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# ІНТЕЛЕКТУАЛЬНІ ТРАНСПОРТНІ ТЕХНОЛОГІЇ

## V МІЖНАРОДНА НАУКОВО-ТЕХНІЧНА КОНФЕРЕНЦІЯ

## ПРОГРАМА КОНФЕРЕНЦІЇ

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# ПІДВИЩЕННЯ АБРАЗИВНОЇ ЗНОСОСТІЙКОСТІ ГІБРИДНИХ БАГАТОКОМПОНЕНТНИХ ЧАВУНІВ ШЛЯХОМ ВИСОКОТЕМПЕРАТУРНОГО ЗАХАРТУВАННЯ

# ENHANCING ABRASIVE WEAR RESISTANCE OF HYBRID MULTI-COMPONENT CAST IRONS BY HIGH-TEMPERATURE QUENCHING

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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 $^{o}$C-tempering. The quench temperature (QT) was varied in the range of 900-1200 $^{o}$C with a step of 50 $^{o}$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 $Al_2O_3$ particles).

The as-cast alloys had a multi-phase structure consisting of primary and/or eutectic borocarbide $M_2(B,C)_5$, carboborides M(C,B), $M_7(C,B)_3$, $M_3(C,B)$, and the matrix (ferrite, martensite, pearlite/bainite) in different combinations and volume fractions (Fig. 1).

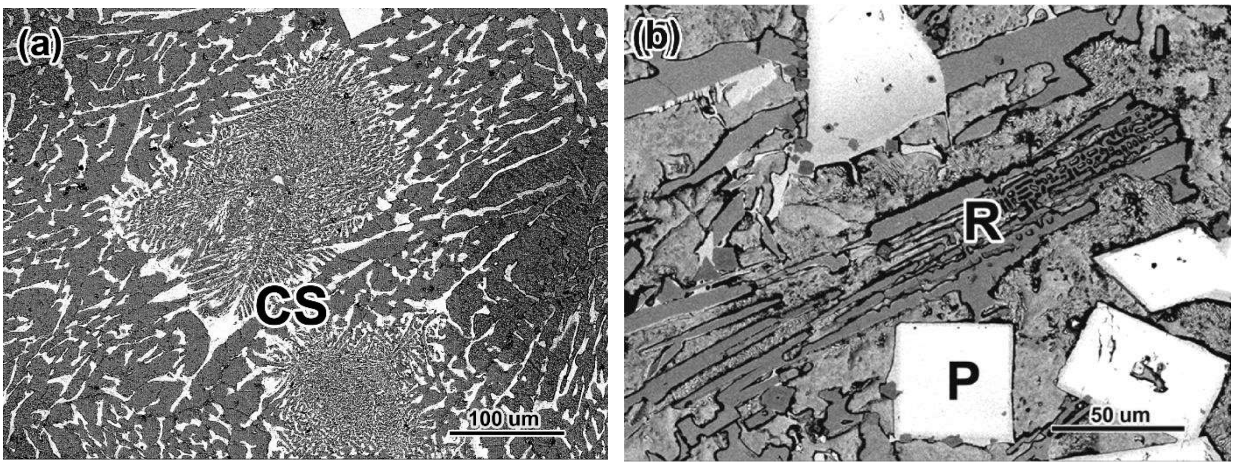


Figure 1. Microstructure of studied alloys containing: (a) 0.3 wt.% C and 1.5 wt. % B, (b) (c) 0.7 wt.% C and 3.5 wt. % B.

Generally, the increase in quenching temperature from 950 to 1150-1200 ºC 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.

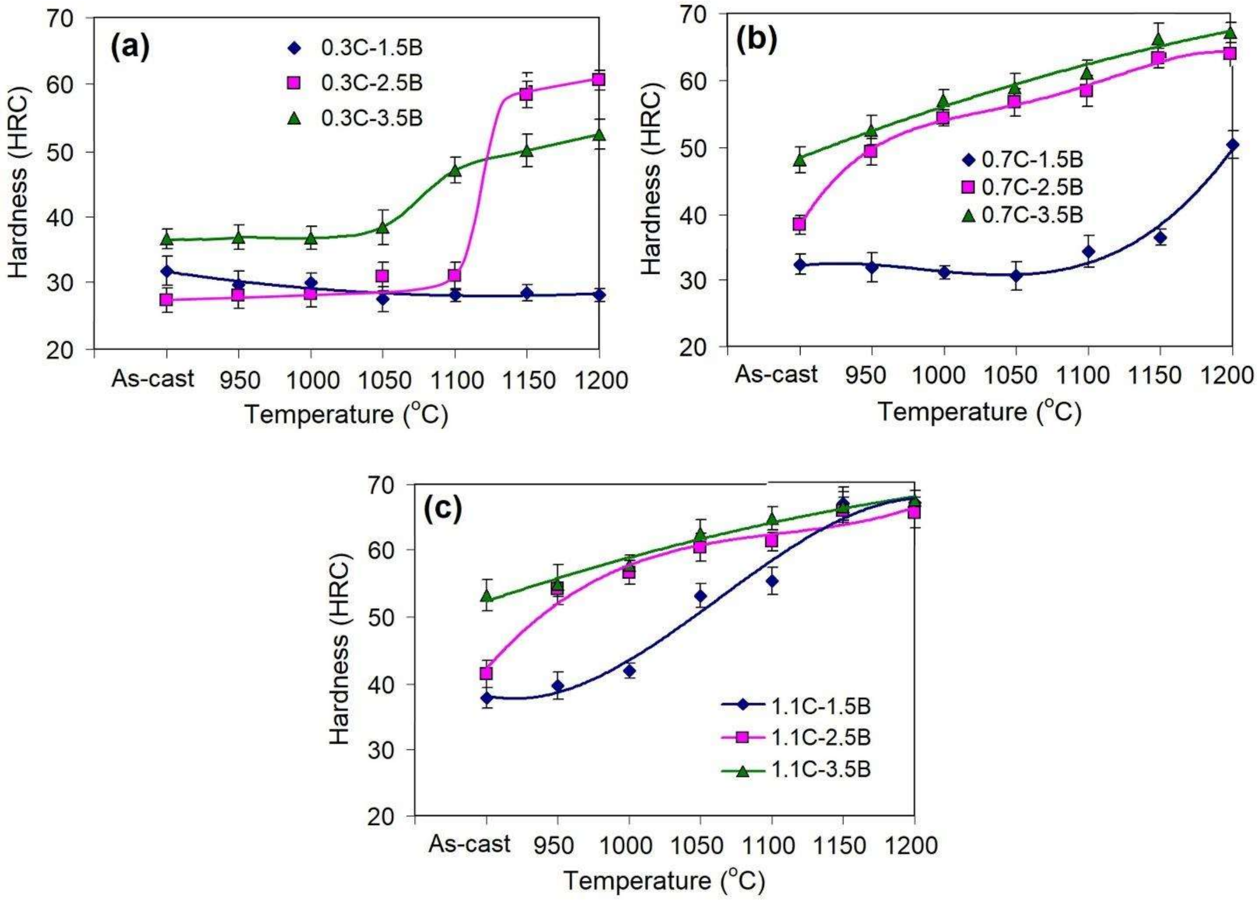


Figure 2. Effect of quenching temperature on the bulk hardness of MCCIs containing: (a) 1.5 wt.% B, (b) 2.5 wt.% B, and (c) 3.5 wt.%.

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 ºC reaching maximal 50-59 HRC. In other alloys, hardness increased proportionally to QT starting from 950 ºC, 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.

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.

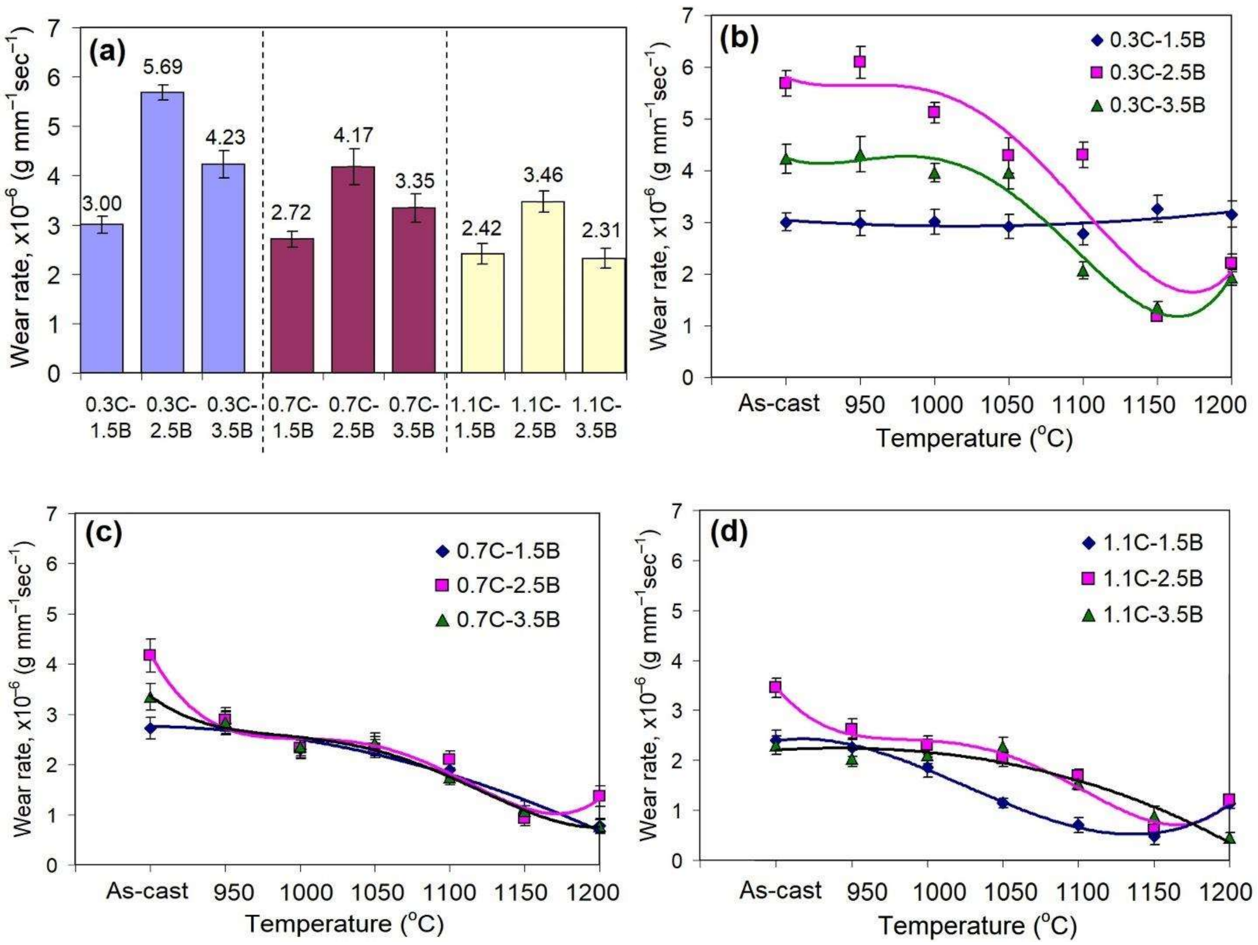


Figure 3. (a) WR values of the as-cast alloys. Effect of quenching temperature on the wear rate of the alloys containing: (b) 0.3 wt.% C, (c) 0.7 wt.% C, and (d) 1.1 wt.% C.

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 multi-component cast iron containing 1.1 wt.% C and 1.5 wt.% B quenched from 1150 ºC (Fig. 4).

Under the testing, the optimized alloy performed a hardness of 67 HRC and a wear rate of $0.88 \times 10^{-6}$ g·mm$^{-1}$·sec$^{-1}$. Similar wear resistance was shown by the multi-component cast iron having 1.1 wt.% C and 3.5 wt.% B (quenching from 1200 ºC, 67 HRC, WR of $0.81 \times 10^{-6}$ g·mm$^{-1}$·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.

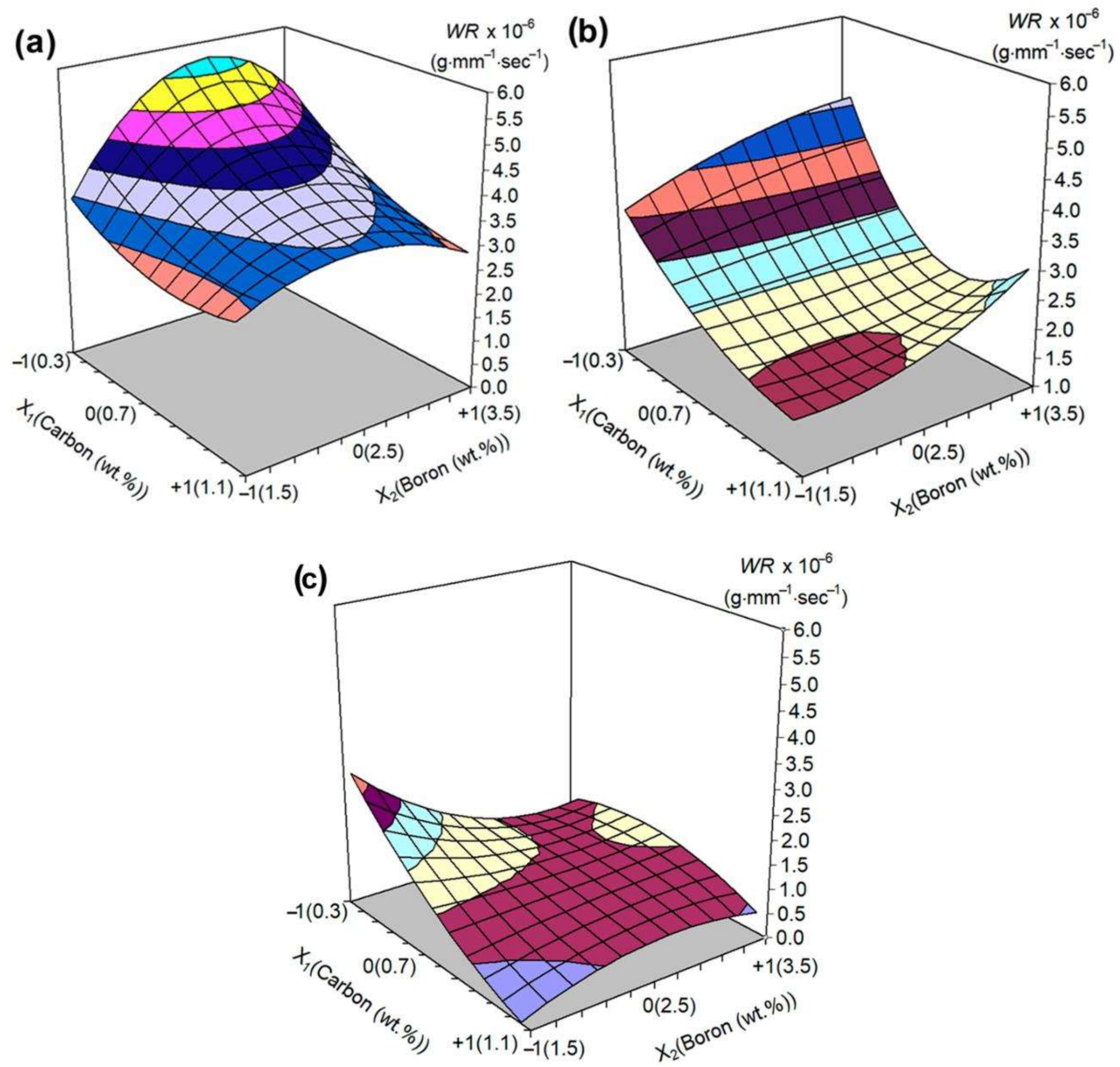


Figure 4. The response surfaces of a wear rate depending on the chemical composition of the alloys: (a) the as-cast state, (b) QT=1050 ºC, (c) QT=11050 ºC.

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# МЕХАНІЧНІ ВЛАСТИВОСТІ ТОВСТИХ ЛИСТІВ СТАЛІ МАРКИ 5L API X70, ВИРОБЛЕНОЇ З ВАЖКОГО СЛЯБА

# MECHANICAL PROPERTIES OF THICK SHEETS OF X70 API 5L GRADE STEEL PRODUCED FROM HEAVY SLAB

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This work investigated the microstructure and mechanical properties of 40 mm thick sheets of low-carbon (0.06-0.07 wt.%C) (Cr, Ni, Mo, V, Nb)-micro-alloyed steel, produced from heavy slab in order to comply with the requirements of X70 (API 5L) grade. It was found that applying a heavy slab of increased thickness is feasible for the production of thick (≥ 30 mm) steel sheets intended for oil/gas pipelines. Using a 300 mm thick slab increases its rolling reduction by 12-36 % when producing 40 mm thick sheets which enabled the better deformation to eliminate the cast structure in the axis zone of the billet. This resulted in structure refining which enhances the low-temperature impact behaviors (Charpy V-notch test, DWTT) of steel ensuring compliance with an X70 (API 5L) grade.

The sheets were produced through the three-stage thermo-mechanical controlled processing (TMCP) with a rolling finish in a single-phase interval (820-840 $^{o}$C) or in a two-phase interval (760-780 $^{o}$C) followed by accelerated cooling (AC). For both