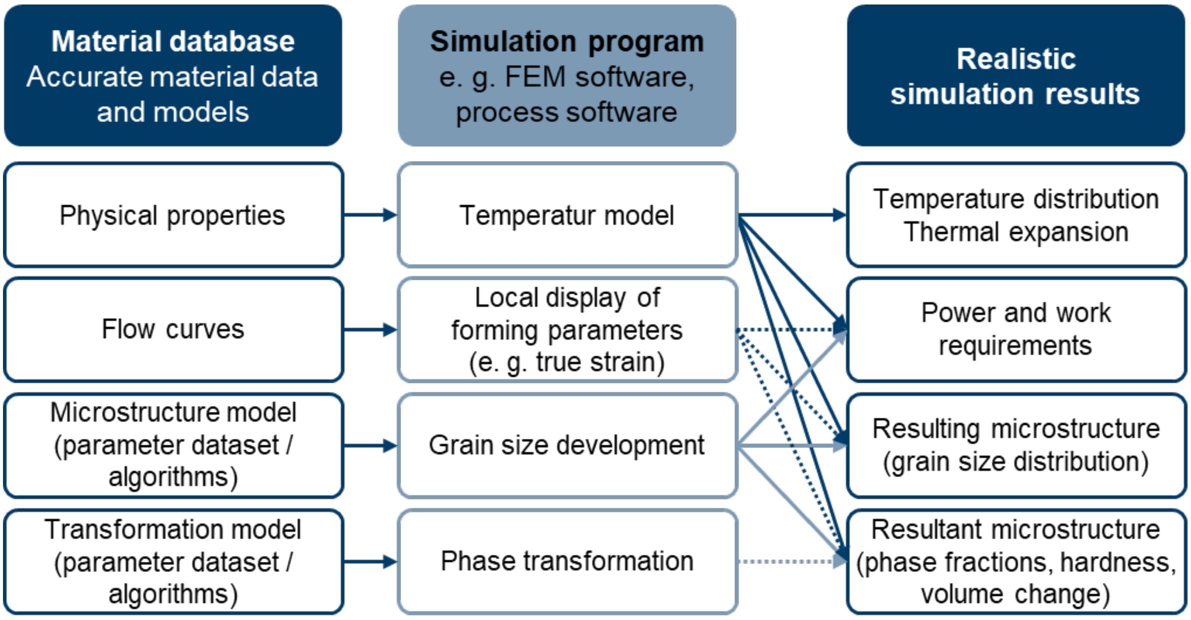

Figure 2: Use of material datasets in simulation.

In every day handling of simulation projects, cases occur in which the dataset for the required material is not available, but data for a similar alloy exist. For this purpose, MatILDa® can combine parameter sets of different materials in a so-called "virtual material" [1]. Note that certain ranges of validity should be respected. In this context, neural networks based on an extensive data evaluation of CCT diagrams can be used for the calculation of phase transformation, too. They apply to a selected range of analyses of a steel grade or a limited steel group and are described as a function of the chemical analysis, the cooling rate and the austenitizing temperature.

In principle, material data and models can be used to simulate any forming and heat treatment process. Hereafter, applications of the validated datasets of MatILDa® are summarized, which demonstrate the advantages of accurate material data and models in simulation projects of real forming processes and process chains:

- Microstructure and property calculation in the open-die forging process to optimize the process sequence [10].
- Microstructure simulation of a bar mill to optimize the temperature control and to avoid subsequent annealing treatment for selected materials [10].
- Die forging of an Inconcel 718 in a 3-step manufacturing process to predict the grain size during forging [11].
- Temperature and microstructure simulation as well as distribution of forming intensity for a KOCKS-3-roll RSB® [12].
- Determininating the interaction between technological parameters and microstructure formation for the process chain, producing a turbine disk made of Inconel 718 by four cylindrical upsetting operations and final shaping with subsequent trimming [13].

3. COSTS AND BENEFITS OF VALIDATED MATERIAL DATA

A large number of these material data and models exist and should be used. Of course, a cost-benefit analysis justifies the decision to acquire material data. For better assessment, the experience of the authors is summarized.

For known alloys, material data can be gathered from literature. This is time-consuming and the integration of these data requires special know-how. Acquiring the complete spectrum of material properties in material investigations as well as creating material models (e.g. microstructure and transformation model) causes considerable costs: for *one steel* alloy, approx. 70,000 € must be expected. In that case, the acquisition of existing knowledge is a real alternative. This is illustrated in Fig. 3, showing a comparison of the costs for recording a new material dataset for *one steel* alloy with the corresponding acquisition of material data and models, as well as the license fee for a material database with *a large number of steel alloys*.

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New acquisition of the complete property spectrum incl. creation of the material models for one steel alloy	Acquisition of material data and models for one steel alloy	License fee for a material database with material datasets for numerous steels

Figure 3: Approximate costs for material data of steel alloys.

The estimation of the financial benefit depends on the materials and the manufacturing process. For production processes, the following optimization fields emerge for the use of simulation software in combination with exact material data:

- *For process design:* The very precise prediction of the required forces and resulting stresses as well as the finishing mechanical properties in a manufacturing process can lead to savings in resources and work effort by eliminating costly test campaigns. For example, when making design changes to tools, the stresses can be reliably estimated.
- *When processing new alloys in existing processes:* Processes can be adjusted more precisely to the new requirement by means of precise simulation, with savings in resources and work effort due to unnecessary test series. This applies, for example, to the selection of suitable temperature control for a new alloy.
- *For the identification of product defects:* When analyzing product defects, a realistic simulation can provide information about their origin. This is done, for example, in die-forging by checking the filling of the dies or the achievable microstructure.

Once you have been convinced by the higher compliance of the simulation results by using accurate and validated material datasets, you will establish realistic material data and models as standard in simulation. Therefore, it is worthwhile for industrial users, who regularly simulate their forming or heat treatment processes to use a material database designed for this purpose. The following aspects should be considered when looking for suitable material datasets or a database for the simulation:

- The material datasets should be easily integrated and used in the simulation program. This can be done via interface or data import.
- The validity range of the material datasets should represent the process windows of the industrial process (temperature, true strain, strain rate, ...).

- The test setting from material investigations should be assigned to the material datasets. At best, the main stress in the forming process corresponds to the main stress state of the test.
- Material data should be provided by competent contact persons with very good materials expertise, who can assess the suitability of the material datasets for the respective requirements.

4. SUMMARY

Nowadays, almost every forming and heat treatment process can be simulated. The demands on the accuracy of the simulation results are very high, whereby a considerable potential for improvement is seen in the use of accurate, experimentally determined material data and models matching the forming parameters and the main stress state of the forming process. In addition to physical properties, flow curves and CCT diagrams resulting from practical material investigations are available in the material database MatILDa®. It also includes a microstructure model built from semiempirical and data-based approaches to describe recrystallization behavior as well as grain growth and neuronal networks to extend the calculation of transformation behavior. Data can be transferred to FEM or other simulation programs via an interface. The material database MatILDa® is designed to make material simulation accessible to a wide range of industrial users because of its uncomplicated interface, and, moreover, it can be used by specialists as a tool to analyze parameter influences in forming and heat treatment processes.

REFERENCES

[1] A. Borowikow, H. Schafstall, H. Blei, D. Wehage, M. Borowikow: Integrierte Gefügemodellierung bei der FEM-Simulation mit Hilfe der Werkstoffdatenbank “MatILDa®“, Numerische Simulation Verarbeitungsprozesse und prozessgerechte Bauteilgestaltung 2.-3. November 2004, Kompetenzzentrum Neue Materialien Bayreuth (2004).

[2] A. Borowikow, D. Wehage, M. D. Bambach: Einfluss von Fließkurven auf die Berechnung des Kraft- und Arbeitsbedarfs bei der Simulation von Warmumformprozessen. massivUMFORMUNG (March 2021), pp. 24-29.

[3] C. M. Sellars, L. A. Whiteman: Product Technology Conference on “Controlled rolling prozessing of HSLA-steels”. York (1976).

[4] N. D Cuong: Mathematische Modellierung und Simulierung der Gefügebildungsvorgänge beim Warmwalzen in Kalibern, vorzugsweise beim Walzen von Stabstahl und Draht. Dissertation TU Bergakademie Freiberg (1991).

[5] A. Borowikow: Modellbetrachtungen zur Ver- und Entfestigung höherfester schweißbarer Feinkornstähle. TU Bergakademie Freiberg, Berg- und Hüttenmännischer Tag (1990).

[6] W. Lehnert, D. C. Nguyen, H. Wehage: Simulation of austenitic microstructure in rod and wire rolling of quenched and tempered steel grades. Steel research (1995) No.11, p. 66.

[7] W. Lehnert, D. C. Nguyen, H. Wehage: Werkstoffgefüge beim Walzen von Draht und Stabstahl. Draht Vol. 44 (1993) No. 10, pp. 559-566.

[8] W. Lehnert; D. C Nguyen, H. Wehage, R. Werners: Simulation der Austenitkornfeinung beim Walzen. Stahl und Eisen (1993) No. 6, p. 113.

[9] H. Wehage, U. Skoda-Dopp, U. Quitmann, W. Sauer: Stichplansimulation und -optimierung für das Warmflachwalzen. MEFORM 98. Umformtechnisches Seminar Modellierung von Umformprozessen am Institut für Metallformung der TU Bergakademie Freiberg (February 1998).

[10] A. Borowikow, D. Wehage, H. Blei: Modell zur Gefüge- und Eigenschaftsberechnung für online und offline Anwendungen. XXVI. Verformungskundliches Kolloquium, Planneralm, AT (March 2007), pp. 123-137.

[11] N. Biba, A. Borowikow, D. Wehage: Simulation of Recrystallisation and Grain Size Evolution in Hot Metal Forming. AIP Conference Proceedings Vol. 1353, No. 1, American Institute of Physics (2011), pp. 127-132.

[12] M. Kruse, M. Schuck, A. Borowikow: Innovations in simulation of microstructure developments. Materials Science Forum Vols. 706-709 (2012), pp. 2170-2175.

[13] N. Biba, A. Borowikow, D. Wehage: Möglichkeiten und Grenzen der simulationsbasierten Prozesskettenoptimierung. Internationale Konferenz „Neuere Entwicklungen in der Massivumformung“. Fellbach bei Stuttgart (May 2015).