Basic Information:
Course Title: Mathematical modelling and simulation of thermo-metallurgical influence of welding and related processes
Lecturer: Prof. DSc Nikolay Doynov
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Total Teaching Hours: 30

Annotation (up to 150 words)

The aim of the proposed course is to deepen the basic knowledge and skills in the application of deterministic methods for modelling the effects leading to property changes in the heat-affected zone of processes such as welding, local heat treatment and additive manufacturing. The focus of the course is on unsteady and quasi-steady thermal processes, microstructural alternations, and diffusion processes of gases dissolved in the metal. The course is intended for the training of PhD students mainly in mechanical engineering (02.01.00.) and metallurgy (02.09.00.), but is also applicable to other specialties of technical sciences (02.00.00.).

The content includes the basic modelling principles, classification of approaches and methods, and practical application aspects. In particular, it covers: functional-analytical and numerical (FEM) solutions: transient temperature field; non-isothermal diffusion and diffusionless processes of solid state phase transformations, precipitations in steels and Al-alloys; solubility and diffusion of gases in metal. In addition, the relationship between thermo-physical properties and metallurgical reactions is discussed.

Course content (brief description by topics or modules)

Topic 1. Modeling and simulation, definitions, classification, general approach, physical characterization of processes

Topic 2. Temperature field during welding and related processes – general concepts, differential equation of heat conduction, thermophysical properties, and model parameters

Topic 3. Functional-analytical solutions, fundamental solution, boundary and initial conditions, superposition method, method of mirror images

Topic 4. Numerical solutions by FEM, implicit and explicit analysis, quasi-stationary solution, spatial and temporal discretization, h- and p-method

Topic 5. Application for solving specific problems, peculiarities in the application and comparison of numerical and analytical solution methods (Dimensioning of the temperature field; Momentary and continuous heat sources; Moving and fast-moving heat sources)

Topic 6. Classification and characterization of heat sources, heat flux distribution, models, and parameters

Topic 7. Modeling of microstructural changes in steels, phase transformations, boundary conditions, general dependencies and parameters (Austenitization process; Anisothermal decomposition of austenite; Dependence of maximum temperature, austenitization time, cooling rate)

Topic 8. Characterization of the temperature cycle during single heating, parameters, linking of temperature and microstructural models in a general model

Topic 9. Phase transition in the solid state – review and classification of models, method for linking isothermal and anisothermal models
Topic 10. Application of phase transformation models, specific features, input data and calibration, processing of results
Topic 11. Features of multi-cycle temperature exposure, dependence on intermediate temperature, maximum temperature, austenitization time, cooling rate
Topic 12. Modeling of dissolution and precipitation process – changes in dispersion-strengthened alloys
Topic 13. Modeling of the recrystallization process – changes in strain-hardened alloys
Topic 14. Diffusion of hydrogen and nitrogen in metal – relationship between solubility and concentration, characteristics of different gases, classification of models
Topic 15. Application of different models, input data and calibration, presentation of results, comparison

Teaching and assessment methods
hybrid

Competencies acquired as a result of training (3–5 points)
The expected outcome is an enhanced theoretical background and practical skills in conceptualising, calibrating and applying models to simulate processes and predict local properties in the heat-affected zone.

Literature:

1. Karkhin, V.A., Thermal Processes in Welding, Springer, 2019
2. Michailov, V., Karkhin, V.A., Petrov, P., Principles of Welding, Politech. Uni. Publ. St. Petersburg, 2016
3. Lindgren, L.-E., Computational Welding Mechanics, Woodhead Publishing, 2007
4. Doynov, N., Ossenbrink, R., Michailov, V., Sensibilitätsanalyse der thermomechanischen FE-Schweißsimulation, Shaker Verl., 2012
5. Grong, O., Metalurgical Modelling of Welding, The Institute of Materials, 1994
6. Buchmayr, B.: Computer in der Werkstoff- und Schweisstechnik, DVS-Verl. Dusseldorf, 1991
7. Ossenbring, R., Thermomechanische Schweißsimulation unter Berücksichtigung von Gefügeumwandlungen, Shaker Verl., 2009

Additional information (optional) (e.g., special requirements, laboratory equipment, prior knowledge)
This course may also be held in English or German, upon request