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Editorial

Understanding Processing–Microstructure–Property Relationships of Structural Alloys

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Although intensively investigated for centuries, structural alloys, especially steels, continue to attract a great deal of research interest [1]. There is a constant demand for better-performing structural alloys that can meet all kinds of application scenarios, and these can only be achieved if microstructures can be controlled to improve mechanical properties. On the other hand, widely investigated structural alloys, especially steels, constituted—and will continue to constitute—the most common application cases in research efforts in microstructure–property and materials development. A deep understanding of the microstructure–property relationship is the key to discovering a desirable microstructure that would yield desirable properties; in this regard, structural alloys offer the best example as to how such a microstructure can be obtained through the optimization of composition and thermomechanical processing [2].

In recent years, new techniques and approaches have become increasingly important in understanding the processing-microstructure–property relationship and related alloy development. Firstly, advanced microstructural characterizations are increasingly commonly applied, which allows for detailed information on microstructures to be obtained [3]. Secondly, the development of computational methods and resources make it possible to simulate real-life problems, where experimental inputs and validations are also necessary. Last but not least, new processing methods such as additive manufacturing are enabling the processing and controlling of microstructures to a degree that has never been seen before [4].

This Special Issue, containing ten articles, has successfully captured the diversity of the studies that focus on the microstructures and properties of structural alloys—especially steels, which I briefly describe here in the coming paragraphs. Please note that this introduction is only a guide and an overview of the articles in this editorial, and readers are encouraged to explore the articles for more details.

Jia et al. [contribution 1] discussed the effect of key alloying elements on the strength and toughness of pearlitic steels to meet the requirement of high-speed and heavy-load trains at the same time. From the two different materials utilized, one only met the toughness requirement of high-speed trains, whereas the other only met the strength requirement of heavy-load trains. The alloying element range in between, which was of interest, was carefully investigated to balance strength and toughness and to avoid significant tradeoffs. They found that C played a decisive role, whereas Si/Mn as common strengthening elements in these steels did not contribute much to toughness. Their results also suggest future research directions regarding grain size control and fine-tuning fracture mechanisms.

Jimbo and Nambu [contribution 2] investigated the upper bainite in Fe-0.6C-0.8Mn-1.8Si (wt.%) steel through electron backscattered diffraction (EBSD) and crystallographic analysis. They found that high-angle grain boundaries (HAGBs) rather than twin boundaries were the locations in which BF formed, assumably due to the lower energies of the latter. In the meantime, they considered not only the orientation relationship between bainitic ferrite across prior austenitic grain boundaries but also the orientation relationship between bainitic ferrite and nearby prior austenite grain, discovering that the latter plays a dominant role in bainitic ferrite formation. Their findings deepen the understanding of bainite nucleation, shedding light on how to strengthen bainitic steel for future studies.

Ji et al. [contribution 3] studied the 316L/Q235B plate and residual stress evolution during solutionization. Beginning with tensile tests at different temperatures for two-end chemistry, namely 316L and Q235B, a Thermoplastic Constitutive Model was developed for the 316L/Q235B composite plate. Utilizing this model, residual stress evolution was simulated during solutionization. Their results demonstrated that optimization of residual stress in composite plates can be achieved through tuning layer thickness, and this can guide future experiments.

Zhang and coworkers [contribution 4] studied the He+ irradiation effect on ferrite-martensite (FM) steel with and without 0.4 wt.% Si. As a common solid solution strengthening element in steels, the effect of Si is less understood in radiation damages at medium or medium-to-low irradiation levels. Their results with peak displacement per atoms (dpa) at 0.82 and 2.11 caused by 250 keV He+ revealed the inhibiting effect of Si on He bubbles, with 0.4 wt.% Si clearly refining the He bubbles. They also highlighted that the irradiation hardening effect was induced by dislocation loops, and the addition of Si significantly increased the number density of the dislocation loops. Their work provides guidance for further composition optimization of FM steel to reduce radiation damage.

Repin et al. [contribution 5] tested out an idea that involved using a high-entropy alloy interlayer to improve the interfacial zone of SS4316L/NiTi multi-material prepared with selective laser melting. Multiple characterization techniques were applied to the characterization of the interfacial zone, which was 100~200 μm. It was found that pores and cracks, due to the formation of brittle inter-metallics, casted doubts on the design of such interlayers, suggesting the need for other alloy interlays for this multi-material system, in addition to further characterization of the same interfacial regions.

Alhamdi and coworkers [contribution 6] investigated an Fe-Mn-Al-Ni shape memory alloy (SMA) additively manufactured via laser powder bed fusion (LPBF). As is widely recognized, the processing parameter space for AM is quite complex, and the authors investigated the effect of laser power and laser speed on its density, surface roughness, porosity, and microhardness. As is typical for work on processing parameters, they derived the optimal LPBF processing parameters for fabricating Fe-34Mn-15Al-7.5Ni SMAs based on dimensional accuracy and the minimization of macro defects, cracks, and voids. In the meantime, they also revealed the interaction between different processing parameters on the materials' properties beyond linear response, which will attract further investigation.

Zhang and Su [contribution 7] investigated the creep properties of Al-Zn-Mg-Cu alloys and the microstructure evolution thereof. The Al-Zn-Mg-Cu alloys had been applied as structural components in airplanes, and the authors focused on a small range of temperature and stress level combos, i.e., 200 °C and 150~180 MPa, based on service conditions. All the creep samples were subjected to a solution + aging treatment, where only the aging time at 120 °C varied. Interestingly, their results revealed that the microstructure change, especially precipitation, at lower aging temperature and shorter aging time (22 h vs. 34 h at 120 °C) strongly influences the creep performance at higher test temperatures (200 °C) and long rupture lifetimes (>250 h). Their work not only provides datapoints for creep rupture properties of Al-Zn-Mg-Cu alloys but also promote further investigations concerning the effect of aging microstructure on creep properties.

Van Iderstine et al. [contribution 8] studied the recrystallization behavior of cold-rolled low-carbon steel by comparing electric resistance heating (eg. Gleeble simulator) with conventional radiative heating (e.g., box furnace). By varying the parameters of cold rolling, the authors systematically investigated a matrix of 60 samples at different cold-rolling reductions, soaking temperature, soaking durations, and recrystallization fractions, which were measured for microhardness and EBSD. Their results notably revealed an acceleration in the recrystallization rate through an electrical resistance heating approach, especially at the early stage of heating, e.g., ~100 s; up to a longer duration time, e.g., 5000 s at 600 °C, the two heating approaches will converge to then show the same recrystallization kinetics. This work provides general guidance on the investigation of recrystallizations, but it also sets the pace for a quantitative understanding of recrystallizations through the well-known Johnson–Mehl–Avrami–Kolmogorov (JMAK) equations.

Pulvermacher et al. [contribution 9] presented a study of lattice strain under uniaxial tension with both neutron diffraction techniques and elastic-plastic self-consistent (EPSC) modeling approaches. The authors used model duplex stainless steel, X2CrNiMoN22-5-3, to include phase-specific effects. Their work demonstrated the capacity of their techniques in capturing anisotropy and associated strain with both austenite and ferrite phases. A comprehensive comparison between the experiments and modeling performed showed that, although the agreement at a lower strain deformation level < 4% was good, clear deviations were observed for higher strain deformation, at 10%. Further improvement in the model, such as having it take additional strengthening mechanisms into consideration, is suggested by the authors.

Finally, Badru et al. [contribution 10] investigated the cold-rolling processing of an Fe-Mn-Si-Cr SMA. They observed evenly spaced cracks on the surface of the cold-rolled alloy slab and used microstructure characterization techniques such as SEM and XRD to reveal the variant of cracks and phases around those cracks. These findings helped the authors reach a preliminary root-cause conclusion, which would be a good starting point for further investigations.

A list of all the contributions is presented below for reference. Additionally, we would like to request that interested authors please consider submitting their studies to the second edition of this Special Issue.

Conflicts of Interest: The author declares no conflict of interest.

List of Contributions:

1. Jia, T.; Shen, Z.; Liu, C.; Zhao, X.; Zhang, X. Study on Mechanism and Influencing Factors of Wheel Strengthening and Toughening of High-Speed and Heavy-Load Train. *Crystals* **2023**, *13*, 81. https://doi.org/10.3390/cryst13010081.
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