Journal of Metals, Materials and Minerals, Vol.22 No.1 pp. 31 -37 , 2012

Three-Body-Type Abrasive Wear Behavior of 26% Cr Cast iron with Molybdenum

Attasit CHOOPRAJONG*[1], Prasonk SRICHAROENCHAI,[2] Sudsakorn INTHIDECH[3] and Yasuhiro MATSUBARA[4]

[1]Department of Metallurgical, Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand
[2]Department of Manufacturing Engineering, Faculty of Engineering,
[3]Mahasarakham University, Mahasarakham, Thaiand
[4]Board of Trustees, Fukuoka Jo Gakuin, Fukuoka, Japan

Abstract

Hypoeutectic 26 wt% Cr cast irons without and with Mo were prepared in order to investigate their abrasion wear resistance. The annealed specimens were hardened from 1323 K (As-H) and then tempered at three levels of temperatures between 673 and 823 K for 7.2ks, the temperature giving the maximum hardness (H_{Tmax}), lower temperature than that at H_{Tmax} (L-H_{Tmax}) and higher temperature than that at H_{Tmax} (H-H_{Tmax}). The abrasive wear resistance was evaluated using Rubber Wheel abrasion test (three-body-type). It was found that hardness and volume fraction of retained austenite (Vγ) in the heat-treated specimens varied with the Mo content and heat treatment condition. A linear relation was obtained between wear loss and wear distance in all specimens. The lowest wear rate (Rw) was obtained in both the As-H or H_{Tmax} specimens. The highest Rw was obtained in both the L- H_{Tmax} or H- H_{Tmax} specimens. Rw decreased with increasing hardness. The lowest Rw obtained in the specimen with 10% Vγ and Rw was independent on Mo content.

Keywords : High chromium cast iron, Three-body-type abrasive wear resistance, Heat treatment, Hardness, Volume fraction of retained austenite

Introduction

Alloyed white cast irons containing 15-30 wt% Cr (hereafter shown by %) have been employed as abrasion wear resistant materials for more than 50 years. The microstructures of these alloys consist of hard eutectic carbides and strong matrix structure providing the excellent wear resistance and suitable toughness. It is well known that 15% to 20% Cr cast irons have been commonly used for rolling mill rolls in the steel plants, while cast irons with 25% to 28% Cr have been applied to rollers and tables of pulverizing mills in the mining and cement industries. High Cr cast irons with hypoeutectic composition are preferable than those with hypereutectic composition because they are free from precipitation of massive primary carbides that reduce the toughness. [(1)]

In the hypoeutectic cast iron, as-cast microstructure consists of primary matrix and eutectic M_7 C_3 carbide. Austenite which is stable at high temperature under an equilibrium condition will transform to ferrite and carbides or pearlite on the way of cooling. Under non-equilibrium condition, however, the austenite may remain stable or

E-mail address: sudsakorn.i@msu.ac.th

partially transforms to pearlite or martensite depending on the chemical composition and the cooling rate.[1,2] Austenite has high toughness and it can be work-hardened to increase the surface hardness during service. However, it is limited to the spalling wear resistance. Improved service performance could be obtained by heat treatment and addition of some alloying elements to provide martensitic matrix with higher wear resistance.

The three-body-type abrasive wear environment consists of two counter materials and abrasive particles. It occurs in the application where moving particles come freely into wearing surfaces. Typical applications involving this type of wear are for ball and rod mills, pulverizers, like vertical mill and roll crushers.[1,3] The suitable wear testing machine for three-body-type abrasion wear is a Rubber Wheel wear tester where SiO_2 particles are used as the abrasives.[1]

Many laboratory tests have been carried out to evaluate the abrasion wear resistance of high Cr cast irons.[4-9] However, the test data did not often validly to simulate correctly the wear behavior occurred in the industrial applications. [1] Therefore, it is considered that the systematic and detailed studies on the abrasive wear behavior are necessary. In this study, hypoeutectic 26% Cr cast irons varying Mo content were prepared and they were heat-treated. Then, Rubber Wheel abrasion wear test was conducted. The relationships between abrasive wear, hardness, volume fraction of retained austenite ($V\gamma$) and molybdenum content are discussed.

Materials and Experimental Procedures

Hypoeutectic 26% Cr cast irons with and without molybdenum were produced using a 30 kg capacity high frequency induction furnace with alumina lining. Raw materials such as mild steel, pig iron, ferro-alloys and pure metals were used as charge materials. The charge materials were melted down and superheated up to 1853 K. After holding at the temperature, each melt was poured from 1793 to 1773 K into preheated CO_2 Y-block mold with a cavity size of 50x50x200 mm, and the surface of the top riser was immediately covered with dry exothermic powder to prevent the riser from fast cooling. The Y-block castings were sectioned to obtain the dimension of 50x50x7 mm. The chemical compositions of each specimen are shown in Table 1.

After annealing at 1273 K for 18 ks, the test pieces were austenitized at 1323 K for 5.4 ks and hardened by fan air cooling. The hardened test pieces (As-H) were tempered in a furnace at 3 levels of temperatures between 673 and 823 K, a temperature just at H_{Tmax}, a temperature lower than hat at H_{Tmax} (L-H_{Tmax}) and an higher temperature than that at H_{Tmax} (H-H_{Tmax}) for 7.2 ks. The specimens were cooled to room temperature by fan air cooling.

The microstructure was observed by Optical microscope (OM) and Scanning Electron Microscope (SEM). The measurement of macro-hardness was performed by Vickers hardness tester with a load of 30 kgf, and micro - hardness of matrix was measured by Micro-Vickers hardness tester with a load of 100 g. More than five indentations were taken at random and the measured values were averaged. The volume fraction of retained austenite ($V\gamma$) was obtained by X-ray diffraction method using a special goniometer with automatic rotating and swinging sample stage.[10] Mo-$K\alpha$ characteristic line with a wavelength of 0.007 nm (0.711 A°) filtered by Zr was used as a source of X-ray beam. The diffraction peaks used for $V\gamma$ calculation were (200) and (220) planes for ferrite (α) or martensite (M) and (220) and (311) planes for austenite (γ).

The schematic drawing of Rubber Wheel abrasion wear tester is shown in Figure 1. The silica sand of AFS 60 grade was used as the abrasives. The sands were fed to the contacting face between the rotating rubber wheel with 250 mm in diameter and test piece. The test was conducted at a rotating speed of 120 rpm. The rate to feed the abrasives was approximate 250-300 g/min. The load applied was 8.7 kgf. After the rubber wheel rotates for 1,000 revolutions or at wear distance 785.5 m, the specimen was cleaned in an ultrasonic acetone and then dried. The weight of the test piece was measured using a high precision digital weight balance with 0.1 mg accuracy. The test was repeated four times or up to the wear distance 3142 m per one test piece.

Table 1: Chemical composition of test specimens.

Specimens	Alloy (wt%)				
	C	Cr	Si	Mn	Mo
Mo-free	2.66	26.08	0.47	0.55	0.18
1% Mo	2.64	26.12	0.50	0.56	1.02
2% Mo	2.63	25.92	0.44	0.45	1.97
3% Mo	2.71	25.98	0.47	0.53	2.96

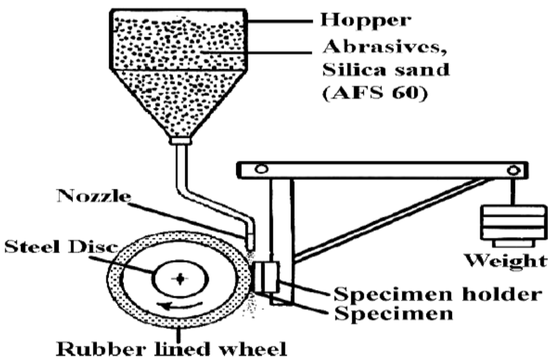


Figure 1: Schematic drawing of Rubber Wheel abrasion wear tester.[1]

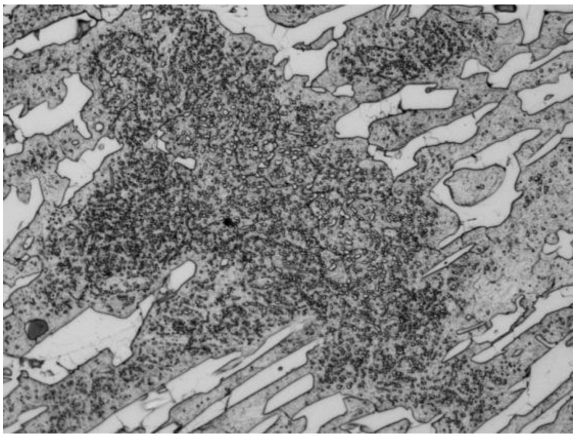
Results and Discussion

Microstructure of Test Specimen

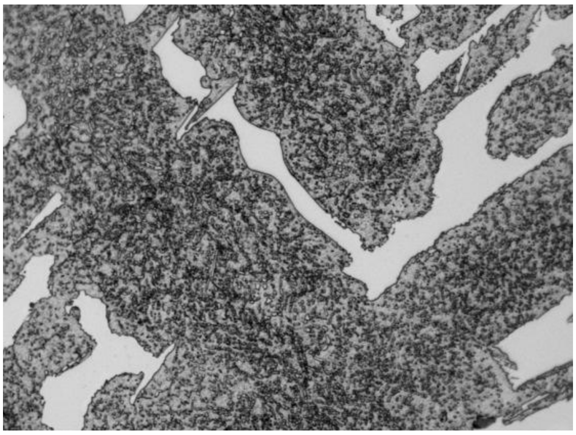
As-hardened microstructures of test specimens are example in Figure 2 by OM. The eutectic carbides appear unchanged from as-cast condition. On the other hand, it is found that the matrix transformed to precipitate a large number of fine carbides. The matrices among the carbides should consist of some martensite and retained austenite, but they cannot be seen in these photomicrographs. It has been reported that the secondary carbides which precipitated in the as-hardened state of high Cr cast iron are mostly $M_{23}C_6$ carbides co-existing with a certain amount of M_7C_3 carbides.[1,3,4,6] The retained austenite which existed in the as-cast state is destabilized to precipitate fine secondary carbides during holding and transforms into martensite during cooling.

Abrasive Wear Test

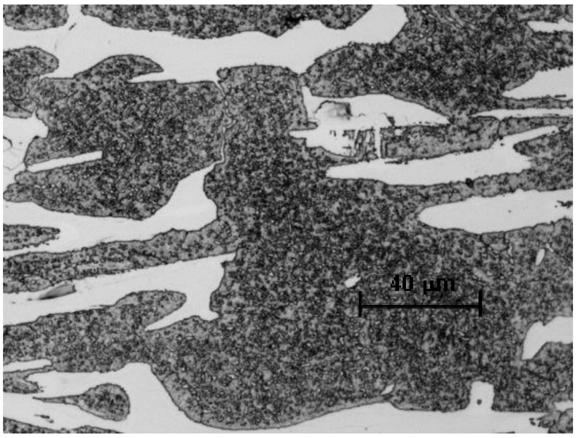
The results of Rubber Wheel wear tester are displayed in Figure 3 as an example for Mo-free and 3% Mo specimens. It is found that the wear loss increased in portion to the wear distance in all the specimens. Since, the linear relations were obtained between wear loss and wear distance in all the specimens, the parameter of wear rate (Rw) which is expressed by the slope of each straight line is introduced. The Rw values are correspondingly summarized in Table 2. It is found that that the smallest Rw is obtained in the as-hardened and H_{Tmax} specimens. The largest Rw value is obtained in the H-H_{Tmax} specimen.



a) Mo-free



b) 1% Mo



c) 3% Mo

Figure 2: Microstructures of as - hardened specimens with different Mo content taken by OM.

Table 2: Wear rate (Rw) of heat-treated specimens with different Mo content.

Specimen	Wear rate (Rw) , mg/m			
	As-H	L-H_{Tmax}	H_{Tmax}	H-H_{Tmax}
Mo-free	0.046	0.067	0.054	0.057
1% Mo	0.056	0.068	0.054	0.078
2% Mo	0.051	0.055	0.047	0.052
3% Mo	0.053	0.066	0.059	0.096

Relationship between Rw and macro-hardness is shown in Figure 4. The Rw values decrease in proportion to the macro-hardness. The relations are expressed by next equations,

$$Rw = -1.6 \times 10^{-4} \times (HV30) + 0.19 \quad (R = 0.73)$$

It is clear from above relations that the higher macro-hardness provides better wear resistance. It can be said that the hardness has strong effect on the Rw. This could be due to the microstructure. The hardness of heat-treated specimen rises due to an increase in the amount of martensite and precipitated carbides in the matrix. It was reported that the martensite wore by cutting mechanism, and the wear resistance was improved by marginal with increasing the hardness.[1,6,9] Under wear condition, the martensite offers high abrasion wear resistance due to the high strength enough to support eutectic carbides and thus, diminishes carbide fracture. In addition, the secondary carbides increase the matrix strength through a dispersion hardening effect, and this also lead to the improvement of the wear resistance.

The amount of retained austenite also affects the wear resistance of high Cr cast iron. The relationship between Rw and $V\gamma$ is shown in Figure 5. Though, the data are scattering a little, the Rw decreases gradually to the minimum point and then increases again as $V\gamma$ increases. The smallest Rw is obtained at about 10% $V\gamma$. This suggests that a certain amount of $V\gamma$ improves the abrasion wear resistance. This result agrees with the results from the other researches using different wear test methods, pin-on-disc test, which is about 20% Vγ.[8] The decrease in the Rw with raising the Vγ is considered due to the work hardening effect of retained austenite. In the case of very low Vγ value, some pearlite possibly appears there which reduces the wear resistance. In the case of high Vγ value, excessive retained austenite reduces not only the hardness but also work hardening effect. Resultantly, the Rw increases gradually as the Vγ rises.

The effect of Mo content on Rw is shown in Figure 6. Molybdenum does not show significant effect on Rw. The Rw values are little scattered and it seems independent on the Mo content. Although, Mo raises the macro-hardness, the Rw values are almost same. It is known that the stress.

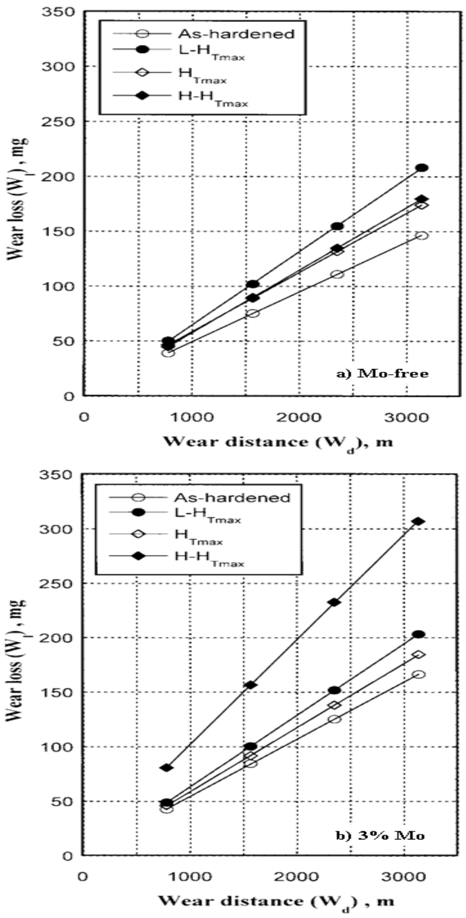


Figure 3: Relationship between wear loss and wear distance of heat-treated Mo-free and 3% Mo specimens.

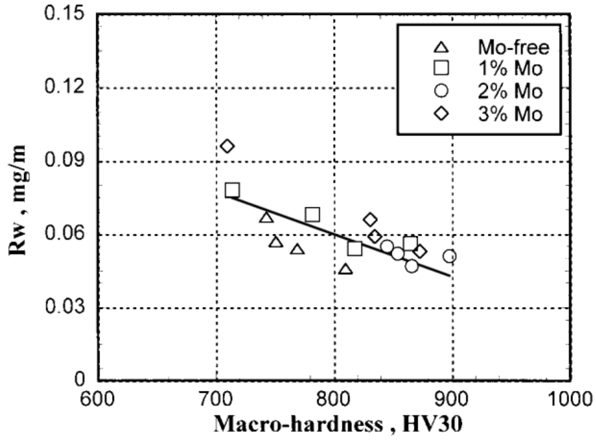


Figure 4: Relationship between wear rate (Rw) and macro-hardness of heat-treated specimens with different Mo content.

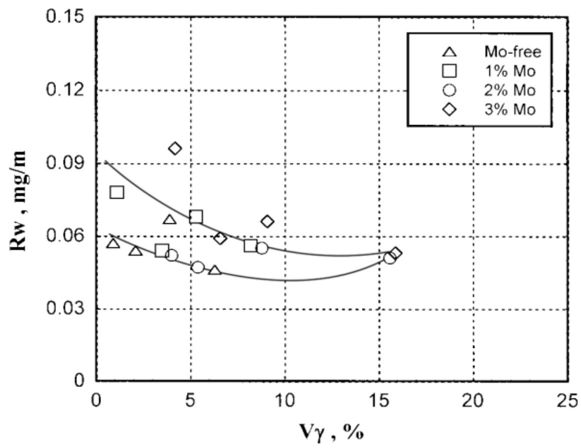


Figure 5: Relationship between wear rate (Rw) and volume fraction of retained austenite (Vγ) of heat-treated specimens with different Mo content.

concentration on the worn surface in this test is quite low. The hardness of abrasive particle about 1200 HV is smaller than that of eutectic M_7C_3 carbide which is about 1500-1800 HV.[1] Therefore, the matrix regions with lower hardness wore preferentially. It had been reported that the removal rate of matrix controls greatly the fracture of carbide and subsequently, the work hardening of austenite is hard to appear effectively because of the low stress concentration.[1,11] In this case, the harder matrix provides the better resistance to the abrasive wear. From this viewpoint, it is considered that the matrix could have a major effect on the Rw. The average values of matrix hardness are 737 HV0.1 for Mo-free, 722 HV0.1 for 1% Mo, 780 HV0.1 for 2% Mo and 733 HV0.1 for 3% Mo specimens, respectively. It is found that the matrix hardness is almost the same except for 2% Mo specimen. Therefore, it is not a surprise that the Rw do not change so much by Mo addition.

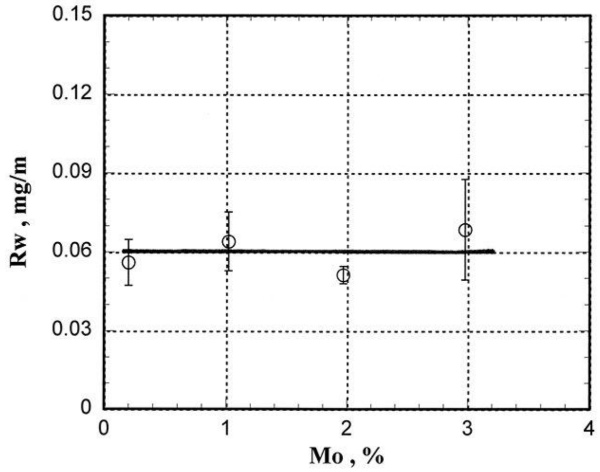


Figure 6: Effect of Mo content on wear rate (Rw).

Conclusions

Abrasion wear behaviour of heat-treated hypoeutectic 26% Cr cast irons without and with Mo was investigated. After annealing, the specimens were hardened from 1323 K (As-H) and tempered at three levels of temperatures, a temperature giving the maximum hardness (H_{Tmax}), and lower and higher temperatures than the H_{Tmax} temperature (L-H_{Tmax}, H-H_{Tmax}). The effects of hardness, volume fraction of retained austenite (Vγ), heat treatment condition and Mo content on the wear behaviour were clarified. The following conclusions have been drawn from the experimental results and discussions.

1. In heat-treated state, the hardness and Vγ varied with heat treatment condition and Mo content.
2. A linear relationship was obtained between wear loss and wear distance regardless of heat treatment condition and Mo content.
3. The largest wear resistance was obtained in both the as-hardened specimen (As-H) for Mo-free and 3% Mo cast irons and the H_{Tmax} specimen for 1% and 2% Mo cast irons. The smallest wear resistance was obtained in both the L-H_{Tmax} specimen for Mo-free and 2% Mo cast irons and the H-H_{Tmax} specimen for 1% and 3% Mo cast irons.
4. The Rw decreased as the macro-hardness increased and the smallest Rw appeared in the specimen with 10% Vγ.
5. The Rw was independent on Mo content.

Acknowledgments

One of the authors acknowledged to Commission on Higher Education, Thailand Research Funding and Mahasarakham University for research funding (MRG5480036).

References

1. Laird, G., Gundlach, R. and Rohring, K. (2000). *Abrasion - resistance cast iron handbook.* New York : American Foundry Society.

2. Matsubara, Y., Ogi, K. and Matsuda, K. (1981). Eutectic solidification of high chromium cast iron – eutectic structures and their quantitative analysis. *AFS. Trans.* **89:** 183-196.

3. Inthidech, S., Sricharoenchai, P. and Matsubara, Y. (2006). Effect of alloying element on heat treatment behavior of hypoeutectic high chromium cast iron. *Mater.Trans.***47:** 72-81.

4. Sare, I.R. and Arnold, B.K.(1995). The effect of heat treatment on gouging abrasion resistance of alloy white cast iron. *Metall. Mater. Trans.* **26(A):** 357-370.

5. Inthidech, S., Aungsupaitoon, P., Sricharoenchai, P. and Matsubara, Y. (2010). Two-body - type abrasion wear behavior in hypoeutectic 16 % Cr cast irons with Mo. *Int. J. Cast. Met. Res.* **23:** 164-172.

6. Tabrett, C.P., Sare, I.R. and Ghomashchi, M.R.(1996). Microstructure - property relation in high chromium white iron alloys. *Int. Mater. Rev.* **41:** 59-82.

7. Dogan, Ö.N., Hawk, J.A. and Laird, II G. (1997). Solidification structure and abrasion resistance of high chromium white irons. *Metall. Mater. Trans.* **28(A):** 1315-1328.

8. Sare, I.R. and Arnold, B.K (1995). The influence of heat treatment on the high-stress abrasion resistance and fracture toughness of alloy white cast irons. *Metall. Trans.* **26(A):** 1785-1793.

9. Zum Gahr, K. and Doane, D.V. (1980). Optimizing fracture toughness and abrasion resistance in white cast irons. *Metall. Trans.* **11(A):** 613-620.

10. Kim, C. (1979). X-Ray method of measuring retained austenite in heat treat white cast irons. *J. Heat. Treating* . **1:** 43-51.

11. Bedolla-Jacuinde A., Correa, R., Mejia, I., Quezada, J.G. and Rainforth, W.M. (2007). The effect of titanium on the wear behaviour of a 16%Cr white cast iron under pure sliding. *Wear.* **263 :** 808-820.