[논 문] 한국재료학회지
Korean Journal of Materials Research
Vol. 12, No. 5 (2002)

합금크롬주철의 탄화물형상 및 열처리가 내마모성에 미치는 영향

류 성 곤†·마쯔바라 야스히로*
계명대학교 재료공학과
*일본 구루메공대 금속재료공학과

Effects of Carbide Morphology and Heat Treatment on Abrasion Wear Resistance of Chromium White Cast Irons

Sung-Kon Yu† and Yasuhiro Matsubara*
Department of Materials Engineering, Keimyung University, Daegu 704-701
**Department of Materials Science and Metallurgical Engineering,*
Kurume National College of Technology, Kurume 830-8555, JAPAN

(2002년 3월 30일 받음, 2002년 5월 11일 최종수정본 받음)

Abstract Eutectic high chromium cast irons containing 17%Cr and 26%Cr were produced for this research by making each of them solidify unidirectionally. Abrasion wear test against SiC or Al_2O_3 bonded paper was carried out using test pieces cut cross-sectionally at several distances from the chill face of castings. The wear resistance was evaluated in connection with the parameters such as eutectic colony size(E_w), area fraction of boundary region of the colony(S_B) where comparatively large massive chromium carbides are crystallized and, average diameter of chromium carbides in the boundary region(D_c). The wear rate(R_w), which is a gradient of straight line of wear loss versus testing time, was influenced by the type and the particle size of the abrasives. The R_w value against SiC was found to be larger than that against Al_2O_3 under the similar abrasive particle size. In the case of SiC, the R_w value increased with an increase in the particle size. The R_w value also increased as the eutectic colony size decreased, and that of the 17%Cr iron was larger than that of the 26%Cr iron at the same E_w value. Both of the S_B and D_c values were closely related to the R_w value regardless of chromium content of the specimens. The R_w values of the annealed specimens were greater than those of the as-cast specimens because of softened matrix structures. As for the relationship between wear rate and macrohardness of the specimens, the hardness resulting in the minimum wear rate was found to be at 550 HV30.

Key words : Eutectic high chromium cast irons, Abrasion wear test, Eutectic colony size

1. Introduction

High chromium cast irons have a superior resistance to abrasive wear, corrosion and heat. Therefore, they are applied to the manufacture of balls, liners, rollers, rings for pulverizing mills, impeller blades for shotblast machine and impact crusher, dredge pump parts, and wear resistant parts for steelmaking and cement plants.

Particularly, eutectic or near-eutectic high chromium cast irons containing chromium from 15 to 30% have an excellent resistance in abrasive and erosive wear due to the M_7C_3 eutectic carbide having higher hardness and toughness than M_3C carbide and the matrix being alloyed with chromium. However, the wear behavior of high chromium cast irons is rather complex because it varies with wear conditions such as wear circumstance, type of abrasives, contact way against the abrasives, and magnitude of load applied. In shotblasting and pin on disc wear test, the wear rate decreases with an increase in chromium content and reaches a minimum value at 25%Cr, and in annealed condition the eutectic irons have more wear resistance than the hypo-eutectic irons because the former has more volume fraction of eutectic carbides than the latter.[1~4] The eutectic structure in high chromium cast irons grows with a cellular interface and shows a colony structure consisting of fine globular carbides in the central region, large massed ones in the boundary region, and matrix structures filling up the gaps of the eutectic carbides.[5] Because the abrasion wear behavior of high chromium cast irons is influenced by microstructural factors, the objective of this research is to investigate the relationship between abrasion wear and morphological factors such as eutectic colony size

† E-mail: yusung@kmu.ac.kr

(E_w), fraction of boundary region of the colony (S_B) where comparatively large massive chromium carbides are crystallized, and average diameter of chromium carbides in the boundary region (D_c) in as-cast and heat treated state of eutectic high chromium cast irons containing 17 and 26%Cr.

2. Experimental procedure

2.1 Preparation of Test Specimen

Eutectic high chromium cast irons with 17 and 26% Cr were prepared using charge materials such as master alloy, ferro-alloys, pure metals and high purity steel scrap. Each charge (5kg) was melted using an alumina crucible in a high frequency induction furnace, and superheated up to 1823K. After deoxidation treatment with 0.1%Al, the melt was poured from 1773K into an exothermic mold that had been set on a water-cooled copper chill plate as illustrated in Fig. 1. After pouring, the melt was immediately covered with dried exothermic powder for the melt to be solidified unidirectionally from the bottom to the top. The chemical compositions of specimens are shown in Table 1. The cast specimens (50mm in bottom diameter, 70mm in top diameter and 150mm in length) were cut cross-sectionally into sliced pieces with 5mm thickness at distances of 10, 30, 60, 85 and 110mm from the chill face. For abrasion wear test, the sliced specimens were machined to have a surface roughness less than 3㎛. To eliminate the effect of matrix structures on the abrasion wear behavior, the as-

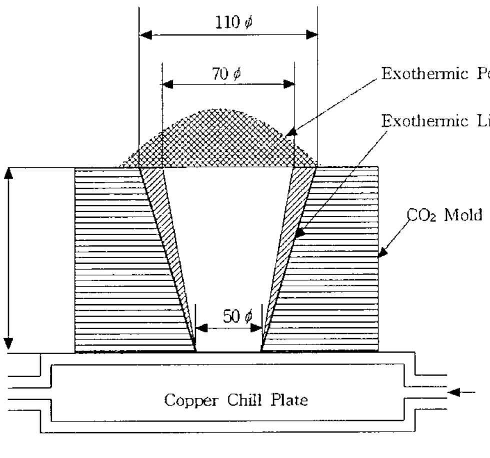


Fig. 1. Exothermic mold assembly for unidirectional solidification

Table 1. Chemical composition of specimen and Cr/C value

No.	C	Cr	Ni	Si	Mn	Cr/C
1	3.55	17.45	1.0	0.68	0.44	4.92
2	3.22	26.32	1.0	0.77	0.46	8.17

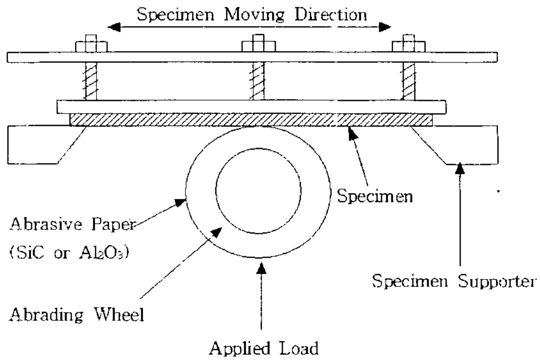


Fig. 2. A schematic drawing of abrasion wear testing machine

cast specimens were also annealed at 1073K for 2hr before abrasion wear test.

2.2 Abrasion Wear Test

A schematic drawing of the main part of abrasion wear testing machine is illustrated in Fig. 2. Under the applied load of 3kgf, the abrading wheel (44mm in diameter and 12mm in thickness) covered with SiC or Al_2O_3 bonded paper was revolved intermittently while moving back and forth by 35mm stroke on the same area of the test piece in dried condition. The revolving speed of the abrading wheel was 0.345mm/s and the worn area on the specimen was 420 (12mm×35mm) mm^2. The wear loss of the test piece was measured after one revolution of the wheel, which was taken 400s and this procedure was repeated up to eight times. In pulverizing mill, the roller and table are always contacted with various kinds of rocks and minerals with high hardness to crush them. In order to simulate the wear phenomena between them in abrasion wear test, SiC or Al_2O_3 has been preferably employed as the abrasives because it is harder and tougher. Eutectic colony size (E_w), area fraction of boundary region of the colony (S_B) where comparatively large massive chromium carbides are crystallized, average diameter of chromium carbides in the boundary region (D_c), and heat treatment were selected as the main parameters affecting the abrasion wear behavior. Macro-hardness was also measured to study its relationship with the abrasion wear behavior.

3. Results and discussion

3.1 Microstructure

The microstructures of unidirectionally solidified specimens were observed at five cross sections from the chill face and those at 30mm are representatively shown in Fig. 3.

It is clear that both structures show a round colony structure consisting of eutectic M_7C_3 carbides and

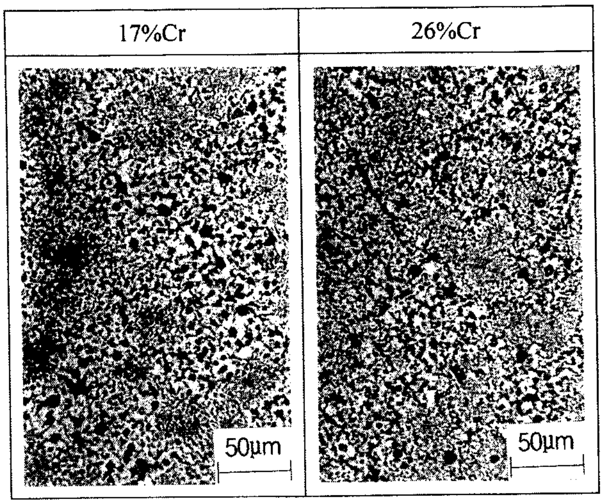


Fig. 3. Cross-sectional microstructures of eutectic high chromium cast iron with 17 and 26%Cr (30mm from the chill face)

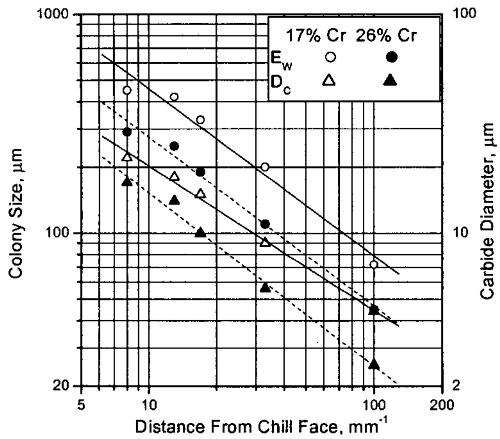


Fig. 4. Relationship among eutectic colony size(E_w), average diameter of chromium carbides in the boundary region(D_c) and distance from the chill face

eutectic austenite(or ferrite) matrix filling up their gaps. The eutectic M_7C_3 carbides in the central region of the colony are of a fine globular shape and those developing from center to boundary are string-like or granular, and those at the boundary region are large massed grains. The 26%Cr iron has smaller colony size and average carbide diameter in the boundary region when compared with 17%Cr iron. The similar microstructures were also observed in another specimens. The eutectic colony size(E_w) and average diameter of chromium carbides in the boundary region(D_c) were measured at each cross section from the chill face and are plotted as a reciprocal function of the distance from the chill face as shown in Fig. 4.

In both specimens, the E_w and D_c values are proportional to the distance from the chill face. It has been reported that the E_w value and carbide spacing at central or boundary region of colony have an inverse linear

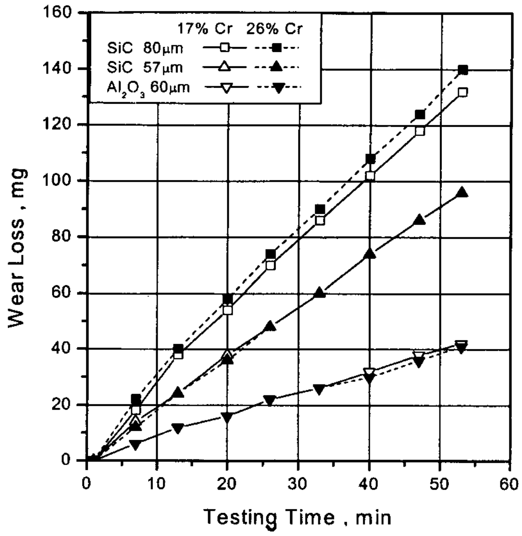


Fig. 5. Relationship between wear loss and testing time in as-cast state(30mm from chill face)

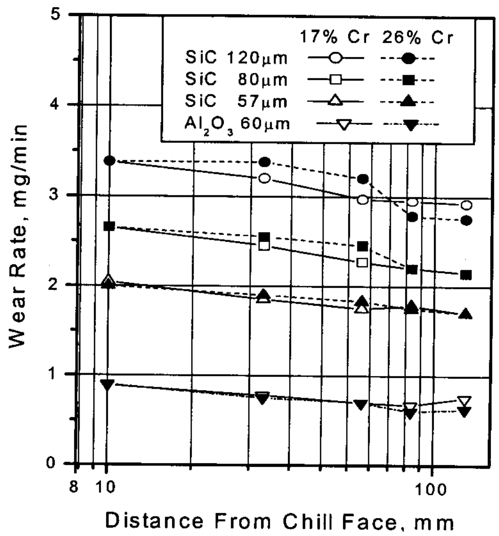
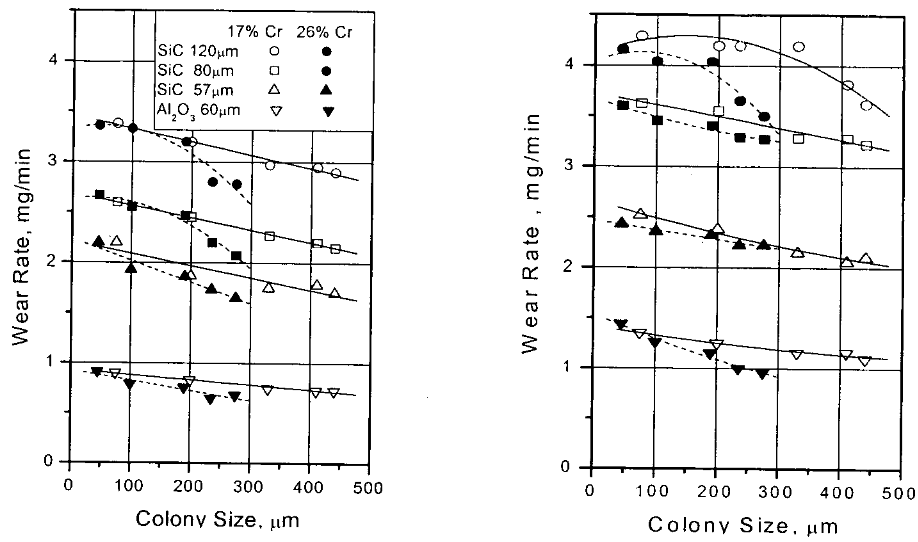


Fig. 6. Relationship between wear rate and distance from chill face in as-cast state

relationship with the eutectic solidification rate(R_E).[6] The R_E value is also reported to decrease linearly as the distance from the chill face increases.[6] Therefore, the results of this experiment that the E_w and D_c values decrease linearly with an increase in the R_E value are consistent with the previous experiments.

3.2 Abrasion Wear Test

The results of abrasion wear test on the two as-cast specimens cut at distance of 30mm from the chill face are shown in Fig. 5. Both specimens show a linear relationship between wear loss and testing time. Since the linear relationships have been obtained between wear loss and testing time in all the specimens, it is convenient to adopt the term wear rate(R_w: mg/min) which



(a) as-cast state (b) annealed state

Fig. 7. Relationship between wear rate and eutectic colony size in as-cast and annealed states

is expressed by the slope of each straight line as an index for comparison of abrasion wear. As shown in Fig. 6, the R_w value decreases with increased distance from the chill face. At the same distance, the R_w value against Al_2O_3 is lower than that against SiC, and the R_w value for SiC increases with an increase in its particle size. The R_w values of the 17%Cr and 26%Cr irons are almost the same in the specimen cut at 10mm distance from the chill face. At 30 and 60mm, the R_w values of the 17%Cr iron are smaller than that of the 26%Cr iron. On the other hand, the 26%Cr iron has lower R_w values than the 17%Cr iron at 85 and 110mm where the eutectic solidification rate is relatively slow.

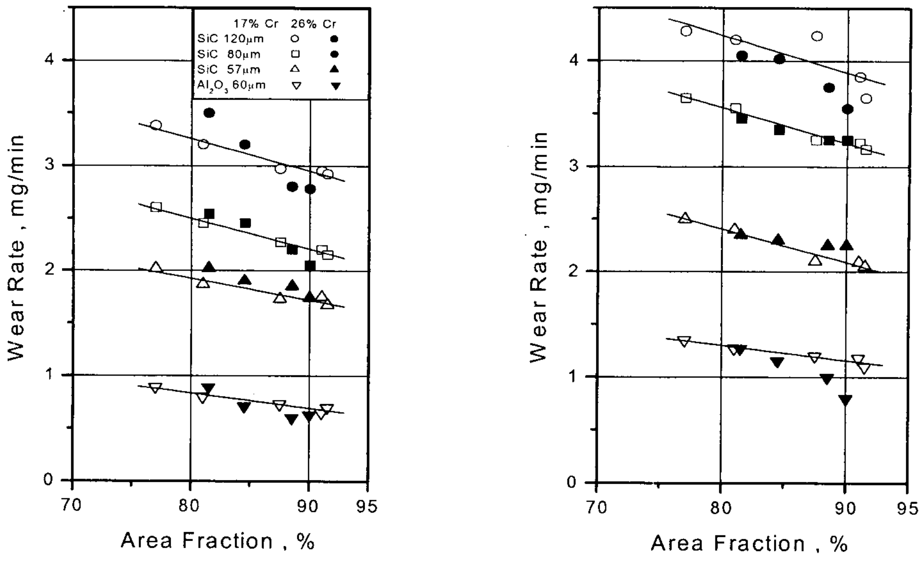
3.3 Relationship between Wear Rate(R_w) and Eutectic Colony Size(E_w)

As mentioned previously, the R_w value of high chromium cast irons varies with the distance from the chill face, that is, coarseness of solidification structure. The relationship between the R_w and E_w values in as-cast and annealed conditions are shown in Fig. 7.

In both conditions, the R_w value decrease with an increase in E_w value, which means wear resistance is enhanced as the eutectic colony size increases. In as-cast state, the R_w values of the 17%Cr and 26%Cr irons are almost the same in the lower range of E_w value, but the 26%Cr iron has a lower R_w value in the higher range of E_w value. In high chromium cast irons, it is reported that the size and distribution of eutectic carbides are dependent upon chromium content.[6] Since the distribution of eutectic carbides in the 26%Cr iron is more uniform than that of the 17%Cr iron at the same E_w value, it is considered that the matrix area filling up the gap of eutectic carbides is narrower in the 26% Cr iron than the 17%Cr iron, resulting in less abrasion wear of the matrix by abrasives. In addition, higher hardness of M_7C_3 carbide which dissolves more chromium could contribute to the less wear loss of the 26% Cr iron. At the lower E_w values ($<100\mu m$), the difference of eutectic carbide spacing between the two irons is negligible in addition to their small eutectic colony sizes, which makes the R_w values of the two irons closer. The R_w value of the specimen against SiC is twice as large as that of the specimen against Al_2O_3 due to the difference in hardness and shape of the two abrasives. It is also shown that the R_w value increases with an increase in SiC particle size. Although the tendency of relationship between the R_w and E_w values in the annealed condition is similar to that observed in the as-cast condition, the R_w value of the annealed specimen is greater than that of the as-cast specimen due to softening of matrix structure, especially conducted against coarse SiC abrasive.

3.4 Relationship between Wear Rate(R_w) and Morphology in Boundary Region of Eutectic Colony

As mentioned in 3.3, it is not easy to explain the mechanism of wear rate as a sole function of eutectic colony size. According to the previous study, it is reported that the effect of chromium content on the size of eutectic carbides at the central region of eutectic colony is negligible.[6] In stead, comparatively large massive chromium carbides at the boundary region of the eutectic colony are considered to have a major role on



(a) as-cast state (b) annealed state

Fig. 8. Relationship between wear rate and area fraction of boundary region in as-cast and annealed states

wear rate. Two parameters, the area fraction of boundary region (S_B) where comparatively large massive chromium carbides are crystallized and the average diameter of chromium carbides at the boundary region (D_c), were investigated to derive a relationship with the wear rate (R_w).

3.4.1 Effect of area fraction of boundary region (S_B) on wear rate (R_w)

Fig. 8 shows a relationship between the R_w and S_B values in as-cast and annealed states.

In unidirectionally solidified specimen, the nearer to the chill face, the faster the cooling rate, resulting in more eutectic nucleation sites. The S_B value increases with an increase in distance from the chill face, ranging from 77% to 91% in this experiment. As shown in Fig. 8, the relationship between the R_w and S_B values is linear with negative slopes of 0.043~0.015 regardless of chromium content. The R_w value decreases with increased S_B value, which means the abrasion wear resistance is enhanced with more area fraction of the boundary region of eutectic colony where comparatively large massive chromium carbides are crystallized. The linear relationship with negative slopes of 0.046~0.022 is observed in the annealed specimens where the R_w values are 1.3~1.6 times as large as those of the as-cast specimens.

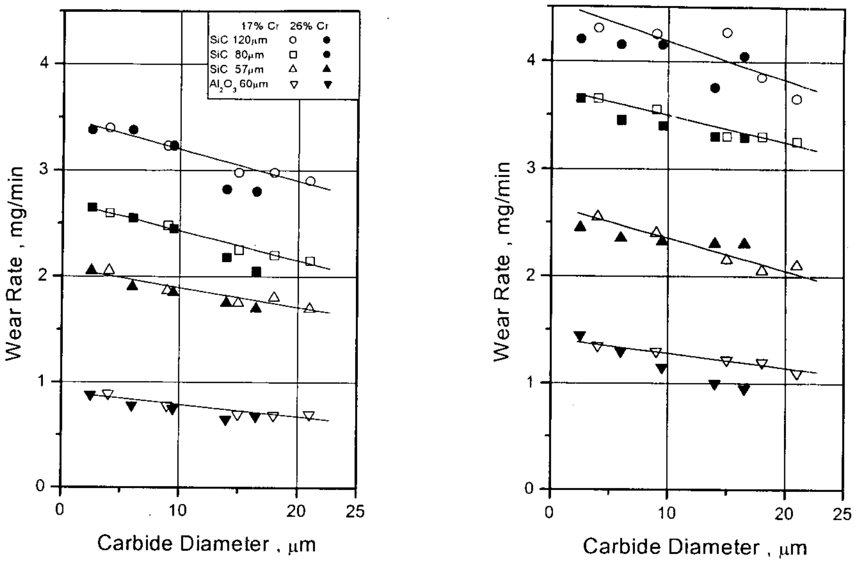
3.4.2 Effect of average diameter of chromium carbides in boundary region (D_c) on wear rate (R_w)

The relationship between the D_c and R_w values is shown in Fig. 9, revealing a linear relationship between the two values regardless of chromium content. The D_c value ranges from 2.5 to 21μm and the R_w value decreases with an increase in the D_c value, meaning the abrasion wear resistance is enhanced as the average diameter of chromium carbides at the boundary region increases.

The slopes of lines range from -0.049 to -0.018 in the as-cast specimens and have more negative values with increased SiC particle sizes. The relationship between R_w and D_c in the annealed state is similar to that observed in the as-cast state. The slopes range from -0.027 to -0.018 and are not much affected by type and particle size of the abrasives. The annealed specimens have larger R_w values than the as-cast specimens, which means that the abrasion wear resistance has decreased due to softening of the matrix. As shown in Fig. 9(a), the actual R_w values are a litter higher than the line at higher D_c level due to the inhomogeneity of matrix structures in the as-cast state. However, this phenomenon is not observed in the annealed state where the effect of matrix structure on the abrasion wear behavior has been eliminated, as shown in Fig. 9 (b)

3.5 Relationship between Wear Rate (R_w) and Macro-Hardness (H_M) of Specimens

The volume fraction of eutectic carbides in the 17 and 26% irons are 37.2 and 38.2%, respectively. Although the difference of volume fraction of eutectic carbides between the two irons are negligible, the size and distribution of eutectic carbides and the composition of matrix structures are different which result in the difference in their macro-hardness (H_M) values.



(a) as-cast state (b) annealed state

Fig. 9. Relationship between wear rate and average diameter of chromium carbides in boundary region of as-cast and annealed states

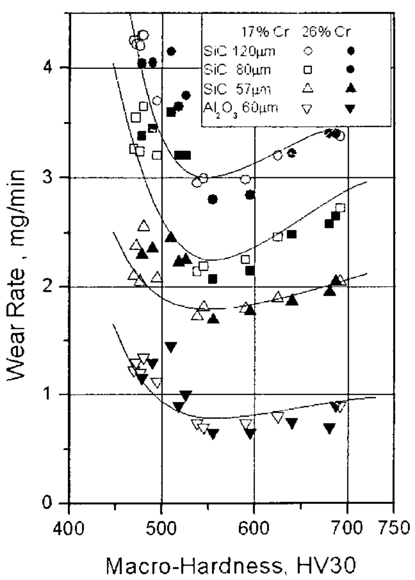


Fig. 10. Relationship between wear rate and macro-hardness.

Fig. 10 shows a relationship between the R_w and H_M values. The R_w value decreases rapidly with an increase in H_M value and reaches a minimum value at 550 HV30, and then increases slowly again with an increase in the H_M value. Zum Gahr has reported that the abrasion wear loss of high Cr-Mo white cast irons decreases with an increase in volume fraction of carbides (V_c) and reaches a minimum value at the certain V_c value.[7] Since the hardness tends to increase with an increase in the V_c value, the result of this experiment that the R_w value has a minimum value at certain H_M value is consistent with the results of Zum Gahr. The specimens with hardness less than 500 HV30 are annealed ones, in which the effect of softened matrix structures on the abrasion wear rate is clearly manifested. From these results, it can be said that the R_w value increases remarkedly when the SiC particle size becomes larger like 80 and 120㎛ or when the wear stress is greater, and that the matrix structure contributes greatly to the wear resistance.

4. Conclusion

In eutectic high chromium cast irons solidified unidirectionally, the relationship between abrasion wear behavior and parameters such as carbide morphology and heat treatment was investigated and the following conclusions were obtained:

1) The wear rate(R_w) of eutectic high chromium cast iron was dependent upon the type of abrasives employed. The R_w value of the specimen against SiC was higher than that against Al_2O_3 under the similar particle size and in the case of SiC abrasives, the R_w value increased with an increase in its particle size.

2) The R_w value decreased with an increase in the eutectic colony size(E_w). At the same E_w value, the R_w value of the 26%Cr iron was lower than that of the 17%Cr iron. Regardless of chromium content, the R_w value decreased with an increase in area fraction of boundary region(S_B) where comparatively large massive chromium carbides are crystallized, and the average diameter of chromium carbides in boundary re-

gion (D_c).

3) The abrasion wear behavior of the annealed specimen was similar to that of the as-cast specimen, but the R_w value in the annealed state was 1.3～1.6 times as large as that in the as-cast state.

4) The R_w value decreased rapidly with an increase in the macro-hardness of specimen (H_M) and reached a minimum value at 550HV30, and then increased slowly again with an increase in the H_M value.

Acknowledgements

This work was supported (in part) by the Korea Science and Engineering Foundation (KOSEF) through the Center for Automotive Parts Technology (CAPT) at Keimyung University.

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