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Editorial

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Biographical notes: Janez Grum is a Professor of Materials Science at the University of Ljubljana, Slovenia, Faculty of Mechanical Engineering. He is a scientific board member of several journals. This includes an Editor-in-Chief of the *International Journal of Microstructure and Material Properties* – IJMMP. He is a World-recognised Scientist and a Lecturer. He has published numerous articles and was a contributor of books (12) and book chapters (28). He has directed close to 30 MSc and PhD thesis. An extensive list of his responsibilities and achievements clearly indicates well-deserved respect by the world scientific community.

Valery Rudnev, *FASM*, is considered by many as one of the leading global figures in the induction heating and heat treating. He is known within the American Society for Materials (*ASM Int'l*) and among induction heating professionals as '*Professor Induction*'. In 2006, he was elected as a Fellow of the *ASM Int'l* in recognition of his distinguished contributions to the field of materials science and materials engineering. In 2013–2106, he served as the Chairman, the Technical Committee of the Forging Industry Association of North America. His credits include a numerous publications and more than 40 patents and inventions. He authored and co-authored numerous chapters and articles for eight handbooks.

The present special issue of the *International Journal of Microstructure and Material Properties* (IJMMP) comprises a number of papers devoted to different aspects of modern heating and heat treating by means of electromagnetic field. Special focus is on heating and heat treating of metallic materials.

Papers selected to be published in this issue reflect recent scientific/engineering achievements obtained by recognised experts in the field of heating and heat treating by means of electromagnetic induction. Special attention is paid to practical aspects, developing novel technological processes and know-how as well as intricacies of modern numerical computer modelling and optimisation procedures in obtaining optimal process parameters based on various technological criteria, real-life constrains and cost functions.

Electromagnetic induction makes it is possible to generate highly controllable heat intensity quickly at specific areas of the workpiece with high precision and repeatability ensuring the needed quality and reproducibility of the product. In contrast to thermo-chemical hardening systems, induction machines are often more energy efficient and environmentally friendlier. In addition, induction equipment requires practically no startup and shutdown time; it uses minimum floor space and typically produces less distortion in the workpiece.

The basic electromagnetic phenomena of induction heating have been discussed in several textbooks. An alternating voltage applied to an inductor (also referred as induction coil) results in an alternating current flow in the coil circuit. An alternating current produces in its surroundings a time-variable magnetic field that has the same frequency as the coil current. This magnetic field induces eddy currents in the workpiece located in close proximity to an inductor. Induced currents have the same frequency as the coil current; however, their direction is opposite to the parent current. These eddy currents produce heat by the Joule effect.

The current distribution within an inductor and workpiece is not uniform and is affected by several electromagnetic phenomena, including

- skin effect
- proximity effect
- ring effect
- slot effect
- end and edge effects, etc.

All these effects play an important role in understanding the induction heating phenomena.

Recognising that there is almost endless variety of inductor types and applications, several advanced technologies were discussed in this issue producing impressive practical and scientific results.

Hardening of steels, cast irons and powder metallurgy materials represents the most popular application of induction heat treatment. A typical induction hardening procedure involves heating the entire component, or the region that needs to be hardened, to the austenitising temperature, holding it (if required) for a period long enough for completion of the formation of austenite, and then rapidly cooling it below the temperature where martensitic transformation begins.

The three most common forms of induction hardening are: surface hardening, through hardening and selective hardening. In many applications, electromagnetic induction is a preferable choice for heat treating due to several measurable process benefits. These include but are not limited to

- overall cost effectiveness, high production rates and space savings (small footprint)
- environmental friendliness, considerable reduction to heat exposure and advantages in safety (neither combustion nor unfriendly environments are used)

- high energy efficiency and the ability to provide selective heating of the surface areas where phase transformation is required.
- short startup and shutdown times.
- no energy is needed to build or maintain the heat in non-operative conditions of the hardening equipment.
- piece-by-piece processing/monitoring with individual component traceability, superior metallurgical characteristics, high product quality and repeatability
- minimisation of the distortion and development favourable transient and residual stresses that are imperative for an optimisation of industrial characteristics of the workpiece.

Excessively distorted heat-treated components require grinding and straightening operations. Complex processes take place during surface grinding. Monitoring of grinding operations is not an easy task. Excessive heat generation due to inappropriate grinding conditions can alter the quality of the components, negatively affecting its performance and the wear resistance of working surfaces by developing undesirable microstructures, causing spotted or low hardness readings, decreasing beneficial compressive residual surface stresses, and in some cases, even reversing desirable residual stress distribution. Aggressive grinding can also lead to crack development. Besides that, the amount of grinding stock that is removed from the hardened case directly affects the life of the cutting tool, process robustness and overall cost effectiveness.

Forces applied during straightening of already hardened components could potentially cause cracking and inevitably lead to a substantial reduction of desirable compressive residual surface stresses potentially compromising the performance characteristics. Therefore, the minimisation of the amount of grinding stock, production of workpieces as straight as possible and potential elimination of a straightening operation are vital goals of modern heat treating technology and is the subject of the novel processes discussed in this paper.

Numerical computer modelling of induction heating processes utilising various mathematical simulation methods (including finite-elements, edge-elements, finite-differences and boundary elements, just to name a few) remains a popular subject in discussing any modern heating and heat treating technologies. The numerical model of the induction process is defined by a coupled multi-physics problem, including material transformation, electromagnetics, heat transfer and circuit analysis. Review of existing numerical computer modelling techniques, application of mixed formulations as well as assessment of their advantages and drawbacks and remedies to improve modelling approaches are also discussed in this issue.

The selection of inductor and process parameters has substantial implications on the metallurgical and mechanical properties. Several case studies are reviewed in this issue utilising computer modelling and laboratory developments illustrating how inductor design factors and a selection of process recipes/protocols are influencing obtained results and capability to meet customer process requirements.

The global competition in metal hot forming including forging processes is becoming increasingly popular within the last few years in particularly for small- and medium-sized shops, which are building the main part of the European forging community. In the frame of the European-funded project REForCh a novel process chain with a new forging and induction heating sequence is developed. This technology has been also reviewed in this issue allowing improving cost-effectiveness of materials, modifying the forging/heating process schedules, reducing an energy consumption and CO_2 emission. The presented results of this research apply the problem-oriented simulation and optimisation of the pre-heating and reheating stages and developing the resource efficient process chain. Existing equipment is implemented in the preheating step and a new reheating system is optimally designed and studied.

Many other subjects and heat treating/heating technologies are discussed in this issue and we would like to express our gratitude to all contributors to this special issue of the IJMMP.

Our sincere thanks to a staff of this journal who provided enormous help in selecting papers, coordinating the reviewers and the authors and in preparing the papers for publications.

We sincerely hope that the papers presented in this special issue will be a valuable source of information to researchers, metallurgist, engineers, students and scientists in their professional activity.