Study the effect of using different quenching mediums on erosive wear behavior of high chromium white cast iron

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Abstract. In order to accomplish economically good martempering process, it is required to find a cheaper and more available alternative quenching medium for the ordinary nitrate mixture used in this process. A high chromium white cast iron, which is generally used as mill liners in mining, crushing, and cement plants, is subjected to severe conditions of wear/impact. These conditions lead to failure and reduction in part life as well as increase in the cost of repairs, therefore, it is important to enhance its mechanical properties. The effect of different quenching mediums used in martempering treatment on the erosive wear, microstructure and mechanical properties of this cast iron was studied. In this study, two types of quenching mediums were used: Nitrite mixture (50% NaNO$_3$ + 50% KNO$_3$) and Hydroxide mixture (50% NaOH : 50% KOH). The specimens were austenetized at 950°C for 1 hr then the first group was quenched in nitrate mixture and the other was quenched in hydroxide mixture, both at about 350°C, for (1/2, 2, 4, 6, 8) hrs. It was concluded that the two mediums enhance erosive wear resistance, but the nitrate mixture show the best erosive wear results among the other treatments, especially at martempering about 350°C for 4 hrs.

Keywords: quenching mediums, Martempering, High chromium white cast iron (HCWCI), Erosive wear.

1. Introduction and literature survey
High chromium white cast irons (HCWCI) are widely used for material crushing, handling and grinding applications in the minerals and mining industries according to their excellent wear resistance. [1]. In many industries the slurry erosion is considered as a major issue. Slurry erosion is defined as the material degradation by impacts of a solid particle i.e. erodent suspended in a liquid. The main problem of the erosion is economic losses that result from the need to replace or repair the failed part that lead to temporary shutdown of technological process. Erosion makes material surface layers lose mass gradually hence, changes the elements geometry, which lowers the efficiency and service life [2]. Al-Bukhaiti, M. A., et al studied the influence of impact angle and also velocity of erosive stream on slurry erosion behavior of high chromium cast iron. Silica sand (500–710 μm size) was used as an erodent. The results were obtained for angles of (30, 45, 60, 90) deg to the exposed surface and velocities of (5, 10, 15) m/s. The highest erosion resistance of high chromium cast iron was found at normal impact and the lowest at an angle of 30 deg, irrespective of velocity [3]. Israa F. Y. and Ali H. Ataiwi study the erosive wear resistance of high chromium white cast iron samples, which were destabilized at two temperatures of (955°C, 1100°C), air cooling followed by tempering heat treatment at (400°C, 700°C) at every destabilized temperature. The impact angle is used at 45° and the time of subjecting to erosive stream for 10 hours. Findings show that the rate of erosion of
specimen (destabilized at 1100°C, air cooled + tempering at 400°C air cooled) is the best result. In addition, the hardness of this treatment is increased from (57 to 58) HRC after 10 hours [4]. Higuera-Cobos et al studied the influence of different cooling media used with destabilization treatment on the microstructure, hardening and abrasion resistance behavior of a hypo-eutectic HCWCI. The results show that air cooling followed by immersion in CO$_2$ can effectively reduce the retained austenite but not completely. The air cooled samples show the best combination of hardness and wear resistance, due to the percentage of retained austenite and a moderate precipitation of chromium carbide [5]. Abd El-Aziz et al studied the influence of Cr/C ratio on wear and corrosion behavior of (HCWCI) alloys. Three different chemical compositions of alloys of HCWCI were tested in (3.5 % NaCl, 0.5 M H$_2$SO$_4$, and 0.5 M of NaOH) solutions as corrosive media. The corrosion behavior of the HCWCI alloys strongly depends on the Cr/C ratio and Cr ratio content in the M$_7$C$_3$ carbide to that in the matrix (CrM$_7$C$_3$/Matrix). The results indicate that the alloy (with the lower Cr/C ratio) gives the lowest abrasive wear loss while the alloy (with higher Cr/C ratio) gives the highest abrasive wear loss [6]. Ataiwi and Zainab studied the use of suitable, economic and more available alternative to nitrate mixture in Iraqi markets that is used in ordinary martempering heat treatment as a quenching medium. This alternative medium is a mixture of potassium hydroxide and sodium hydroxide. They studied the effect of both hydroxide and nitrate mixture on the microstructure and mechanical properties of (HCWCI). It is found that both the quenching mediums produce higher hardness values at 350°C martempering temperature for 4 hr quenching time [7]. The aim of this study is to clarify the effect of hydroxide mixture and nitrate mixture as a quenching medium in martempering of high chromium white cast iron and relate their effects on the mechanical properties of this cast iron, which is used extensively as liners in millers at cement plants.

2. Materials and methods
The metal sample of the category (A-532 Class III Type A) [8] is used. It is obtained from (Kufa Cement Plant) mill liners. The chemical composition of the sample is investigated via (AMETEK, SPECTRO MAXx) in (State Company for Inspection and Engineering Rehabilitation [S.I.E.R]-Ministry of Industry and Minerals, Iraq). Chemical composition of the sample used in this work is shown in table1:

| Table 1. Chemical composition of measured sample vs. ASTM [8] |
|-----------------|---|---|---|---|---|---|---|---|
| **Element**     | **C** | **Si** | **Mn** | **P** | **Cr** | **Mo** | **Ni** | **Fe** |
| **Measured**    | 2.43 | 0.8  | 0.7   | 0.017 | 27.25 | 0.014 | 0.16  | Bal    |
| **ASTM**        | 2.3 – 3  | 1 max. | 0.5-1.5 | ----- | 23 - 28 | 1.5 max | 1.5 max | Bal    |

The heat treatments used here are annealing, quenching and martempering with two types of quenching mediums: nitrite mixture (50% NaNO$_3$ + 50 % KNO$_3$) and hydroxide mixture (50% NaOH : 50% KOH) with differing quenching intervals. All heat treatment processes used in this work can be illustrated in figure 1.
The samples were prepared to be examined under an optical microscope by polishing using (320 up to 2000) grit papers and using 1μm polycrystalline diamond paste. The specimens were etched using 0.5 g copper (II) chloride in a solution of 11 ml absolute methanol, 11 ml distilled water and 11 ml concentrated HCl (Kalling’s reagent). The specimens were examined under the scanning electron microscope and X ray diffraction spectroscopy. Impact toughness of the specimens were tested using Charpy impact tester and the hardness was tested using Vickers macro hardness tester. Slurry erosion wear test was done by a locally made testing device.

2.1 Slurry erosion wear testing device
A slurry erosion device has been made according to ASTM Standard (ASTM, G73-10, 2010; G76-13, 2013) and was used to test the erosion of specimens in this study. Slurry jet erosion testing device is shown in figure 2. Silica sand with average diameter (400-800μm) were used as erodent particles. The slurry consists of 10% weight percent sand and the remaining is tap water. The specimen (2cm*2cm*1cm) was mounted into the test stage below the nozzle with a vertical distance of 10 mm from the end of the nozzle to the test surface into the erosion test machine at impingement angles 45°. The examined pressure was 0.4-0.6 bar. All the erosion tests were done at ambient temperature for 10 hours. The specimens were weighed approximately every two hours with an electronic scale with an accuracy of ± 0.0001 g to prepare for measurements of weight loss. The slurry device was equipped with a cooling fan to dissipate the heat generated in the stirrer during operation.
3. Results and discussion

In Table 2, the results showed that the different heat treatment effects the microstructure and mechanical properties of the specimens in different ways. Comparing the obtained results of treated specimens with as-received ones, the treated specimens showed an increase in hardness of quenched and martempered specimens whereas there was a decrement in hardness values of annealed specimens. This different behavior can be explained by the influence of several factors such as temperature, time, severity of quenching, types of microstructure and second phase particles in the heat-treated specimens. More details were found in our previous study [7].

| Sample no. | Condition                | Average Hardness | Average Impact Values(J) |
|------------|--------------------------|------------------|--------------------------|
| A          | As-received              | 857              | 2.3                      |
| B          | Annealed                 | 663              | 1.6                      |
| C          | quenched                 | 784              | 1.8                      |
| D1         | martempered +1/2 hr      | 789              | 1.3                      |
| D2         | martempered + 2 hr       | 978              | 1.5                      |
| D5         | martempered + 4 hr       | 1051             | 1.55                     |
| D4         | martempered + 6 hr       | 850              | 1.75                     |
| D6         | martempered + 8 hr       | 729              | 0.96                     |
| N1         | martempered + 1/2 hr     | 946              | 1.7                      |
| N2         | martempered + 2 hr       | 955              | 2                        |
| N5         | martempered + 4 hr       | 1014             | 2                        |
| N4         | martempered + 6 hr       | 768              | 2.2                      |
| N6         | martempered + 8 hr       | 889              | 1.6                      |
3.1 Vickers macrohardness and impact values
From the table 2 it is observed that the highest hardness values were obtained at martempered specimens for (4 hr + quenching) in both molten hydroxide and nitrate mixtures. While the highest impact value was observed in as received and in martempered specimens for (6 hr + quenching) in nitrate mixture. These results were already found by our previous study [7].

3.2 Microstructure and XRD results
From the microstructure images in [7], it is observed that the microstructures of the specimens martempered at the hydroxide and nitrate mixtures are approximately the same. These structures consist of (austenitic, ferritic, or martensitic) matrix with eutectic and secondary carbides that are dispersed in these matrixes in approximately the same shapes and patterns except that for specimens, which were martempered in hydroxide and nitrate for 8 hrs (for more details see ref. 7).

From XRD charts [7], the as-received specimen consists of ferrite, austenite and secondary carbide, while annealed and air quenched specimens consist of ferrite, austenite, martensite and secondary carbide at different amounts. The microstructures of other specimens martempered in hydroxide mixture for 4 and 6 hrs. reveal the appearance of martensite.

3.3 Slurry erosion wear test results
The results of erosion wear of the different types of heat treatments are plotted in figure 3 shown below. The y-axis represents the weight loss in grams whereas the x-axis represents the time at which the specimens were subjected to erosion stream. The results show that the two types of quenching mediums (nitrate and hydroxide) mixtures used in martempering heat treatment give better erosion wear resistance than the as-received and annealed samples (see figure 3and 4) as it can be noticed that the line B (figure 3) represents the weight loss of annealed specimen, which is the highest loss between all of the samples whereas line (N5) (martempered in nitrate mixture) represents the lowest loss in weight (higher erosion resistance).

![Figure 3. weight loss vs. time](image-url)
It was found that the best results of erosion resistance of the all treatments used in this study was for sample (N5) martempered in nitrate mixture at about (350°C) for 4 hours. It was observed that the bulk hardness is an indicative for erosive wear resistance i.e. the material having high hardness wearing the least [9], this agreed with nitrate mixture sample. In hydroxide mixture samples, the best erosion resistances were at 1/2 hr (D1) and 8hr (D6) despite their lower hardness values compared with the other hydroxide mixture samples. This may be due to the corrosive behavior of hydroxide mixture.

3.4 SEM
The images of SEM (see figure 4) were obtained for the as-received (WA), annealed (WB) and air quenched (WC) specimens. In addition, SEM images were also obtained for martempered samples in nitrate mixture for the best erosion resistant one (WN5) and the worst one (WN1) and also for hydroxide mixture for the best erosion resistant (WD1) and the worst one (WD4).
Figure 4. SEM images of different heat treatments, where (C) refer to cutting, (P) refer to plowing and (F) refer to fracture.

From the SEM images (figure 4) it was found that the mechanism of erosion wear, in as-received (WA), annealed (WB), and air quenched (WC) samples, includes cutting and fracture of the hard carbides [9]. For martempered samples at both quenching mediums (WN1, WN5, WD1, WD4) the erosion mechanism also includes cutting and fracture and that the best erosion resistant samples (WN5 and WD1) exhibit less cutting and fracture of the matrix and carbides while the worst erosion resistant sample (WN1 and WD4). This erosion behavior of nitrate mixture samples (WN1 and WN5) is a reflection of its hardness in which the highest hardness sample has the least wear rate and vice versa, this result agreed with Nelson et al [9]. The hydroxide mixture samples (WD1 and WD4) have the inverse erosion behavior in which the hardest sample (WD4) has less erosion resistance than the lower hardness sample (WD1). This behavior may be due to corrosion of matrix due to longer quenching time in hydroxide mixture and this effect is clear in figure 4 – WD4.

4. Conclusion
   a) The two quenching mediums seem not to have direct effect on the distribution of the carbides in the matrix in the microstructure.
   b) Both nitrate and hydroxide mixture used as quenching mediums in martempering treatment showed a remarkable increment in erosive wear resistance. Specimens, with martempering at
about 350°C for 4 hours at nitrate mixture, have the best erosive wear resistance compared to others (with percentage increase in erosion resistance by 96.66% as compared with as received).

c) The SEM images of both types of quenching medium used showed that the common erosion mechanisms are cutting and fracture of the carbides and the best erosive wear resistance sample (WN5) have the lowest cutting and fracture.

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