metals

Editorial

Recent Advances in Cast Irons

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1. Introduction

Cast irons are widely used in industry due to their excellent castability, allowing for the production of near-net shape components with complex geometries without the need for additional forging or machining processes. They also are a cost-effective material with good machinability, corrosion resistance, and vibration damping properties, as well as relatively high wear resistance, thanks to graphite's self-effect. However, achieving the optimal combination of microstructure and mechanical properties requires optimizing the process parameters, solidification conditions, and heat treatment for a specific chemical composition. Hence, continuous research efforts in cast iron are crucial for the improvement of in-service performance.

In this frame, this Special Issue includes original research papers and a review that cover the most recent research and development aimed at improving the chemical, physical and metallurgical characteristics of cast irons that, in turn, affect their mechanical, tribological and corrosion performance.

2. Contributions

The book collects manuscripts from cutting-edge academic researchers and consists of one review paper regarding the research progress in improving the corrosion wear resistance of a novel hypereutectic high-chromium cast iron (HCCI) [1] and eight experimental research papers focused on methods for enhancing the corrosion, mechanical and microstructural features of cast irons in general, i.e., nodular, gray, vermicular, austempered ductile iron (ADI) and HCCI [2–9].

The review by Gong et al. [1] provides a detailed analysis of the development and research progress in improving the corrosion wear resistance of a novel hypereutectic HCCI, obtained by increasing its chromium and carbon contents. HCCIs are frequently used in abrasive environments where wear and corrosion can be present. The study analyzes various methods for improving the corrosion wear resistance of HCCI, such as primary carbide refinement, heat treatment, deep cooling treatment, and alloying elements addition. Given that the corrosion resistance of HCCIs is closely related to the microstructure of the matrix and number, size, shape, and distribution of carbides, primary carbide refinement, heat treatment, deep cooling treatment and alloying are addressed in detail. The review suggests research directions to expand the application of HCCI and research directions and contents to enhance the corrosion wear resistance of these materials by modification, alloying and heat treatment methods.

Concerning nodular cast irons, relevant contributions have been proposed [2,3,5]. The paper by Vicente et al. [2] concerns the applicability of the Hollomon–Jaffe parameter, usually used to establish an equivalence between time and temperature in a tempering treatment, to predict the hardness of nodular cast iron after quenching and tempering treatments. The obtained results reveal the efficacy of the parameter in studying the tempering process and in estimating the final hardness of the alloy from this and from its initial hardness. In addition, focusing on ductile cast iron, Stan et al. [3] propose a study on the analysis of the cooling curve to detect the solidification pattern of non-Si

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alloyed (<3.0% Si), low (3.0–3.5% Si), and medium Si alloyed (4.5–5.5% Si) cast irons also considering inoculation simultaneous effects. From the events on the cooling curve (i.e., the lowest and the highest eutectic temperatures and the temperature at the end of solidification), and on its first derivative (i.e., the maximum recalescence rate, the lowest level at the end of solidification and different graphitizing factors), the authors found that silicon is an important influencing factor, but the base and minor elements also affect the equilibrium eutectic temperatures. In addition, the highest positive effect of inoculation was detected in non-Si alloyed cast irons, while low Si alloyed cast irons are more sensitive to high solidification undercooling, compared to medium Si ductile cast irons, at a lower undercooling level, and also at lower inoculation contribution. The paper by [5] deals with static tensile and strain-controlled fatigue tests on specimens taken from real off-highway axles made by an EN-GJS-450-10 nodular cast iron. More in detail, specimens with either machined or as-cast surfaces were fatigue tested under strain-control loading to determine the high-cycle downgrading factor due to the cast skin effect. The formers were fatigue tested under different strain ratios to analyze the influence of the mean strain. The experimental findings revealed that the stress ratio is different from the nominal strain ratio and that the tested material exhibits a hardening behavior, as suggested by the comparison of the cyclic stress–strain curve with the monotonic static curve highlighted. Lastly, the analysis of the fracture surfaces showed that machined specimens exhibit crack initiation from the surface, while as-cast specimens fail in most cases from the as-cast surface or from sub-surface defects, such as silicon oxides.

Within ductile irons, recent findings on ADI material have been reported by Cruz Ramírez et al. [7] and Angella et al. [6]. The paper by Cruz Ramírez et al. [7] deals with the metallurgical and mechanical performances of camshafts made of high-strength ADIs. Two austempered ductile irons were produced from ductile irons, low alloyed with vanadium and austempered at 265 °C and 305 °C, and tested through both block-on-ring wear tester and electric spin rig testers to check and ensure the durability of the camshaft under engineering specification parameters. The authors found that austempering at 265 °C leads to the formation of a fine ausferrite microstructure that aids in obtaining the highest wear resistance in the block-on ring wear test. No wear or pitting evidence was detected on the camshaft lobes and roller surfaces after the test protocol during the electric spin ring test at low and high conditions for the ADI alloyed with 0.2 wt. % V heat treated at 265 °C. A further contribution concerning the mechanical behavior of ADI has been proposed by Angella et al. [6] that investigated the ausferrite stability with three different nominal contents of nickel through tensile testing. The results on the effects of the solidification rates (thickness sections) of the original ductile iron on the resulting ADIs' microstructure and tensile mechanical properties are reported. Castings with different wall thicknesses and with different nickel contents were austenitized at the same temperature and time, and then austempered at three different temperatures and time conditions. Hence, the combined effects of section thickness, chemical composition and austempering conditions on the tensile mechanical properties of ausferrite were investigated and related to the ausferrite stability. As a result, while the nickel content and section thickness affect the graphite morphology, they do not significantly impact the ausferrite stability and tensile behavior when the section thickness was below 25 mm. However, the study finds that the tensile plastic behavior is consistently affected by specimen geometry, indicating the importance of considering specimen geometry in the analysis and comparison of tensile properties of ADIs.

The contributions of Obregon et al. [4] and Tonolini et al. [8] contain recent findings on gray cast irons (GCIs). Within the development of new lightweight materials, Obregon et al. [4] report the development of novel lightweight cast irons, with different amounts of Al (from 0 wt. % to 15 wt. %), to investigate the correlation of the amount of Al and its effect on the microstructure. The obtained results show that for the investigated EN-GJL-HB195 grade cast iron, the perlite content decreases with the increment of wt. % of Al, while the opposite occurs with the ferrite content, since the addition of Al promotes the stabilization of ferrite. In the case of graphite, a slight increment occurs with 2 wt. % of Al, but a great decrease occurs until 15 wt. % of Al. In the work of Tonolini et al. [8], the wear resistance of GCI samples, taken from brake discs industrially produced with different percentages of niobium, was evaluated. Indeed, brake discs play a crucial role in the operation of vehicles, and GCIs with a pearlitic matrix and type-A graphite are the most widely used material in their manufacturing. However, due to the environmental impact of disc wear during braking, alternative materials and/or compositions to the standard ones are being investigated. Against this backdrop, the study investigates the effect of varying the niobium content (0–0.7 wt. %) on the microstructure and wear behavior through pin-on-disc (PoD) wear tests, with low-metallic-friction material discs serving as the counterparts. It was found that the wear strength of the alloy is enhanced by the addition of niobium, in comparison to the base alloy, which promoted an increase in the hardness and the formation of hard NbC particles that acted as a load-bearing phase. It was found that adding relatively low amounts of niobium (i.e., 0.3 wt. %) leads to the highest wear resistance, whereas any further increase does not significantly alter the properties and resulted in the coarsening of NbC particles. Hence, it is recommended that the composition of cast iron should not exceed 0.3 wt. % niobium to improve wear resistance and keep alloying costs low.

Finally, the contribution by Liu et al. [9] examines the surface evolution of vermicular cast iron in a high-frequency cyclic plasma and facial cooling airflow to gain insights into the behavior and mechanism of such material under unique thermal shock environments with different cooling conditions. The authors reported that the mass and linear loss show an inverted V-shaped relationship with the flux of the cooling airflow, while the change in roughness decreases continuously. Additionally, as the cooling airflow increases, the eroded region decreases, iron oxides lessen, and surface temperature fluctuation weakens. Finally, through thermodynamic calculations and thermal analysis, it was demonstrated that oxidation and mechanical erosion have contrary tendencies with the rising flux in the facial cooling airflow. The study showed that the transformation of the dominant factor from oxidation to peeling off by thermal stress and scouring leads to the evolution of mass and thickness.

3. Conclusions and Outlook

The Special Issue delves into the latest research and development endeavors aimed at enhancing the metallurgical mechanical, tribological, and corrosion performance of cast irons. The review and the papers cover various topics and demonstrate overall that cast irons are still highly relevant and can be studied in detail to enhance their performance, also taking into account their environmental impact.

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