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PHYSICAL AND COMPUTER MODELING OF EXTRA-HIGH TEMPERATURE PROCESSES: PROBLEMS AND CHALLENGES

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The Fifteenth International Conference on Advanced Engineering Computing and Applications in Sciences
ADVCOMP 2021
October 03, 2021 to October 07, 2021
Barcelona, SPAIN

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Nguyen Thi Thu Trang received the master's degree in engineering from Vietnam National University of Agriculture, Vietnam 2015. She is currently a PhD student at AGH University of Science and Technology, Poland.

Her research interests are Materials Engineering, Metal Forming, Physical and Computer Simulation of metal deformation processes, etc.

AGENDA

01 **The purpose of the presentation**

02 **Integrated modeling methodology (IMM) in context of designing of new technologies** (a brief introduction and the leading idea)

03 **Physical simulations**
(Gleeble 3800 thermo-mechanical simulator)

04 **DEFFEM 3D software for Gleeble thermo-mechanical simulators**
(design philosophy of DEFFEM package, modeling approach, examples, highlights)

05 **Conclusions and further work**

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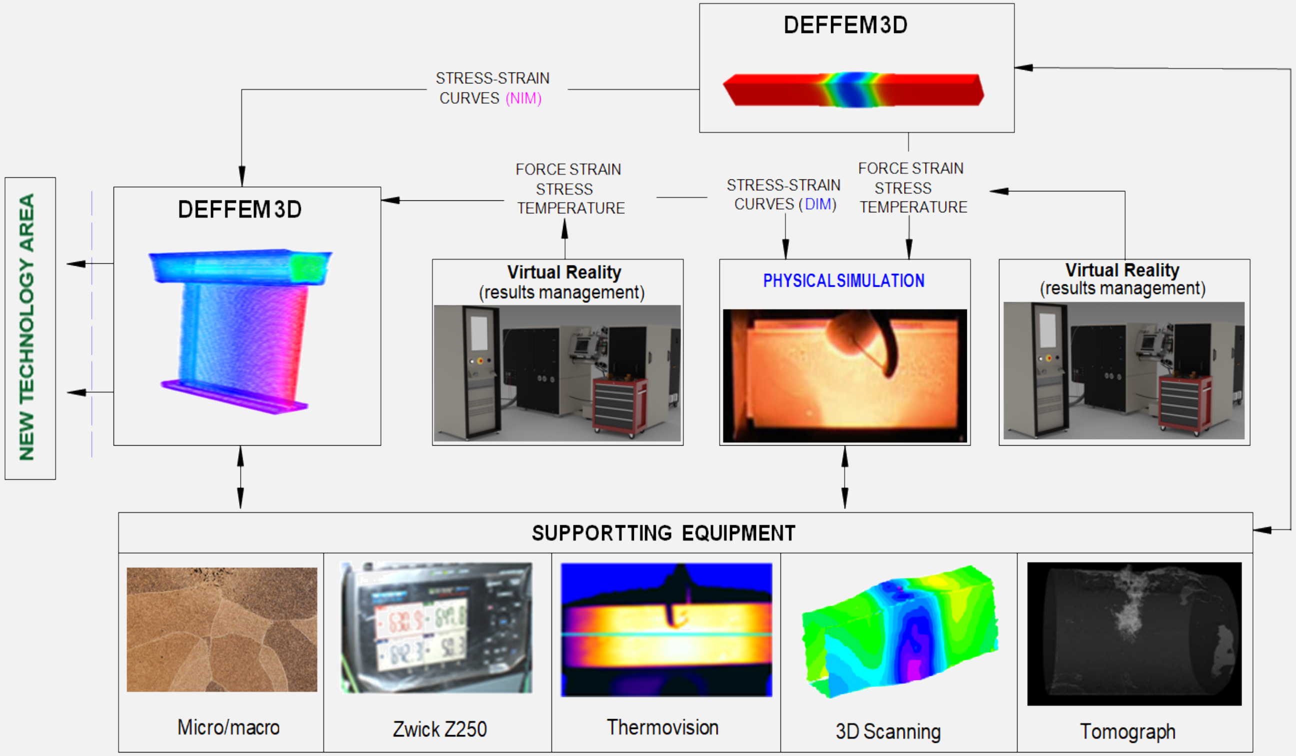
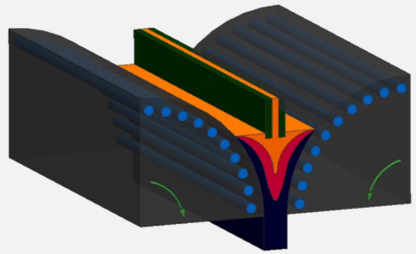
01. THE PURPOSE OF THE PRESENTATION

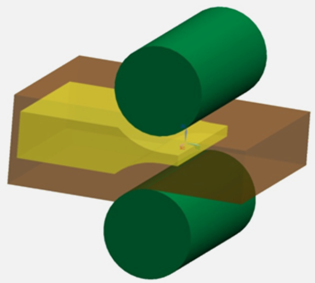
Presentation of the main assumptions of the methodology of integrated modeling of extra-high temperature steel processing in the aspect of supporting the design of new technologies (e.g. soft-reduction and direct strip casting processes) + a brief overview of problems and challenges.

02. IMM IN CONTEXT OF DESIGNING OF NEW TECHNOLOGIES CORE OF IMM





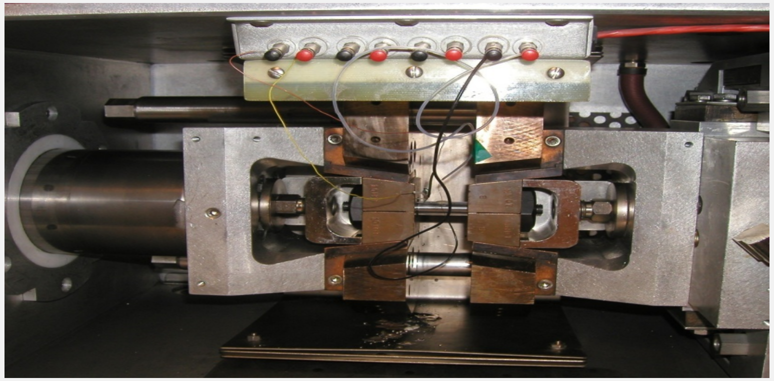
Casting with two rolls



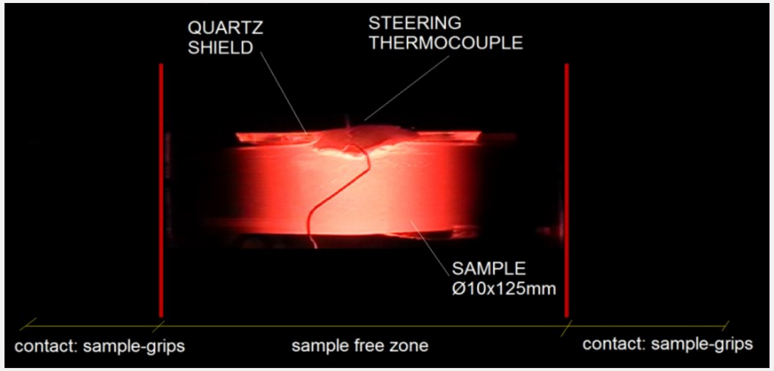
„Soft-reduction”

03. PHYSICAL SIMULATIONS

GLEEBLE 3800 THERMO-MECHANICAL SIMULATOR



The experimental equipment Gleeble 3800 simulator



Simulation of resistance heating (S355 grade steel)

Materials testing and processes:

- Mechanical properties (mushy-zone),
- Melting and solidification,
- Continuous casting,
- Hot rolling,
- Forging,
- Extrusion,
- Heat treatment,
- Welding and so on....

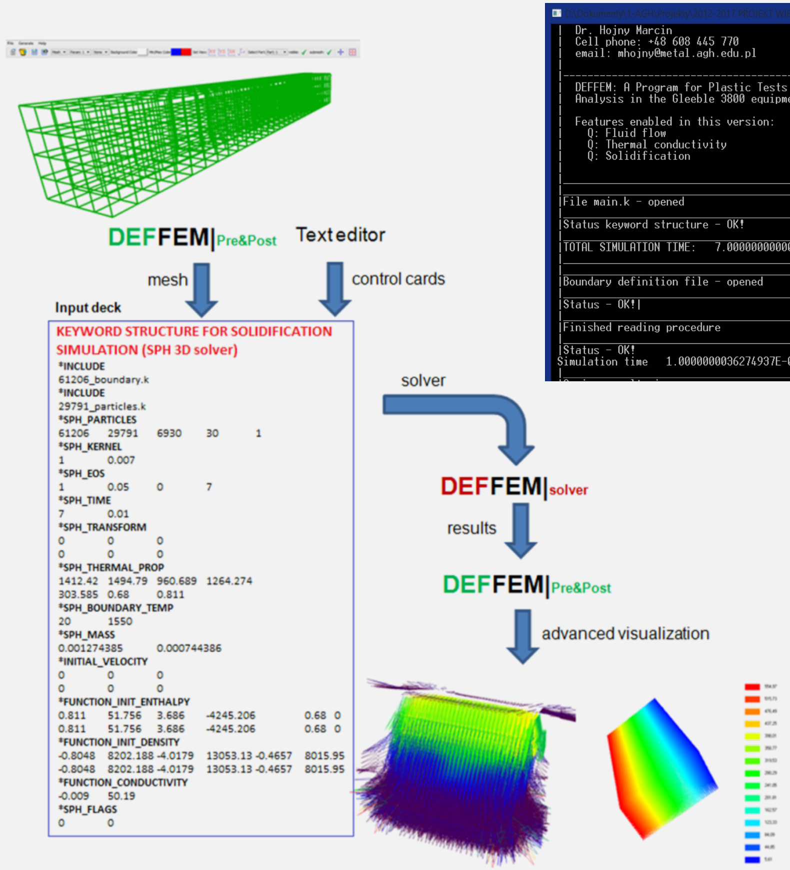
The essential aim of the simulation was the reconstruction (on a small sample) the changes of temperature and stress for material which was subjected deformation in conditions similar to industrial process.

In this case, the exact response of the material to the applied loads is precisely recorded, which is not possible directly during real production.

04. DEFFEM 3D SOFTWARE

- Developed since 2009;
- NetBeans IDE 8.0 developer environment;
- C++ and Fortran object language (solvers);
- Only C++ object language programming for advanced Pre&Postprocessor;
- In-house, highly-adaptive numerical code 3D;
- Over 50 000 lines of code;

- **No external (commercial) modelling software necessary;**
- **Special algorithms and modules supporting designing new technologies;**



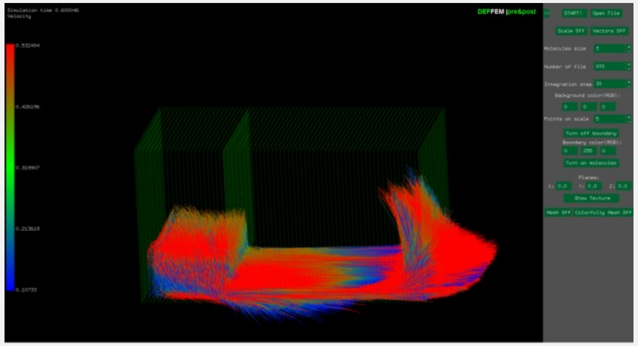
04. DEFFEM 3D SOFTWARE

HIGHLIGHTS (POSTPROCESSOR)

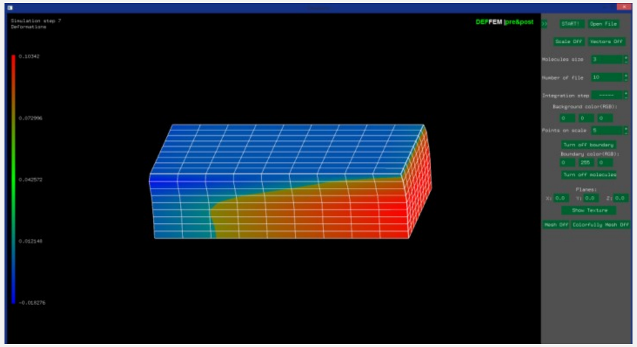
- Full vector visualization based on GLSL graphic pipeline programming language;

GPU processor

- Isolines algorithms;
- Stereoscopic algorithms (dedicated for BARCO system, microstructure 3D results analysis & mezoscale fluid flow);



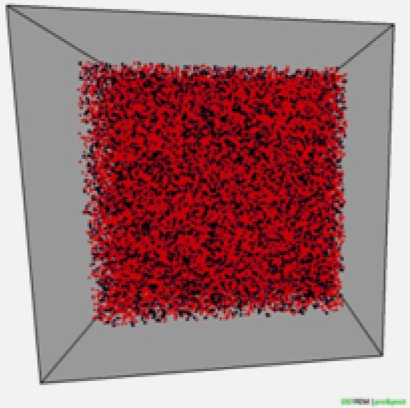
*Fluid flow (vector velocity, **GLSL language**)*



*Forging (shading option, **OpenGL**)*

The modular design of the system based on Barco Gemini

Porous structure



04. DEFFEM 3D SOFTWARE

HIGHLIGHTS (SOLVERS)

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01

MODIFIED RIGID-PLASTIC MODEL

A high accuracy in fulfilling the constant or controlled volume condition is required in the proposed solution. This approach arises from the fact, that errors caused by not fulfilling these conditions may be comparable with the volume changes caused by the variable metal density in the mushy zone. Also because of large differences in the yield stress for individual sub-areas of the deformation zone, which in the temperature range in question are caused by even slight temperature fluctuations, and related difficulties in meeting the non-compressibility condition, **this condition was included in the analytical form, which makes the solution more complicated, but substantially improves its accuracy.**

02

FUNCTIONAL MODEL OF RESISTANCE HEATING

The heat source efficiency in the model is a function of resistance, which in turn depends on temperature and special function which represents intensify of heating.

03

MICRO GRAIN-GROWTH MODEL

Considering the temperature gradient on the intensity of grain growth during **heating-melting-cooling (complex cycle)** process (scaling function).

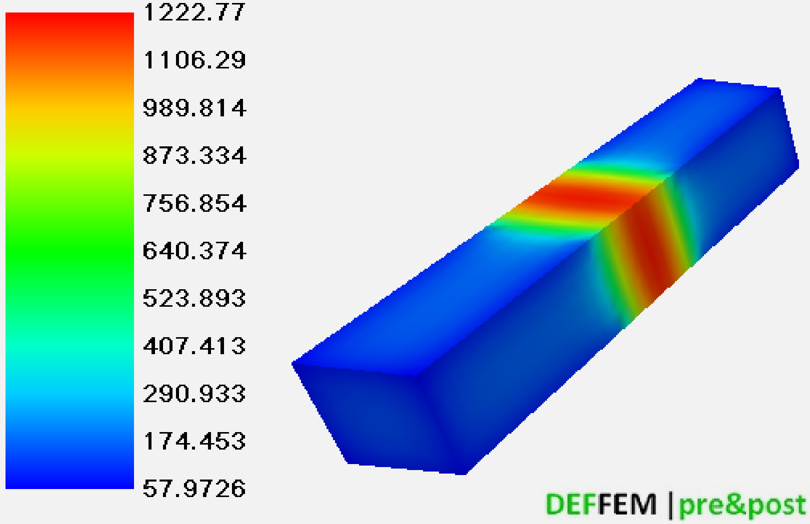
04. DEFFEM 3D SOFTWARE

APPLICATIONS (GLEEBLE 3800)

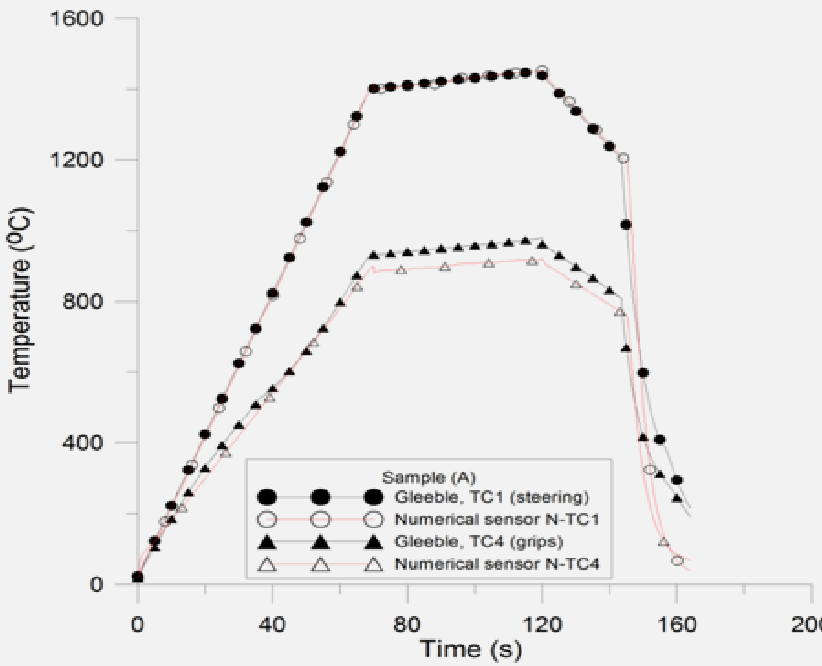
01

RESISTANCE HEATING

Heating-melting-cooling simulation process.



The temperature field during the process of controlled cooling at a rate of 10 °C/s (145-th second of the process)



Changes in temperatures obtained by physical and numerical simulations according to the readings of thermocouples and numerical sensors

04. DEFFEM 3D SOFTWARE

APPLICATIONS (GLEEBLE 3800)

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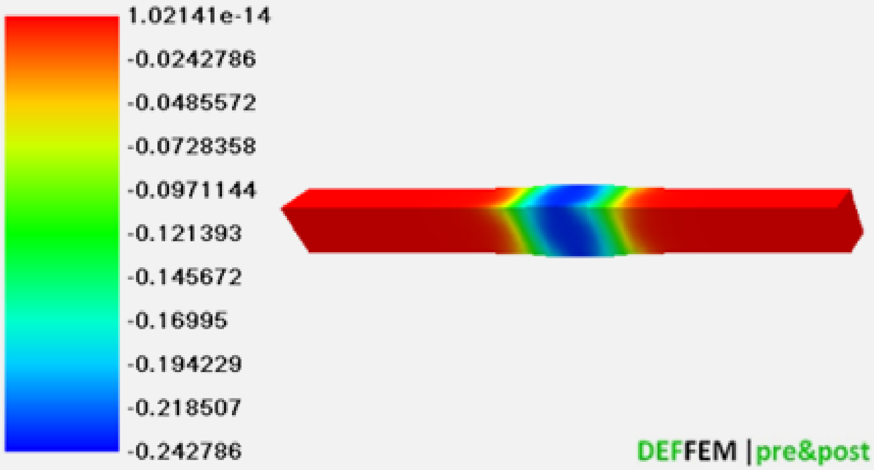
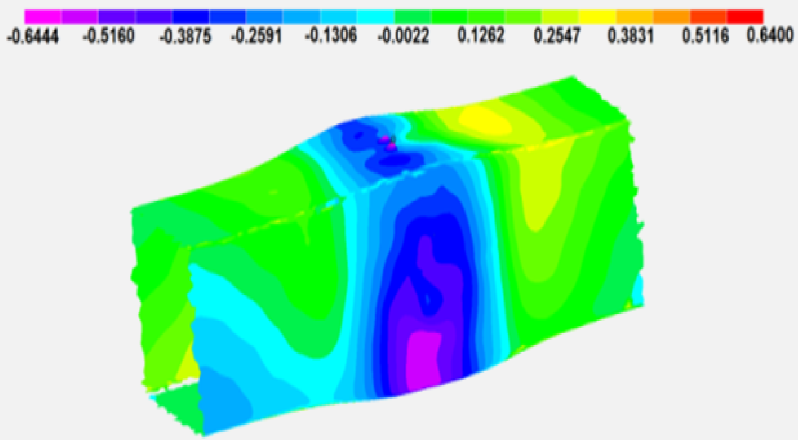
02

DEFORMATION

Deformation in the semi-solid state.



Strain distribution, eps-z component (nominal temperature 1200 ° C, sample type C, steel S355)

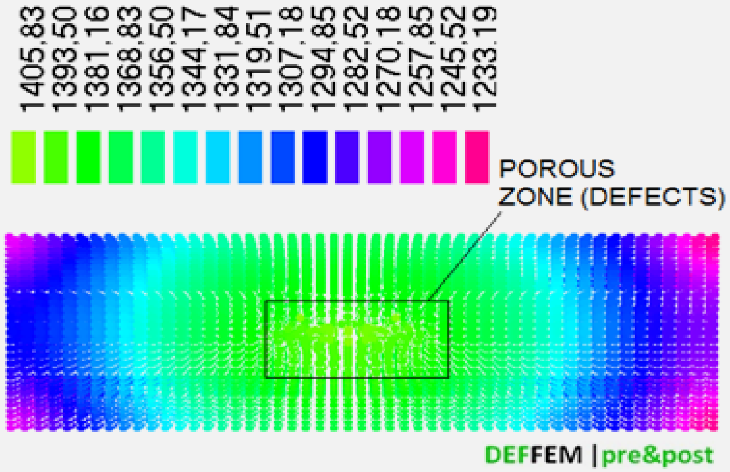


Map of deviations between the finite element mesh and the mesh obtained from the 3D scanner after scanning the actual sample after deformation (sample type C, nominal temperature 1400 ° C, steel S355)

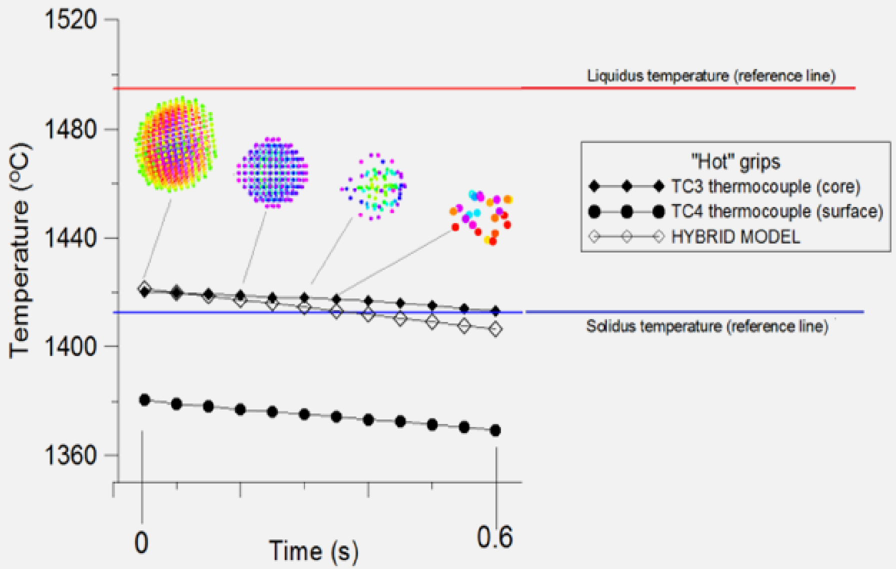
03

SOLIDIFICATION

Hybrid solutions (FE+SPH). Heating-melting-cooling simulation process with local flow of liquid steel.



Particle temperature distribution in the longitudinal-section of the sample after completion of the solidification process with visible possible porous zone (defects) within the sample



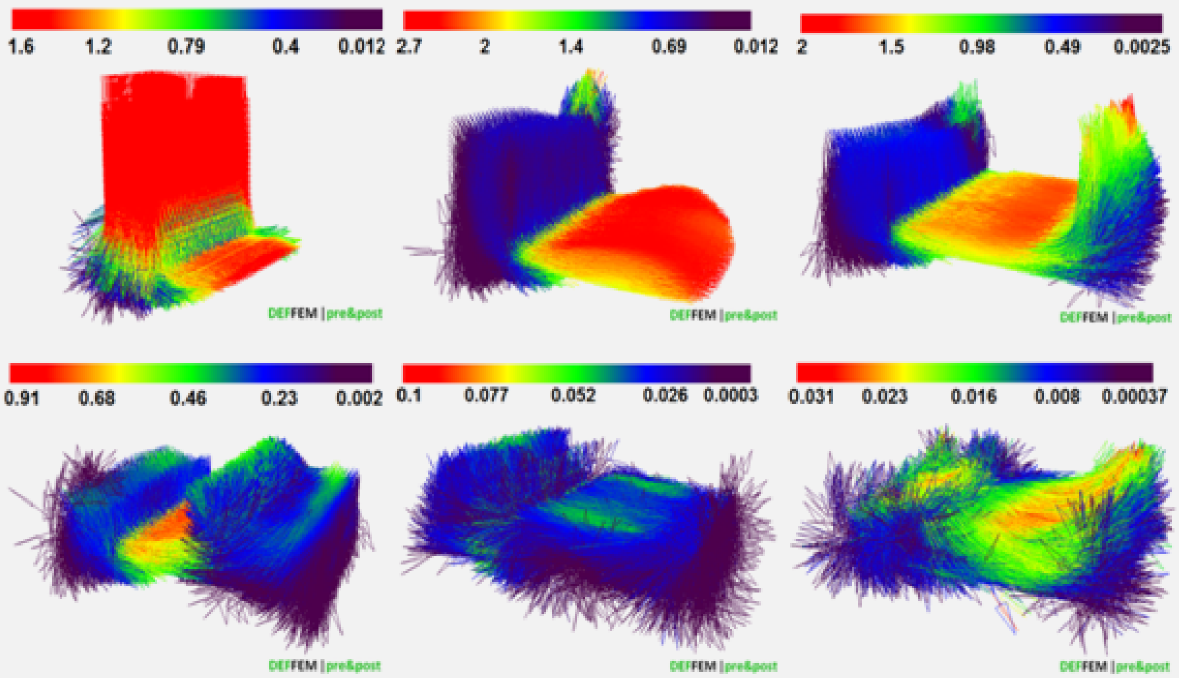
Temperature change versus time (experiment and hybrid model, solidification stage)

04. DEFFEM 3D SOFTWARE

04

FLUID FLOW

Fluid flow simulation with optional thermal effect.



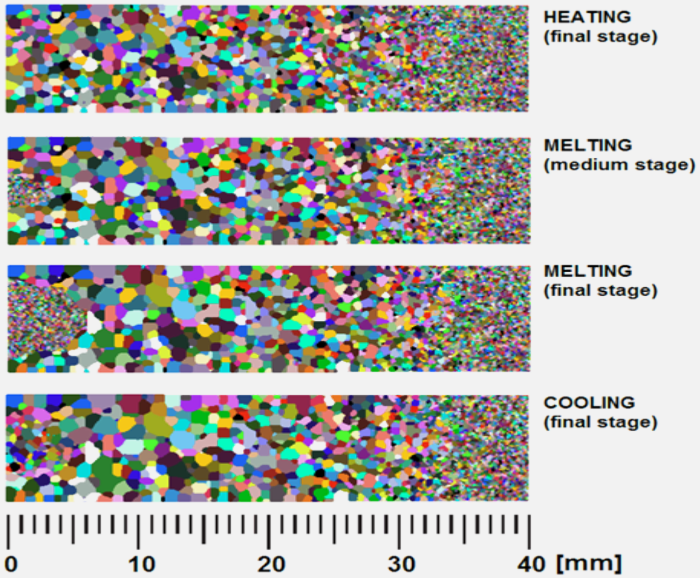
Velocity distribution
(selected stages of test simulation)

04. DEFFEM 3D SOFTWARE

05

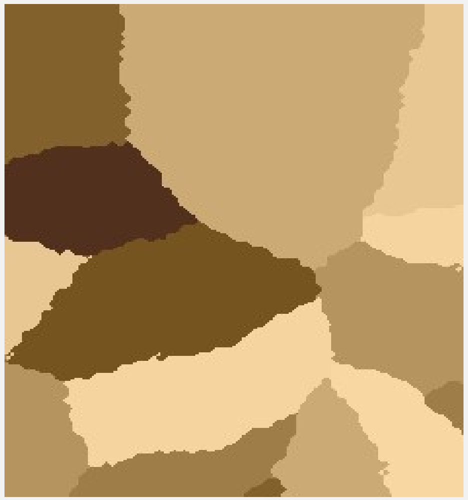
GRAIN GROWTH

Grain growth simulation with boundary mobility function. Resistance heating combined with the melting and controlled cooling of steel samples.

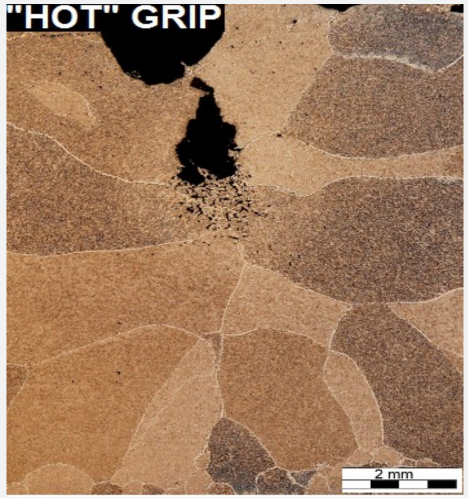


Virtual macrostructure of the sample in the longitudinal section in the sample axis for the selected four process stages (second degree boundary mobility function)

SIMULATION



EXPERIMENT



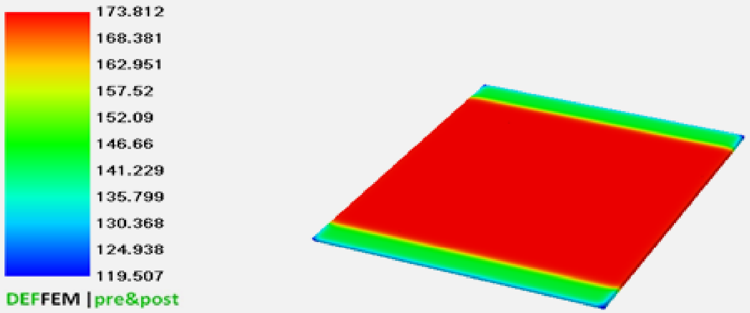
Macrostructure after heating the sample to the nominal test temperature of 1450ºC and cooling at 1 ° C / s („hot" grips)

04. DEFFEM 3D SOFTWARE

06

HOT FORMING (RESISTANCE HEATING OF THE BLANK)

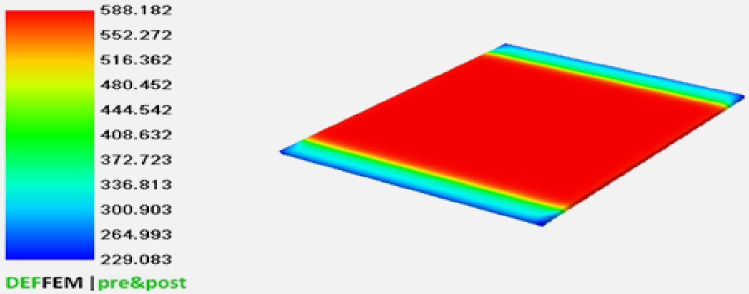
Support in the design of hot forming technology for the strengthening of the intermediate hull directing airflow in a jet engine.



AMS 5596

Temperature achieved during the industrial test: ***201 ° C***
Calculated temperature: ***173 ° C***

AMS 5596



Temperature achieved during the industrial test: ***603° C***
Calculated temperature: ***588° C***

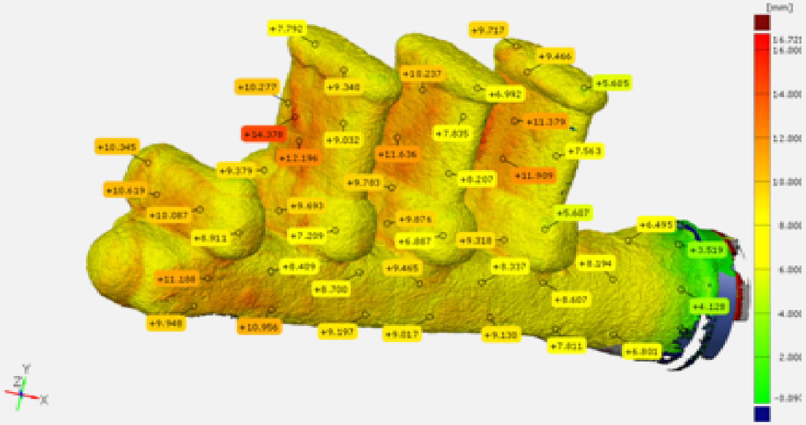
04. DEFFEM 3D SOFTWARE

APPLICATIONS (INDUSTRY TESTS)

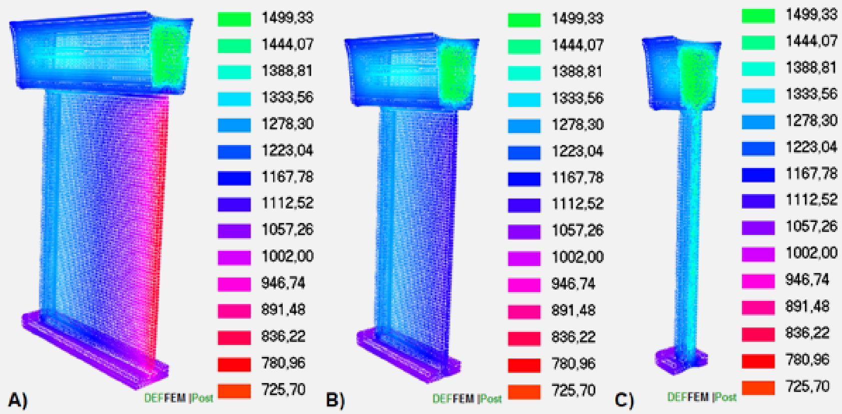
07

CASTING

Simulations of casting in ceramic molds obtained using the lost wax method.
Application of the DEFFEM 3D package in computer-aided design of casting critical parts of aircraft engines.



The map of real thickness of the mould obtained in mapping the 3D scans of the ceramic mould and the wax system



The temperature field distribution in chosen cross-sections of the blade (section by the X plane)

An innovative feature of the solution is the coupling of the SPH solver based of the DEFFEM package with 3D scanning systems. The proposed solution will allow the numerical calculations to take into account the actual geometry of the mold for variable thickness distribution on the cross-section of the ceramic mold wall.

05. CONCLUSIONS AND FURTHER WORK (PROBLEMS AND CHALLENGES)

The developed methods and numerical tools, combined with the capabilities of modern thermo-mechanical simulators of the Gleeble series, allow theoretical support for the design of new technologies. Problems and challenges (directions of further work) are shown in Table 1.

Table 1. Problems and challegnes

1	Prediction of extra-high temperature stress-strain curves
2	Strong mesh distortion (deformation close to solidus line)
3	Non-uniform temperature distribution in the sample volume
4	Prediction macro/microstructure (grain size)
5	Prediction of heat transfer coefficients
6	Experiments (deformation close to solidus line)
7	Physical simulation of direct strip casting (DSC) process

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THANK YOU

The work was realized as a part of fundamental research financed by the Ministry of Science and Higher Education, grant no. 16.16.110.663.