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Efremenko V.G.^{1,2}, Chabak Yu.G.^{1,2}, Golinskyi M.A.¹, Petryshynets I.²,
Kudin V.V.³, Shimizu K.⁴, Zaitsev D.V.¹

¹ Pryazovskyi State Technical University, Dnipro, Ukraine

² Institute of Materials Research, Slovak Academy of Science, Kosice, Slovakia

³ National University Zaporizhzhia Polytechnic, Zaporizhzhia, Ukraine

⁴ Muroran Institute of Technology, Muroran, Japan

EFFECT OF QUENCHING TEMPERATURE ON HARDNESS AND THREE-BODY-ABRASION WEAR RESISTANCE OF HYBRID MULTI-COMPONENT CAST IRONS

In this work, enhancing the tribological characteristics of the novel cast metallic materials – hybrid multi-component cast irons (MCCIs) – by applying a strengthening heat treatment is described [1, 2]. The experimental materials were the cast alloys of a nominal composition (5 wt.% W, 5 wt.% Mo, 5 wt.% V, 10 wt.% Cr, 2.5 wt.% Ti, Fe is a balance) added with 0.3-1.1 wt.% C and 1.5-2.5 wt.% B (total 9 alloys). Heat treatment was an oil-quenching followed by 200 °C-tempering. The quench temperature (QT) was varied in the range of 900-1200 °C with a step of 50 °C (with a 2-hour holding at QT). The correlation of QT with microstructure and properties was estimated using microstructure/worn surface characterization, differential scanning calorimetry, hardness measurement, and three-body-abrasive wear testing (using Al₂O₃ particles).

The as-cast alloys had a multi-phase structure consisting of primary and/or eutectic borocarbide M₂(B,C)₅, carboborides M(C,B), M₇(C,B)₃, M₃(C,B), and the matrix (ferrite, martensite, pearlite/bainite) in different combinations and volume fractions (Fig. 1).

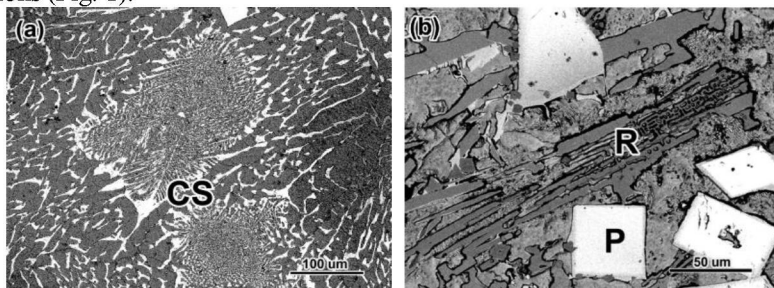


Figure 1. Microstructure of studied alloys containing: (a) 0.3 wt.% C and 1.5 wt. % B, (b) (c) 0.7 wt.% C and 3.5 wt. % B.

Generally, the increase in quenching temperature from 950 to 1150-1200 °C resulted in a gradual increase in hardness (maximally to 66-67 HRC) and a decrease in wear rate in most alloys (Fig.2, Fig. 3). This was due to the change in phase-structure state of the alloys under quenching namely the secondary carboboride precipitation and replacing ferrite and pearlite/bainite with martensite.

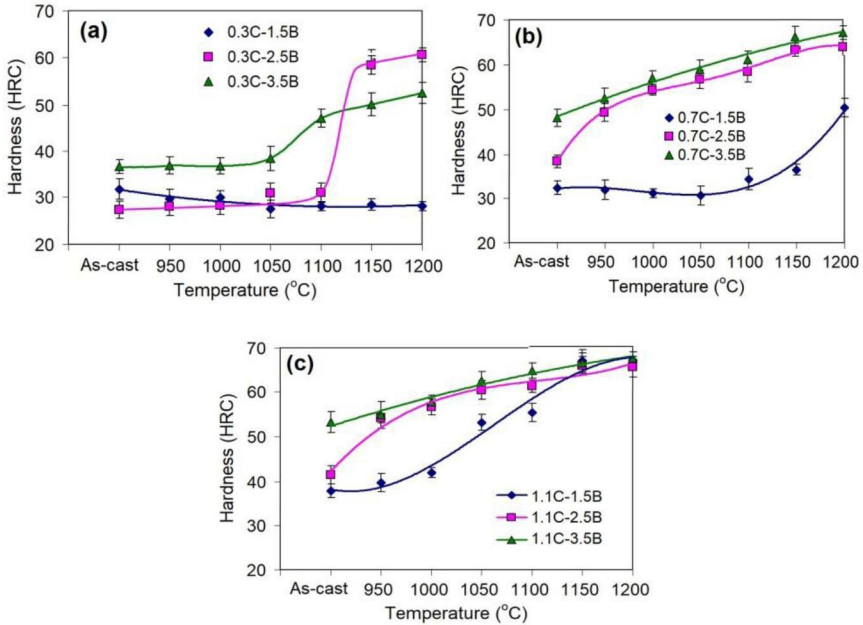


Figure 2. Effect of quenching temperature on the bulk hardness of MCCIs containing: (a) 1.5 wt.% B, (b) 2.5 wt.% B, and (c) 3.5 wt.%.

Under low carbon (0.3 wt.%) and/or boron (1.5 wt.%) contents, a noticeable increase in hardness was observed at a QT above 1050 °C reaching maximal 50-59 HRC. In other alloys, hardness increased proportionally to QT starting from 950 °C, and reached 63-67 HRC. Accordingly, the wear rate decreased by 3-6 times (relative to the as-cast state). This was due to the formation of a martensitic matrix strengthened by secondary carboboride precipitates. Alloy 0.3C-1.5B retained a ferritic matrix regardless of QT, and its properties were hardly changed by quenching.

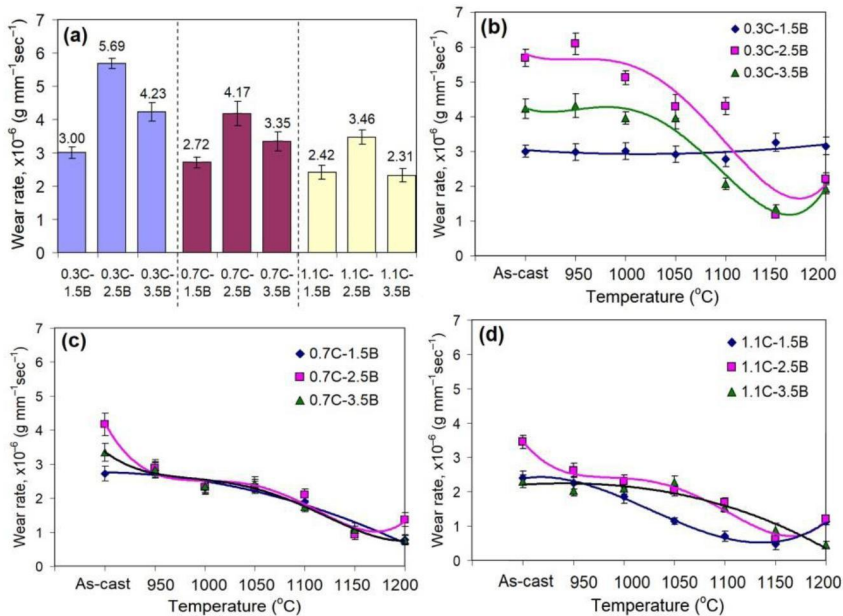


Figure 3. (a) WR values of the as-cast alloys. Effect of quenching temperature on the wear rate of the alloys containing: (b) 0.3 wt.% C, (c) 0.7 wt.% C, and (d) 1.1 wt.% C.

Carbon increased the wear resistance of MCCIs due to the formation of carboborides $M(C,B)$, $M_7(C,B)_3$ and $M_3(C,B)$, as well as by expanding the γ -area thus contributing to the appearance of martensitic matrix under the quench cooling. Boron had a versatile effect on wear resistance, which is associated, on the one hand, with the formation of wear-resistant borocarbide phases and on the other, with the occurrence of coarse primary inclusions that were easily spalled off during wear.

At any hardness, the alloys with near-eutectic structure performed higher wear resistance as compared to the hypereutectic ones. This is attributed to a more favorable wear mechanism of the multi-cycle formation/removal of the fine micro-scales. In hypereutectic alloys, the predominant wear mechanism is a spalling of coarse primary borocarbides. With the QT increase, the difference in wear rate of alloys decreased due to matrix hardness improvement: hard matrix better resisted wear preventing the easier exposure and fracture of primary borocarbides.

The factorial design of experiment 3^2 was used to optimize the alloy composition. According to the regression models derived, the highest wear resistance is attributed to the MCCI having 1.1 wt.% C and 1.5 wt.% B quenched from 1150 °C (Fig. 4).

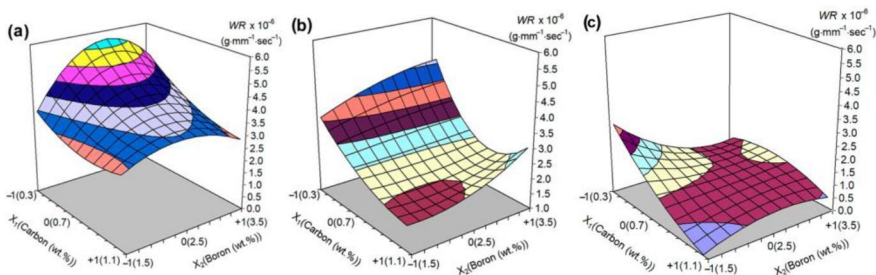


Figure 4. The response surfaces of a wear rate depending on the chemical composition of the alloys: (a) the as-cast state], (b) QT=1050 °C, (c) QT=11050 °C.

Under the testing, the optimized alloy performed a hardness of 67 HRC and a wear rate of $0.88 \times 10^{-6} \text{ g} \cdot \text{mm}^{-1} \cdot \text{sec}^{-1}$. Similar wear resistance was shown by MCCI with 1.1 wt.% C and 3.5 wt.% B (quenching from 1200 °C, 67 HRC, WR of $0.81 \times 10^{-6} \text{ g} \cdot \text{mm}^{-1} \cdot \text{sec}^{-1}$). The above alloys were 2.94 and 3.20 times more wear-resistant than the reference alloy (a 13 wt.% Cr cast iron, 66 HRC) indicating the high potential of the MCCIs to stand hard-abrasive applications.

Acknowledgments

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