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Editorial

High-Temperature Behavior of Metals

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1. Introduction and Scope

The design of new alloys as well as the optimization of processes involving whichever form of high-temperature deformation cannot disregard the characterization and/or modelling of the high-temperature structural response of the material.

If this has been quite extensively investigated for conventional hot working processes, there is still a lot to do to accumulate data and models and properly manage innovative deformation processes, including more complex time and temperature combinations, where process-related microstructural changes can severely affect the same processability of the material as well as its final properties (structural or functional).

Similar considerations hold in the case of conventional or innovative metallic materials for which 'high-temperature deformation' occurs during the high-temperature service of the structural components. If extensive scientific literature is available for conventional material and for 'conventional' service conditions reproduced by the constant load creep test condition, there is much to investigate in the field of alloy and processing design. The ultimate task is to widen the temperature and loading ranges of existing or innovative materials, including improving the characterization methods and data for material behavior under complex service conditions (i.e., environmental effects and combination of repeated cycles, stress relaxation, presence of flaws, etc.).

Proper modelling of high-temperature material behavior in all these situations, while considering the need of extending the ranges of applicability of these models, is another important task to be considered in view of optimizing high temperature processing and service of materials. In the latter case, the knowledge of the effects on the initial microstructure as well as the microstructural changes taking place during in-service deformation is of course of paramount importance for the optimization of high-temperature structural alloys.

The present 'High-Temperature Behavior of Metals' Special Issue and book is a collection of contributions presenting the recent advances in the field of high-temperature structural behavior of metallic materials for a wide range of metallic materials. This collection ideally follows the 'Creep and High Temperature Deformation of Metals and Alloys' Special Issue and book [1], as the reader can witness the continuous evolution in the field of alloy optimization, experimental methods, material modelling on the topic of the high temperature behavior of metallic materials.

2. Contributions

Scholars have been invited to submit research papers dealing with innovative research on specific aspects of high-temperature deformation behavior, so that the readers could get at the same time the common basic approach to this topic as well as different experimental methodologies for microstructural and structural high temperature material characterization and establishing of their correlations in view of modelling. Among the submitted manuscripts, 12 papers have been published in the issue. They are here introduced, considering their main aim/s.

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2.1. Mmicrostructural Changes Induced by High Temperature Exposure

The strict correlation between microstructure and structural response has always been of paramount importance in the field of high temperature alloys, both for the need to initially optimize the microstructure in view of material performance, and for obtaining a microstructural stability for bulk and surface material. The initial microstructure also plays a role when hot deformation behavior is considered, even if in this case the optimized final microstructure often remains the main target of the process.

A first contribution dealing with microstructure evolution at high temperature was that by Balaško et al. [2]. The tool steel AISI H11 initially soft annealed or hardened and tempered was exposed for up to 100 h in air in a temperature in the range 400–700 °C, in order to investigate the effect of oxide formation by combining experimental analysis and thermodynamic predictions. It was thus noticed that in the highest temperature range (600–700 °C) the oxidation kinetics is slower for the hardened and tempered steel, since the higher amount of dissolved elements in its matrix form a denser inner oxide sublayer, preventing further diffusion of iron and oxygen.

The effects of reheat to 820 or 890 °C of a 9CrMoW steel (92 grade) weld metal produced by GTAW were investigated by Chuang et al [3]. One-minute exposure at the highest reheat temperature was enough to change microstructural features of the steel, which displayed the tendency to early creep failures in creep tests performed at 630 °C.

The paper by Fuyang et al. [4] dealt with a heat resistant casting steel, the HP40Nb grade. The microstructural changes occurring during its exposure at 900 and 950 °C, with or without the concurrent presence of stress, affected the carbides' composition amount and morphology in intra- and interdendritic regions.

The effects of microstructure or microstructural stability, either directly correlated to the manufacturing process, or induced by heat treatment or by prolonged high temperature exposure simulating service, have also been considered in other contributions: for the two Al-SiMg alloys differently produced and heat treated by Gariboldi et al. [5] and Paoletti et al. [6], for the friction stir welded Mg alloy WE54 studied by Álvarez-Leal et al. [7], for the dynamic recrystallization in martensitic steels changes reviewed by Derazkola et al. [8], the Ni-based alloys investigated by Llizzi et al. [9] and Engels [10], and finally the Mo-Si alloys investigated by Krauss et al. [11].

2.2. Hot Deformation

The hot deformation response of metallic materials with given composition is strictly correlated to their initial microstructure as well as to their changes occurring during deformation at high temperature. The high deformation temperature here acts concurrently to the other parameter typically controlled to characterize the high temperature behavior of metals, i.e. strain rate. The analysis of the stress–strain curves obtained at different temperature and strain rate levels can help to interpret what is going on within the material during its deformation.

The contribution by Derazcola et al. [8] considers the above effects in a review on dynamic recrystallization taking place during hot deformation in martensitic stainless steels. The literature analysis led the authors to state that, among the three types of dynamic recrystallization (discontinuous, geometrical and continuous), all taken into account in literature on martensitic stainless, the continuous dynamic recrystallization is the most common for the investigated material class, characterized by high stacking fault energy.

The optimization of processing parameters was the target of the paper by Liang et al. [12]. The investigated material was in this case a Ci-Ni-Al brass, for which hot deformation behavior was characterized by the temperature range 600–800 °C at strain rates ranging from 0.01 to 10 1/s. The analysis of data led to the adoption of a Zener–Hollomon type model for which strain-related parameters were identified. The processing map was constructed based on the dynamic material model and optimized strain-rate/temperature for the alloy processing were identified.

The contribution by Lizzi et al. [9] also analyses the mechanical response/microstructure correlation. The investigated material here is IN718PW, a prototype alloy with chemical composition close to the matrix of classical Inconel®718 alloy but produced by powder metallurgy processes. Compression tests performed at temperatures in the range 900–1025 °C and strain rates in the 0.001–10 1/s range showed that the combination of high temperature and controlled strain caused stress-softening. The phenomenon is partly due to dynamic recrystallization, similar to the reference alloy, but is also partly due to diffusion-controlled pore coarsening. The analyses of the mechanical response of IN718PW alloy led to the estimation of the activation energy and strain rate-stress exponent, both close to those of the reference alloy at a temperature range exceeding solvus temperature, where precipitates do not exist.

The hot deformation behavior was also investigated by Álvarez-Leal et al. [7] for WE54 Mg alloy, where the friction stir welding process produced a fine-grained structure, correlated to process severity. The material characterization was performed from room temperature up to 450 °C, with different testing methods so that peak stress under strain rates from 10^{-4} to 10^{-1} 1/s were obtained. A superplastic behavior for the alloy was possible in the temperature range from about 250 to 400 °C. In cases where this behavior was reached, the analyses of strain rate vs. stress double logarithmic plot show data aligned with a slope close to 2, suggesting grain boundary sliding to be the main deformation mechanism. The microstructural instability of the fine-grained structure was responsible for the change in material behavior above 400 °C.

2.3. Creep and Creep Modeling

Constant load creep tensile or compression tests are a common method to characterize the high temperature behavior of metals, obtaining data later considered for select and fitting proper creep models. In addition to conventional constant-load tests, under specific conditions step-loading could be (carefully) considered as a minor-effort method to obtain at least some material creep data.

In the case of modified Al-7Si-Mg casting alloys investigated by Gariboldi et al. [5], the strengthening role played by nanometric-size precipitate or dispersoids and by their thermal stability at 300 °C for the deformation resistance of the material has been discussed. The amount and morphology of the eutectic Si and of coarse intermetallic phases, both of them at the interdendritic region and responsible for the microstructural damage leading to the final fracture, have also been considered by the above authors.

In the Al10SiMg alloy produced by additive manufacturing by Paoletti et al. [6], the microstructure and its modification during material production, heat treatment and creep tests has been studied. The microstructure role on the creep resistance at 150–225 °C has then been described by physically based models for as-produced and annealed alloy conditions.

In the contribution by Fuyang et al. [4], the heat resistant casting steel HP40Nb was characterized in hot tension and tension creep in the as-cast and aged condition. Similar tests have been performed on fresh-to-aged weld joint. The creep deformation and damage were modelled; high temperature behavior was then used to simulate the high temperature response of fresh-to-aged reformer pipe weld joint in terms of the progression and redistribution of Von Mises stress and material damage.

The paper by Krauss et al. [11] underlined the effect of microstructure and the need for a clear understanding of it in a different way. Clear differences have been demonstrated between the creep properties of Mo, Mo solid solution, Mo5SiB2 and some Mo-Si-B alloys, these latter candidate materials for future gas turbine engines operating at temperatures exceeding those possible for Ni-based alloys. Future modelling of the complex multiphase materials can save experimental efforts and time in the process of alloy optimization. In this process, the creep characterization and modelling of Mo3Si, as one of the phases present in the Mo-Si-B alloys, is a fundamental step. The interesting and careful compression multistep creep characterization performed on small specimens in Ar/H or vacuum environment in the temperature range 1093–1300 °C has been illustrated in the contribution. The identification of the optimal model (and of its parameters) to describe the high-temperature behavior of the Mo3Si has been finally considered.

Creep deformation mechanisms are typically described in terms of secondary creep strain rates. Their analysis has often been correlated to phenomena taking place at a microscopical level and leading to deformation. There is still work to do in this field on understanding and modelling the creep deformation behavior of metals and alloys. The contribution by Kassner [13] covers some of these features. Specifically, he focuses the attention on the so called Harper–Dorn, power-law and power-law-breakdown creep regimes, occurring in a metal at increasing applied stress (or decreasing temperatures) with increasing slope in the double logarithmic plot (temperature normalized) strain rate-stress plot. Results of recent experimental tests or computational works suggest that the presence/absence of Harper–Dorn creep can be correlated to the initial dislocation density in the material. On the other hand, the power law creep is well explained considering recent calculations on dislocation climb-rate. Finally, power-law breakdown can be explained by taking into account the vacancy concentration of plastically deformed materials.

The description of microstructural features of the alloy was also at the base of models describing creep-resistance of Al10SiMg alloy produced by additive manufacturing and differently heat treated, proposed by Paolucci in [6].

2.4. High Temperature Behaviour in the Presence of Loading/Temperature Changes and Environmental Effects

In addition to the classical short-time high-temperature material characterization by means of tension or compression tests, or of its long-term characterization by means of constant load/stress conditions in creep tests, different loading conditions should be taken into account when the expected service conditions significantly differ from those used in conventional material characterization. Among these conditions, isothermal fatigue characterization is one of the most widely performed.

In the present Special Issue and book, the mechanical behavior of the polycrystalline Ni-based superalloy Rene80 has been investigated by means of isothermal strain controlled fatigue tests performed at 850 °C by Engel and co-authors [10]. The alloy was investigated in two different microstructural conditions: with coarse randomly oriented grain structure and fine textured structure. In each case, two sets of isothermal fatigue tests have been performed, one on notched and the other on smooth specimens. The experimental behavior of the alloys was compared to finite element simulations of the specimens reproducing the polycrystalline/texture structure of the material. The presence of the textured structure affected the mechanical behavior of smooth specimens but had a minor effect on that of notched specimens.

3. Conclusions

The Special Issue and Book 'High Temperature Behavior of Metals' includes 12 papers covering in innovative way the relevant topics in the field. All contributions highlight the importance of microstructure and microstructural stability on the high temperature materials' behavior. The quality and variety of materials, approaches and methodologies presented can inspire both scientists and technicians in their approach to structural response of metallic materials at high temperature.

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