Physical and Computer Modeling of Extra-High Temperature Processes: Problems and Challenges

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***Abstract*—The paper describes the methodology of integrated modeling of extra-high temperature steel processing in supporting the design of new technologies (e.g. soft-reduction and direct strip casting processes). The work is supplemented with examples of the practical use of the proposed methodology in supporting physical simulations. The problems and challenges of the proposed solution are briefly described.**

Keywords - Finite Element Method; Monte Carlo method; physical simulation; computer simulation; mushyzone; Smoothed Particle Hydrodynamics.

I. INTRODUCTION

The contemporary approach to the issues of engineering new processes involves the extensive application of computer technologies and methods. Then, the development of electronics, including computers and implementation of numerical simulation methods, has led to the construction of equipment allowing complex technological processes to be tested in the laboratory scale. As the tests are conducted on actual materials, the term "physical simulation" has been adopted as opposed to the numerical simulation. The physical simulation is directly related to a new type of computer controlled tensile testing machines, able to change the experiment conditions automatically during the experiment according to the programme adopted by the engineer. The evaluation of mechanical properties of samples subjected to various simulation variants is the basis for developing a special "process map", which enables the optimal parameters of the continuous casting machine to be determined when casting a specific steel grade [1]. It allows the casting process parameters (e.g. casting speed, cooling rate in the primary and secondary zones) to be adjusted so as to avoid the potential threat of cracks. As may be concluded from the above description, each steel grade requires separate tests. The main problem concerning the experimental work is the sample heterogenous temperature. Keeping temperature constant during the whole experimental procedure is difficult [2]. There are also some problems and challenges with the experimental and numerical simulation procedure:

- prediction of extra-high temperature strain-stress relationships,
- prediction macro/microstructure (grain size),
- prediction of heat transfer coefficients (necessary for numerical simulations),
- extremely high distortions of the mesh during simulation of deformation at temperatures close to the solidus line,
- deformation experiments at temperatures close to the solidus line (semi-solid state).

A lack of good methods for semi-solid steel simulation and significant inhomogeneity in strain distribution lead to a weak accuracy of the resulting stress field. In order to solve the above problems, the methodology integrating the areas of physical and computer simulation was proposed. A schematic diagram of the integrated modeling methodology combining the advantages of physical and computer simulation is presented in Figure 1. It consists of three main layers: physical simulation, computer simulation and supporting equipment. The proposed solution uses a methodological research capability of modern Gleeble 3800 thermo-mechanical simulators to simulate physical processes [1] (first layer), and the benefits of numerical modeling (second layer, DEFFEM3D software [1][2]). Mathematical models are the original solutions of the developed DEFFEM 3D software, such as the thermo-mechanical model of steel deformation in the semi-solid state with variable density, and the multi-scale model of resistance heating coupled with grain growth modelling in the micro scale. More details about mathematical models can be found in monograph [1].

Supporting equipment (third layer) includes scanning microscope, Zwick Z250 testing machine, thermal imaging camera, 3D system scanning and tomograph.

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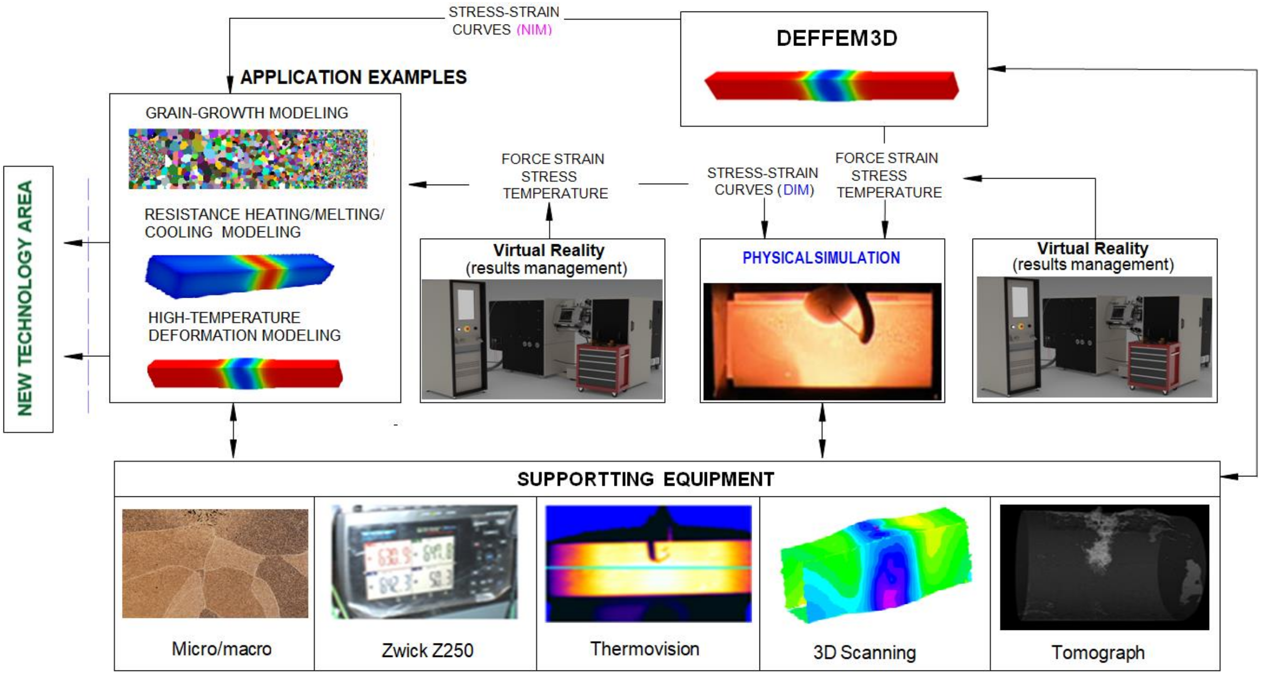

Figure 1. The scheme of the methodology (coupled modeling - physical and computer simulation) with examples application.

II. APPLICATION EXAMPLES

The developed methodology was used in the course of research and development works on the interest rate of new technologies for the aircraft industry:

- application of the methodology in computer-aided design of casting critical parts of aircraft engines. Simulations of casting in ceramic molds obtained using the lost wax method. Figure 2(a) presents an example temperature distribution during cooling of the blade of jet engine.
- support in the design of hot forming technology for the strengthening of the intermediate hull directing airflow in a jet engine. Simulation of the resistance heating of the sheet before the forming process. Figure 2(b) presents an example temperature distribution during resistance heating of the blank.

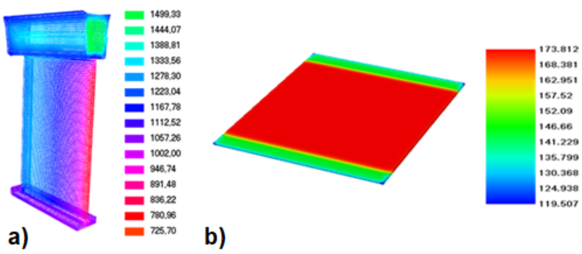

Figure 2. Application examples (aicraft industry).

III. CONCLUSIONS

The developed numerical tool (DEFFEM 3D software), combined with the capabilities of modern thermo-mechanical simulators of the Gleeble series, allows theoretical support for the design of new technologies. This allows for restricting the number of expensive experimental tests to the minimum, e.g. by selecting a suitable heating schedule to achieve the desired temperature at the sample section, or getting additional information about the process, eg. estimating zones with diversified grain growth dynamics, or information on local cooling rates at any point within the volume of the sample tested. Further research will focus on developing numerical tools based on particle methods, such as SPH (smoothed particle hydrodynamics). This approach will allow to solve some of the problems related to the modeling of steel deformation in the semi-solid state using the finite element method.

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