CHAPTER I

INTRODUCTION

1.1 Background

High alloyed cast irons containing 12-30% Cr have been employed as abrasion wear resistant materials for a long time. The research and development of them have been carried out to improve wear resistance and toughness within their cost performance. The chemical composition of high chromium cast irons used for wear parts are 2.0-3.6 mass% C and 10-30 mass% Cr (as shown by %). Particularly, 15% to 17% Cr cast irons containing some alloying elements have been preferably used as materials for the parts and components in the various fields of industries because of their high abrasion wear resistance and reasonable toughness. The industries such as cement, mining and steel-making have been the main users.

In general, pearlite phase in matrix is considered to deteriorate the wear resistance and to reduce the service life. In order to overcome this problem, the third alloying elements such as Ni, Cu, Mn and Mo are usually added to improve the hardenability of the cast iron.

Chromium (Cr) is a strong carbide former and it combines with carbon to form carbide of $(FeCr)_7C_3$ or M_7C_3 type in the cast irons containing high level of chromium. The M_7C_3 carbide is harder and has more discontinuous morphology than the $(FeCr)_3C$ or M_3C type formed in the cast irons with low chromium content [1,2].

The purpose of Mo addition is to avoid the formation of pearlite in the as-cast condition and to improve hardenability during heat treatment. As can be expected, Mo tends to form its own carbides of Mo_2C or M_2C type with very high hardness [3]. At lower levels of Mo, the Mo distributes into both of the austenitic matrix and M_7C_3 eutectic carbides and, at Mo levels over 2%, it is possible that the Mo_2C or M_2C eutectic carbides precipitate in the final liquid along with grain boundaries between austenite (γ) and γ + M_7C_3 eutectic during solidification. Mo dissolved in the austenite improves the hardness by promoting the secondary precipitation of molybdenum carbides and that dissolved in M_7C_3 carbides increases also the hardness of carbides themselves. It has been reported that the presence of M_2C carbides leads to improve the abrasion wear resistance [4].

In the solidification process of hypoeutectic high chromium cast iron, austenite solidifies first and followed by a eutectic reaction of (γ + M_7C_3). The carbide structure is varied depending on the combination of the contents of carbon, chromium and other carbide forming elements, and the eutectic shows colony morphology with fine carbides at the central region and coarse carbides at the boundary region. The size of the eutectic colony is controlled by the eutectic freezing range and cooling rate [2]. On the other hand, the matrix structure can be controlled by the heat treatment. Therefore it can be said that not only abrasion wear resistance but also mechanical properties should be determined by both of the carbide and matrix structures.

For high chromium cast iron, heat treatment is the main approach and most important method to improve the wear resistance and mechanical properties. When the carbide structure is similar, it is considered that factors affecting the abrasion wear resistance could be the hardness and volume fraction of retained austenite of matrix [5]. Quantitative measurement of the retained austenite for the high chromium cast iron was performed successfully by X-ray diffraction method [6]. Then, it is very interesting for the amount of austenite be connected to the wear resistance and other properties.

The presence of retained austenite in the matrix is beneficial because austenite has high toughness and gives the work hardening on the wear surface by the formation of strain-induced martensite [5,7]. However, a large amount of retained austenite in the as-cast state reduces the wear resistance because it promotes the spalling wear. It was reported that high chromium cast iron which had martensitic matrix with some retained austenite showed the largest wear resistance to the spalling [3,7]. Therefore, heat treatment of high chromium cast irons must be conducted so that the optimal combination of the hardness and the quantity of retained austenite can be obtained from the view point of abrasion wear. The general heat treatments of high chromium cast iron consist of annealing, hardening and tempering. During austenitizing, the austenite in the as-cast state is destabilized by the precipitation of secondary carbide and allows the transformation of the unstable austenite into martensite during cooling, and resultantly, the hardness is increased.

The secondary hardening occurs during tempering due to the precipitation of secondary carbides from both martensite and austenite during tempering and the transformation of retained austenite into martensite during cooling [8]. Therefore, it can be said that the precipitation of secondary carbides in the matrix during heat treatment plays a very important role on the final hardness, wear resistance and other mechanical properties of the cast iron [7].

The maximum hardness of 800HV30 by tempering is obtained in alloy-free high chromium cast irons [11]. When much higher hardness is required, the alloying elements, which improve not only the hardenability but also the secondary hardening, should be added to the cast iron. One of the effective elements is Mo. It has some report that ,in hypoeutectic 16%Cr cast irons with Mo, the hardness after tempering can increase over 800HV30 [8].

The abrasion wear process can be mainly classified into Two-body-type and Three-body-type abrasion wears [3]. In the Two-body-type abrasion wear process, the wear environment consists of abrasive particle and counter material. The wear occurs when abrasive particles give the concentrated stress on the surface of counter material, leading up to the heavy plastic deformation. As the wear progress, the tips of abrasive particles are fixed in the surface of counter material, and the matrix is selectively removed first. The examples of machine parts showing such wear behavior are tooth of jaw crusher and hammer and liner of impact crusher which receive extremely high wear stress. The abrasives generally used for the abrasion test is emery papers in which the abrasive particles such as SiC, Al_2O_3 and other ceramic materials are fixed on the paper, that is, imbedded in the ground by glue. Therefore, the Suga wear tester using the emery paper is suitable to evaluate the Two-body-type abrasion wear resistance. In Three-body-type abrasion wear, the wear environment consists of abrasive particles and two counter materials. The wear progresses by the behavior that abrasive particles move freely and roll around between the surfaces of counter materials. The machines in which this type of wear occurs are ball mills and tube mills to pulverize the cement clinker and coal. In this case, the wear stress is normally low. The suitable wear testing machine for the Three-body-type abrasion wear is Rubber wheel abrasion wear tester.

The tests in many laboratories have been carried out to evaluate the abrasion wear resistance of alloyed cast irons. However, the test data did not often validly to simulate correctly the many types of wear behavior occurred in the industrial applications [3]. This is because the abrasion wear behavior is so complex and it varies according to wear conditions such as wear circumstance, type of abrasives, contacting manner against the abrasive, magnitude of load applied and the microstructure of the cast iron [5]. Therefore, It is considered that more researches on the evaluation of abrasion wear resistance of heat-treated high chromium cast irons using different types of abrasion testers have to be done.

From the viewpoints mentioned above, it is considered found that systematic and detailed studies on the abrasion wear behavior of high chromium cast irons improved the condition of heat treatment by addition of Mo are worth doing. There are research papers concerning the wear resistance of heat-treated high chromium cast irons [5,7,31-44] and, recently a systematic research on heat treatment behavior of hypoeutectic 16% Cr cast iron with various Mo content has been reported [8]. However, the systematic researches on the abrasion wear behavior of heat-treated high chromium cast iron with different Mo level using both of Two-body-type and Three-body-type wear tests are quite few.

In this study, hypoeutectic 16% Cr cast irons varying Mo content from 0% to 3% are prepared, and heat treatments of hardening after annealing and tempering are given to the cast iron. Then, two types of abrasion wear tests, Suga abrasion wear test and Rubber wheel abrasion wear test, are carried out and the relationship among behavior of abrasion wear, hardness and volume fraction of retained austenite(V_γ) and Mo content are investigated. In addition, matrix microstructures are used to discuss the wear behaviors.

1.2 Objectives of Research

To clarify the effects of hardness, matrix microstructure and V_γ, which varies according to heat treatment condition and Mo content on wear behavior of hypoeutectic 16% Cr cast irons.

The experiments were carried out as follows:

(1) To heat-treat specimens by annealing, hardening, and three levels of tempering temperatures before maximum tempered hardness (B-H_{Tmax}), H_{Tmax} and over HTmax (O-H_{Tmax}) that are determined referring to the tempered hardness curves in the reference [8].

(2) To measure of macro-hardness and micro-hardness in the as-cast and heat-treated states.

(3) To measure the volume fraction of retained austenite (V_γ) in the as-cast and heat-treated states.

(4) To measure the wear losses using Suga abrasion wear tester and Rubber wheel abrasion wear tester.

(5) To evaluate the wear resistance associated with the variation of hardness, V_γ.

(6) To observe the microstructure by Optical microscope (OM) and worn surface appearance by Secondary electron microscope (SEM) and analyze

the distribution of Mo and other elements by Electron probe microanalysis (EPMA).

(7) To discuss the effects of hardness, V_γ and Mo content and on abrasion wear resistance.

1.3 Advantages of Research

(1) This research reveals the characteristic in Two-body-type and Three-body-type abrasion wear of 16% Cr cast iron with different Mo content using Suga and Rubber wheel abrasion wear testers.

(2) This research clarifies the relationship between abrasion wear resistance and focusing on the hardness and V_γ.

(3) This research clarifies the effects of heat treatment condition and Mo content on the abrasion wear resistance.

(4) These data are keenly helpful for the practical heat treatment to improve the wear resistance of 16%Cr cast iron with Mo.