THE ROLE OF RETAINED AUSTENITE ON PERFORMANCE OF GRINDING MEDIA[1]

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Abstract

In this study, high chrome-based white cast iron (HCWCI) balls were subjected to different heat treatments to yield various amounts of retained austenite, following which they were subjected to pin-on-belt abrasion testing. In addition, the role of retained austenite is elucidated, and with that a frame-work is provided for optimising the amount of retained austenite to achieve excellent wear resistance and toughness for these grinding media materials. The effect of retained austenite on wear behaviour was investigated in terms of work hardening and deformation induced transformation of retained austenite to martensite. The worn surfaces of the high chromium white cast iron were studied by scanning electron microscopy. Surface cracks and extensive deformation were observed on the worn surfaces.

Keywords: Retained austenite; HCWCI; High stress abrasion; Pin on belt; Ball mill; Impact-abrasion testing.

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1 INTRODUCTION

Tribology is a science, which concentrates on interacting surfaces in relative motion. Theoretical laws of tribology and wear are continuously updated by scientific research.(1) Impact wear, abrasion and their combination are the most important cost factors in the areas of mining and mineral processing. Grinding is the last stage in the communition process. The ore particles are reduced in size by a combination of impact and abrasion.(2) The grinding process is the largest energy consumer in the minerals industry. Grinding in ball mills accounts for up to 40 percent of the operating cost of a processing plant.(3)

A single tribosystem in a grinding mill is shown in Figure 1. The environment inside a grinding mill consists of air, water and dust. Grinding media is considered here as the counter-body, which creates impact wear on the solid body. The interfacial element is a large amount of ore particles, which act as an abrasive component in this tribosystem. The liners of a grinding mill are the solid bodies that are affected by the wear.(4,5)

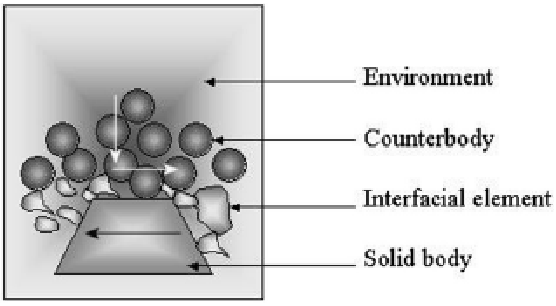


Figure 1. Tribosystem of a single lifter bar.(3)

In grinding media abrasive wear occurs when the balls make contact with the ore they are grinding. This is high stress abrasion since the ball charge is continually cascading from a height greater than half the diameter of the mill, and point contact is made with the ore or perhaps another ball. Thus, spalling of the ball surface is occurring as is deformation from the impact with other balls and ore.(6)

UG2 - the Upper Group Two layer consisting of chromite that is mined for platinum. It is located stratigraphically below the Merensky Reef. Merensky Reef - the key platinum producing layer of the Bushveld intrusive complex identified by Hans Merensky in the 1920's.(7) The percentage content of chromium oxides in Merensky reef is between 12 - 14%, while in UG2 chromium content varies between 26 – 30%.

The abrading particle or particles are constituents of the ore (i.e. UG-2 and/or Merensky Reef) and have hardnesses up to 2100HV. The mode of occurrence of platinum-group minerals ranges from being predominantly associated with base-metal sulphides (either locked within, or at the grain boundaries of, sulphide minerals) to being predominantly associated with gangue minerals (locked in chromite or silicate, or at grain boundaries of chromite and silicate grains).(7)

Ore from the Merensky Reef contains up to 3% base-metal sulphide minerals, distributed as follows, pyrrhotite (45%), pentlandite (32%), chalcopyrite (16%), and pyrite (2 to 4%). The principal constituents of UG2 ore are chromitite (60-90%), orthopyroxene, and plagioclase, together with minor amounts of talc, chlorite, and phlogopite, as well as smaller amounts of base metal and other sulphides and platinum-group minerals. Merensky ore contains much more sulphide than does the

UG2 ore, and the minerals are found in a silicate substrate, while UG2 ore has a chromite matrix.(8)

High chromium cast iron is now being widely used in all industrial countries. A great amount of chromium (≥12%) added to the iron changes the carbide M_3C into a harder carbide M_7C_3 (HV 1300 to 1800) and wear resistance is thus greatly increased. Carbide M_7C_3 forms a branched rod-like structure during solidification which improves the toughness of the iron over that containing M_3C.(9) The typical microstructure of high chromium white cast iron consists of chromium carbides of high hardness dispersed in a matrix which still contains sufficient concentrations of carbon to allow hardening as a result of transformation of austenite to martensite.

One of the major causes of ball breakage is the internal stress that results from delayed austenite to martensite ($\gamma \rightarrow \alpha'$) transformation induced by low temperatures or by impacts. These stresses add to existing residual stresses that lead to the balls spalling during storage and/or service.

Annually, large tonnages of ferrous grinding media are consumed around the globe, costing several million dollars.(10) Platinum (Pt) ores can consume about 0.6 to 0.8kg of grinding media per ton of ore milled.(11)

The role of retained austenite on the performance of cast iron based grinding media (balls) is controversial. One school of thought is that retained austenite improves the performance through work hardening/transformation to martensite. Others argue that the same phenomenon compromises the performance of the balls through spalling. Therefore, the role of retained austenite (γ_{ret}), on the performance of grinding balls is investigated in this study. The major focus will be on controlling the amounts of retained austenite in order to optimize wear resistance in cast iron-based grinding media applications. It is envisaged that the experimental work will establish the effect of retained austenite on the high stress abrasion resistance of high-chromium white cast iron material. In terms of industrial applications, the balls are designed for use in the Platinum (Pt) mining industry; hence special emphasis will be in the suitability of these balls for the milling of Pt-bearing ores such as UG2 and Merensky Reef.

The aspects investigated in this paper are the variation of abrasive wear with various microstructural combinations achieved through heat treatment at different temperatures and the effect of retained austenite and the change in wear as a result of the transformation of retained austenite.

2 EXPERIMENTAL PROCEDURE

2.1 Material

To study the influence of retained austenite on the wear properties of cast iron used in the mining and minerals processing industries for grinding ball applications, one set of test alloys was produced, namely high chromium white cast iron (HCWCI). Specimens for the test work were in the form of 70mm diameter grinding balls. The nominal chemical composition of the material is shown in Table 1.

Table 1. Chemical composition of the test material

Material	**Elements wt.%**									
	C	**Si**	**Mn**	**S**	**P**	**Cr**	**Cu**	**Mo**	**V**	**Fe**
Alloy	2.75	0.45	0.67	0.032	0.025	12.9	0.04	0.26	0.05	Bal

2.2 Heat Treatment

To achieve microstructures with different amounts of retained austenite, cast grinding balls were heat treated at temperatures of 875°C, 925°C, 1000°C, 1050°C and 1100°C and then forced air-quenched (FAQ). The heat treatment schedule is shown in Figure 2 below.

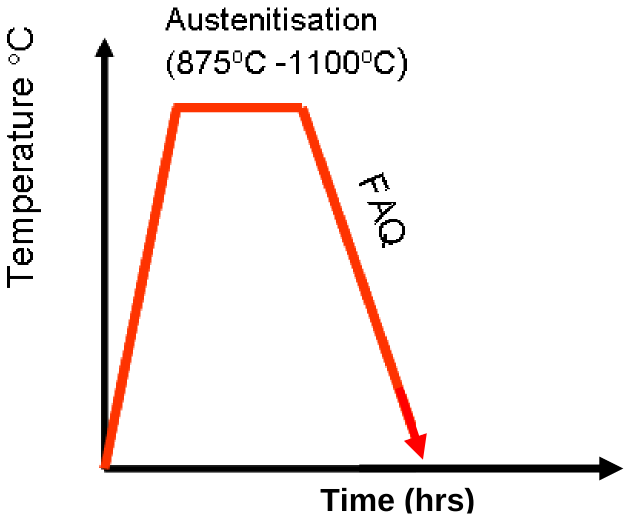


Figure 2. Schematic of the heat-treatment schedule used for the experimental high chrome white cast iron.

2.2 Metallography and Hardness

To determine the influence of retained austenite on microstructure, cross sections of as-cast and heat treated pin samples removed from the grinding balls were prepared for metallography. This involved grinding, polishing and etching using 3% nital to study the microstructures including carbide morphology and retained austenite in the matrix.

To determine the influence of retained austenite on the hardness, the as-cast and heat treated pin samples from grinding balls were prepared upon which Vickers hardness measurements were made. A Shimadzu Vickers microhardness test machine was used to measure the hardness of the matrix and carbides of these specimens. The studies was supplemented by X-ray diffraction and scanning electron microscopy.

2.3 Two Body Abrasion Test

A pin-on-belt (POB) test as shown in Figures 3 and 4 was carried out to investigate the influence of retained austenite on the high stress two-body abrasive wear behaviour of the materials. The test was also used to evaluate the relative performance of the selected experimental alloys when subjected to high-stress two-body abrasion conditions.(12) For this study only silicon carbide of 120 grit size was used. This test includes abrading a dead-loaded specimen of 10mm x 10mm by 20mm against the surface of a bonded abrasive belt. The specimens were electro-discharge machined from the as-cast and heat-treated 70mm diameter grinding balls. A detailed description of this laboratory wear test machine is given in Smith's work.(13)

The continuous belt runs horizontally at a constant velocity while the specimen is made to transverse normal to the direction of the belt movement. Thus the specimen abrades against unworn particles at all times. Prior to testing, the specimen surfaces were run in by abrading for a distance of 10.5m on fresh abrasive cloth.

The specimens were then reweighed to an accuracy of 0.001g and abraded for a distance of 2m. The abrasive resistance was evaluated by the mean value of all the mass losses. The actual conditions which were employed for testing are shown in Table 2 below. Comparing as-cast condition the relative wear resistance (β) is defined by the following:(14)

$$\beta = \frac{mass\,loss\,of\;\,as{-}cast\;\,sample}{mass\,loss\,of\;\,heat\,treated\,sample}$$

The mass loss of the as-cast reference sample, abraded on the same abrasive paper, was used to correct for test-to-test variations. In this way the relative wear resistance (RWR) of materials could be compared.

Table 2. The conditions employed for wear testing

Load (kg)	3.5
Stress (MPa)	0.34
Length of abrasion path (m)	10.5
Type of abrasive (grit)	SiC
Velocity of the belt (m/s)	0.28
Test condition	Dry
Grit size (grit)	120

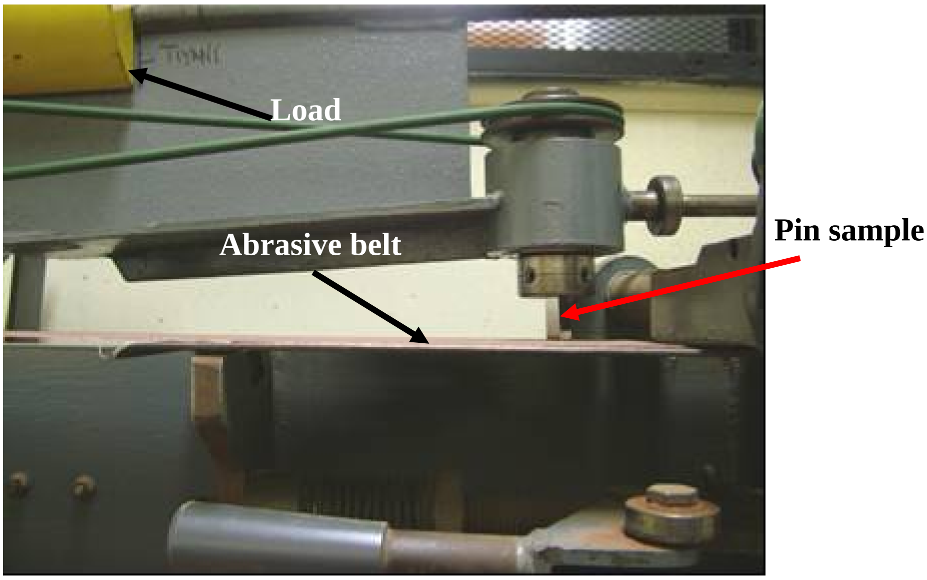


Figure 3. A close up view of the laboratory high stress abrasive wear (Pin on belt) test machine.

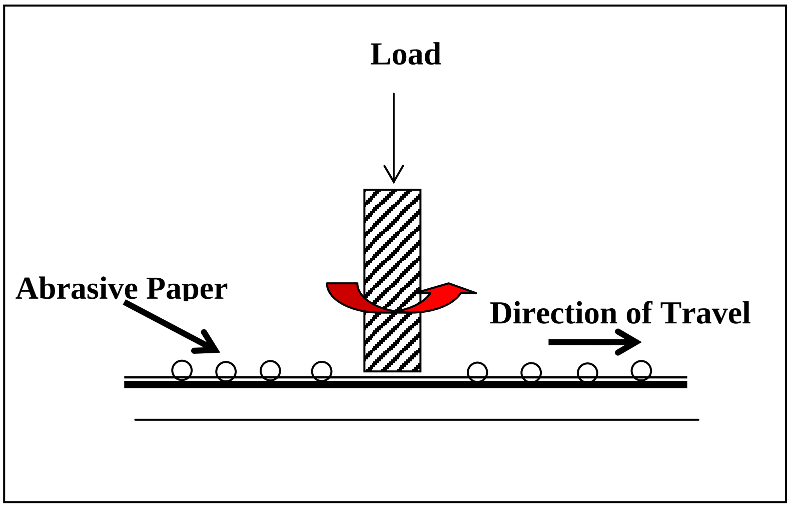


Figure 4. Schematic representation of laboratory high stress abrasive wear test used in the study of wear performance.

2.4 Measurement of Retained Austenite by X-Ray Diffraction

The traditional heat treatment of high chrome white cast iron can result in a martensitic matrix containing over 20% retained austenite which cannot be distinguished by optical microscopy, hence X-Ray Diffractometry was used. X-ray diffraction analyses were performed on several wear pin surfaces to determine the volume percentage of retained austenite. Equipment used for this was a Siemens D500 Diffractometer fitted with a molybdenum (MoKα) tube, using software developed according to ASTM E915(15) and SAE J784a(16) standards.

This is important as the amount of retained austenite may vary with austenitizing temperature and cooling. The worn and unworn samples had dimensions of 10mm by 10mm width and 5mm thick. These were cut by a water cooled Secotom-10 cut off machine.

The unworn samples underwent the usual metallographic polishing in different stages on abrasive papers of progressively finer grits. These were electro-polished in a 20% Perchloric acid ($HClO_4$) solution (i.e. 20ml $HClO_4$ + 80ml Methanol), at 18 volts for 2 minutes to remove surface deformation-induced martensite due to the polishing action. The relative intensities of x-ray diffraction peaks from (110), (200), (211) and (220) of ferrite (α), and those from (111), (200), (220) and (311) of austenite (γ) were measured.

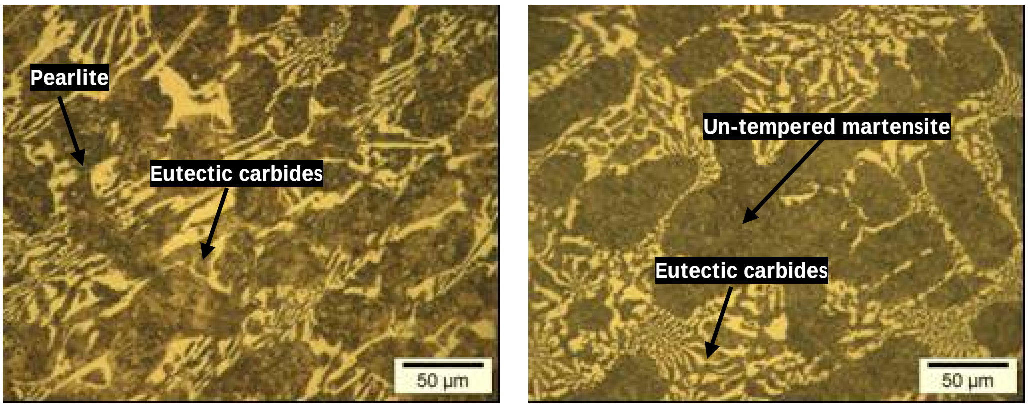
The possibility of retained austenite transforming to martensite under high stress sliding conditions was also investigated by X-ray diffraction analysis. In this case, retained austenite was measured on the specimen before and after the pin on belt abrasive wear test. This was necessary to ascertain if there was a transformation of retained austenite to martensite during abrasion. Computer software, which utilises the integrated areas of both the austenite (111), (200), (220), (311) and ferrite (110), (200), (211), (220) peaks, was used in the determination of the volume fractions of retained austenite (γ_{ret}) before and after abrasion

Following pin abrasion testing, the wear surfaces were examined by scanning electron microscopy (SEM).

3 RESULTS

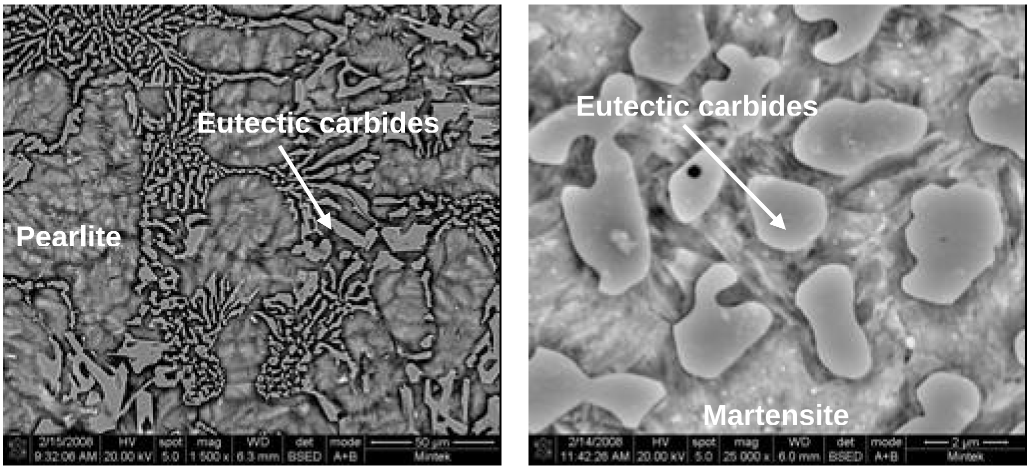
3.1 Effect of Destabilization Treatment on Microstructure and Hardness

The microstructure of the as-cast HCWCI (Figure 5a) consists of pearlite and eutectic carbides with a bulk hardness of about 530HV. The microstructures following the destabilisation treatment can vary, depending on the temperature of the treatment.
The microstructures of the as-cast and heat treated samples are discussed and shown in Figures 5 to 7. All the heat treated samples consists of a mixture of martensite, eutectic carbides, secondary carbides and different amounts of retained austenite. At higher destabilization temperatures, the matrix structure appears to have high amount of retained austenite and martensite. The secondary carbides appear larger, but fewer in number, as the destabilization temperature increases. Secondary carbides $(Fe,Cr)_{23}C_6$ precipitate from random austenite grains and do not nucleate and grow on the eutectic carbide.(13)
As part of a study on the abrasive wear behaviour of alloy irons, and complementary to optical microscopy, both the as-cast and heat treated samples were also studied under the scanning electron microscope. The microstructure of the as-cast 70mm diameter balls contains eutectic carbides, possibly M_7C_3, in a pearlitic matrix, while the heat treated balls had a mixture of eutectic and secondary carbides within a martensitic matrix at near the surface and the centre, see Figures 5 to 7. Figure 5a show the eutectic carbides and pearlite observed in the as-cast balls. Figure 5b shows the microstructure of the heat treated high chrome white iron ball which consists of eutectic and secondary carbides in a martensitic matrix.



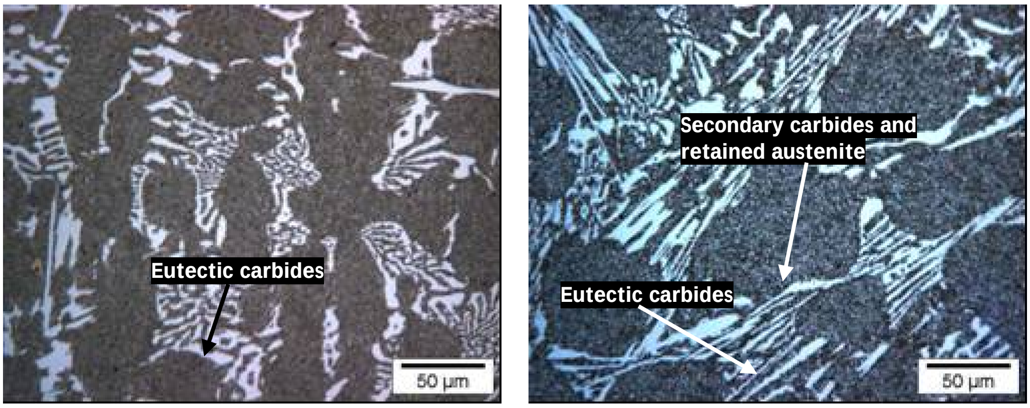
(a) As-cast (b) 875°C forced air quenched

Figure 5. Microstructure of HCWCI showing (a) as-cast eutectic carbides in a pearlitic matrix, and (b) eutectic carbides in a un-tempered martensite matrix after forced air quenching from 875°C.

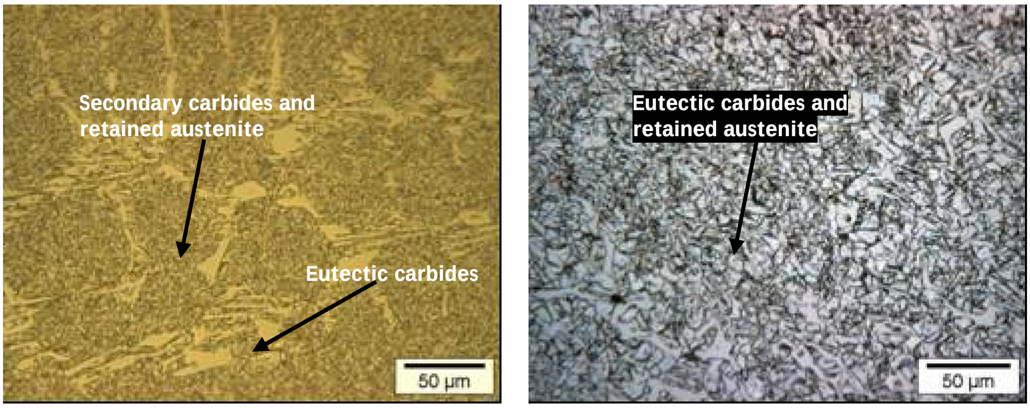


(a) As-cast (b) 875°C forced air quenched

Figure 6. (a) SEM microstructure of high chrome white cast iron showing eutectic carbides and clearly defined pearlite, (b) microstructure of heat treated HCWCI showing eutectic and secondary carbides in a clearly defined martensite matrix.



(a) 925°C and forced air quenched (b) 1000°C and forced air quenched



(c) 1050°C and forced air quenched (d) 1100°C and forced air quenched

Figure 7. Microstructure of HCWCI (a-d) showing eutectic carbides in a un-tempered martensite matrix after forced air quenching from 925°C to 1100°C.

The bulk hardness and retained austenite content for the alloy and destabilization treatment are given in Table 3. All destabilization treatments led to an increase in the bulk hardness compared to that of the as-cast condition. A microstructure has a significant influence on the wear resistance of HCWCI balls during wet grinding. Hardness and structure gradients (i.e. soft austenitic structure) are usually viewed as undesirable because of faster wear of soft constituents. From this table it can be seen that with an increase in the austenitizing temperature the hardness increases to a peak value then decreases and retained austenite content increases. This is also schematically shown in Figure 8. The hardness obtained above a destabilising temperature of 925°C decreases as the retained austenite increases.

Table 3. Vickers hardness results and microstructure of the experimental alloy

Sample number	Quenching Temperature	Structure Constituents	Hardness Hv_{30}	% Retained Austenite
1	As cast	M_7C_3 + P	530	-
2	875°C	M_7C_3 + M + Ks + γ_{ret}	785	8.19
3	925°C	M_7C_3 + M + Ks + γ_{ret}	796	8.57
4	1000°C	M_7C_3 + M + Ks + γ_{ret}	772	22.57
5	1050°C	M_7C_3 + M + Ks + γ_{ret}	739	52.54
6	1100°C	M_7C_3 + M + Ks + γ_{ret}	558	57.25

*Where: **Ks** = secondary carbides, **M** = martensitic matrix, γ_{ret} = retained austenite*

Figure 8 shows the relationship between the hardness and the retained austenite content of the alloys. It can be seen that the hardness decreases with increasing retained austenite content. Of noteworthy mention also is that there appears to be a general trend of increased retained austenite content with increasing destabilisation temperature.

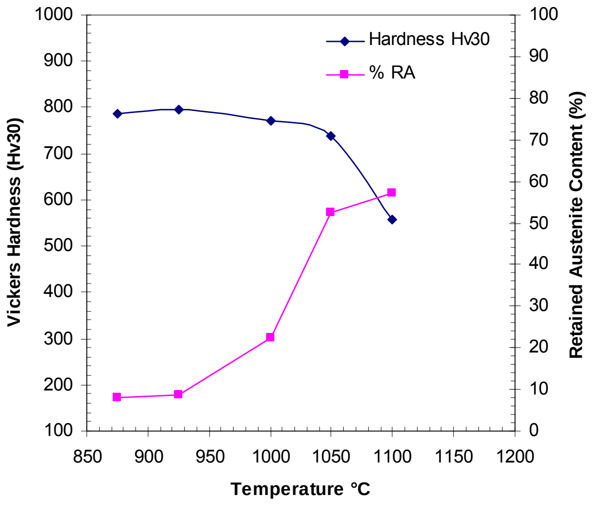


Figure 8. Influence of destabilisation temperature on hardness and retained austenite content.

3.2 High Stress Abrasive Wear Test

The purpose of the high-stress abrasion test or pin-on-belt (POB) test is to determine the resistance of a given material against the abrasive action of particles, which are generally harder than the abraded material, in a two-body abrasion configuration.

Table 4 shows the mass loss and retained austenite results obtained before and after the pin-on-belt wear tests. Duplicate tests were performed on each sample. The difference in mass loss between the heat treated specimens is significantly low (i.e. 0.01g). The standard deviations based on the root mean square were estimated accordingly. The standard deviations and relative wear resistance (β) values are also shown in Table 4 and this accurately reflects the marginal increase in mass loss. The increase in destabilization heat treatment resulted in a marginal increase in mass loss.

Several studies have found that when hard abrasives such as silicon carbide (i.e. carborundum, (SiC)) or Corundum (i.e. alumina or aluminium (III) oxide (Al_2O_3)) are used, an austenite matrix is superior to a martensite matrix.(13) Their pin on belt test results show that increasing the austenite content (%RA) leads to greater wear rates with garnet (1360HV) as the abrasive. In tests using silicon carbide (2600HV), however, increasing the austenite content (%RA) decreased the abrasive mass loss.

Figures 9 to 13 show the XRD peaks of the alloy that equates to percentage retained austenite. A change in the area under the peaks of those specimen that were destabilised at 1000°C to 1100°C indicates that some of the untransformed austenite was triggered under high stress and transformed to martensite during wear.

Table 4. Pin-on-belt abrasion results of HCWCI (tested on 120 grit SiC paper)

Sample number	Condition	Average Mass Loss (g)	Standard Deviation	Relative Wear Resistance	% Retained Austenite	
					Before	After
1	As-cast	0.1912	0.0125	1.00	-	-
2	875°C + FAQ	0.1298	0.0053	0.68	8.19	4.08
3	925°C + FAQ	0.1121	0.0498	0.59	8.57	5.38
4	1000°C + FAQ	0.1327	0.0111	0.69	22.57	12.27
5	1050°C + FAQ	0.1406	0.0168	0.74	52.54	28.17
6	1100°C + FAQ	0.1420	0.0188	0.74	57.25	35.99

Figures 11 and 12 show the austenite peaks, labelled (220), before and after abrasion for specimens heat treated at 1050°C and 1100 °C, respectively. After the abrasive wear tests the once prominent austenite peaks have been reduced to nearly background noise levels. This significant reduction in the size of the (220) austenite peak coupled with some broadening of the ferrite/martensite (200) and (211) peaks in Figures 11 and 12 after abrasion testing suggest that a transformation of the retained austenite to martensite has occurred.

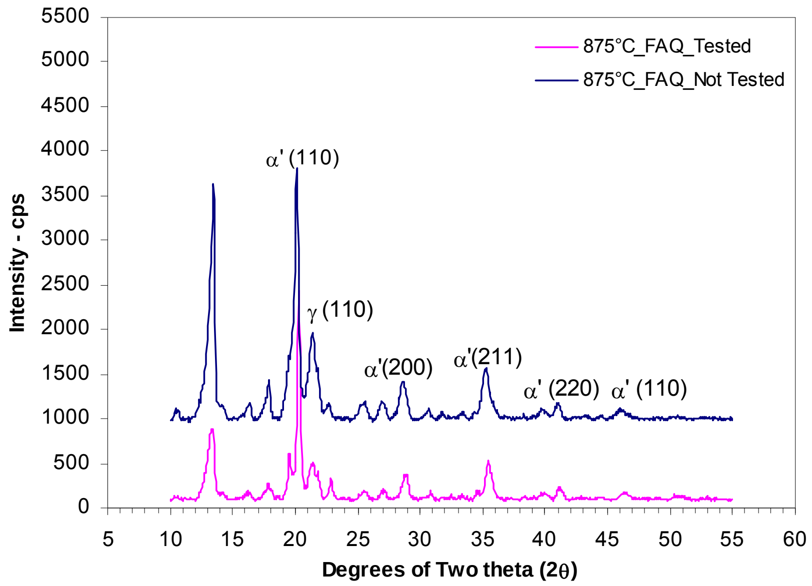


Figure 9. X-ray diffraction diagram showing no transformation in the HCWCI sample heat treated at 875°C and FAQ. The figure shows the austenite peaks, labelled (110) and ferrite peaks (211) before and after high stress abrasion.

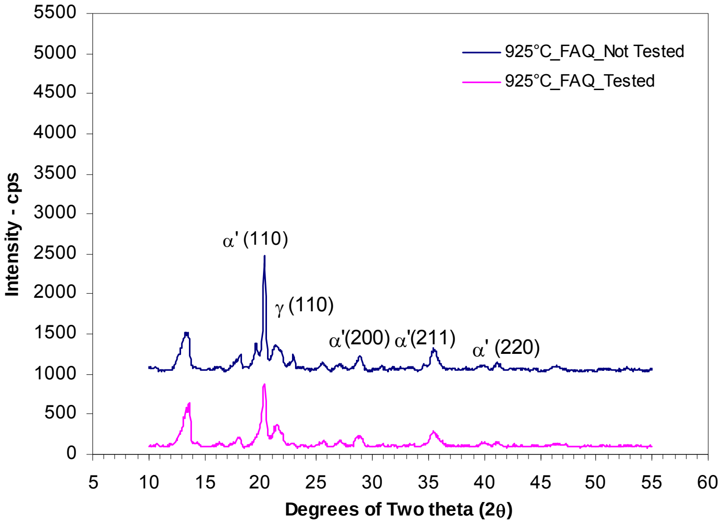


Figure 10. X-ray diffraction diagram showing martensite transformation in the HCWCI sample heat treated at 925°C and FAQ. The diagram shows the austenite peaks, labelled (110) before and after high stress abrasion.

Figure 11.

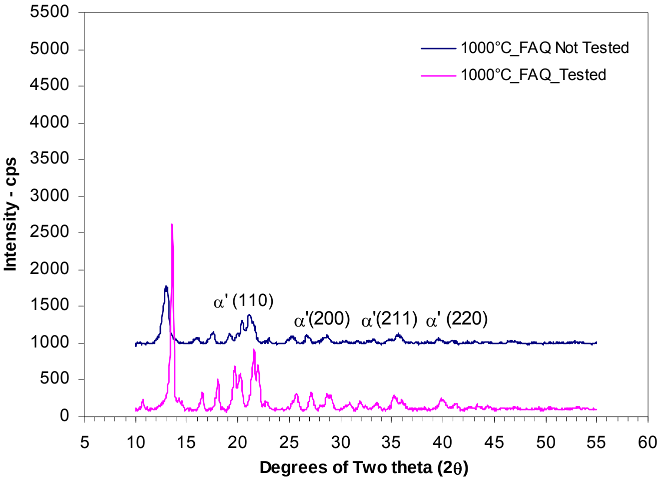


Figure 12. X-ray diffraction diagram showing some austenite to martensite transformation in the HCWCI sample heat treated at 1000°C and FAQ. The diagram shows the austenite peaks, labelled (110) before and after high stress abrasion.

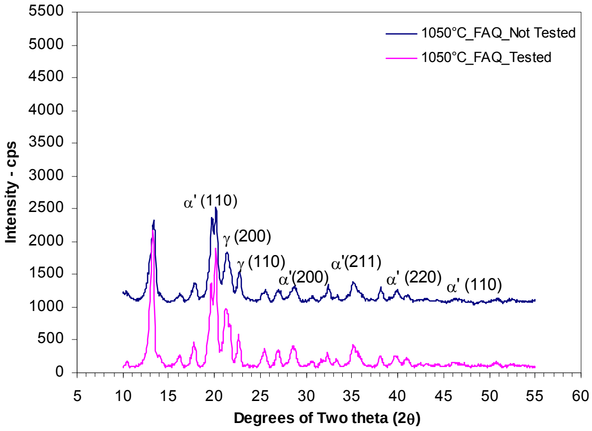


Figure 13. X-ray diffraction diagram showing some austenite to martensite transformation in the HCWCI sample heat treated at 1050°C and FAQ. The diagram shows the austenite peaks, labelled (110) before and after high stress abrasion.

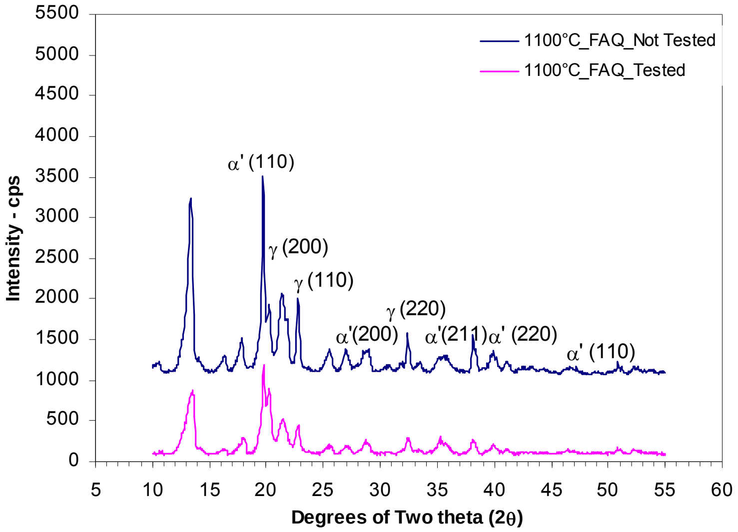


Figure 14. X-ray diffraction diagram showing some austenite to martensite transformation in HCWCI sample heat treated at 1100°C and FAQ. The diagram shows the austenite peaks, labelled (110) before and after high stress abrasion.

The relative wear resistance (β) versus destabilization temperature is shown in Figure 14. The relative wear resistance of the as-cast is shown by a dotted line (the reference point).(14) This shows that there is a large improvement with heat treatment.

The relative wear resistance (β) of a specimen increases with increase in destabilized temperature. During the abrasion process, the matrix was preferentially removed; the rate of removal of the matrix controlled the extent to which the carbides became exposed and fractured. The increase in hardness of the matrix offers stronger support for carbides to inhibit its spalling and prevents large grooves forming during abrasion wear. In addition, the secondary carbides which precipitate in the matrix regions of high chromium iron also influence the abrasion behaviour.

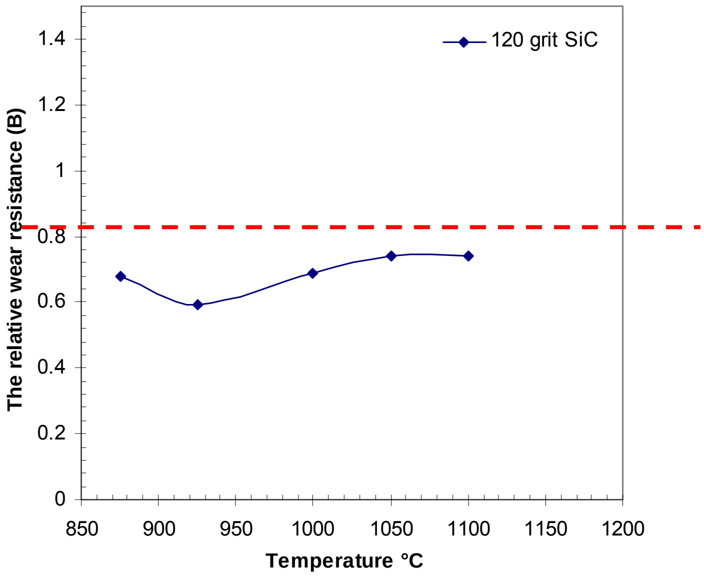
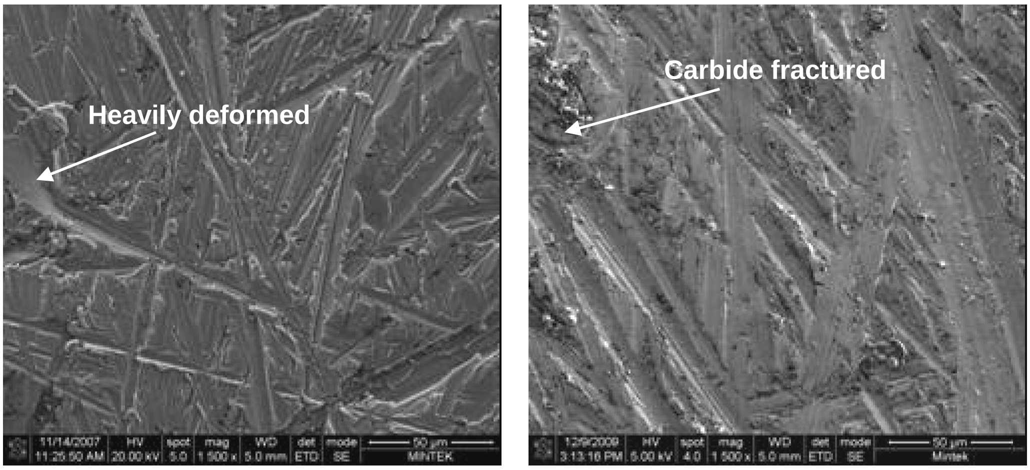


Figure 15. Relative wear resistance as a function of temperature.

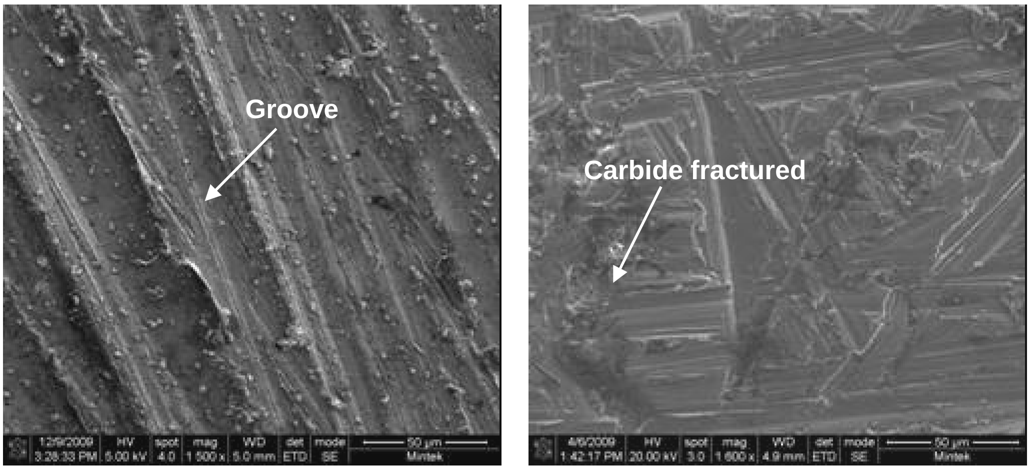
3.3 Wear Mode Observed by SEM

Figures 15 to 17 show representative appearance of worn surfaces in the pin-on-belt abrasion test when silicon carbide is used as abrasive. The long scars show that cutting and grooving by the abrasive particle occurred on the specimen surface. The wear surface of the as-cast alloy appeared heavily deformed and smeared. Comparing the hardness of the SiC with the carbides, the abrasive particle can cut off the specimen effectively. Figure 16(a) show the ploughing mode where a groove is formed which has ridges on both sides but no wear debris is formed. Less micro cracking was seen for the martensitic structures, see Figures 15b and 16a. It appeared that the abrasive particle can easily cut through the carbide very easily.



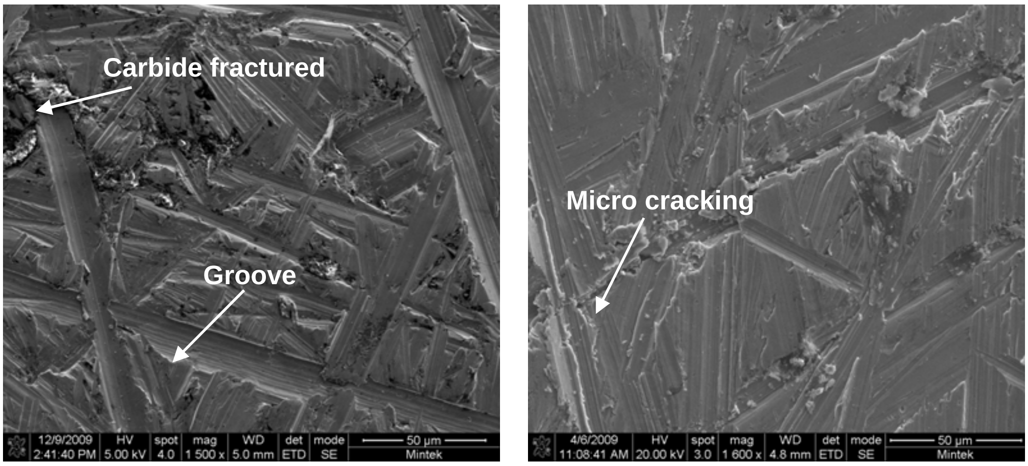
(a) As cast (b) 875°C and air quenched

Figure 16. SEM micrograph of the worn surface obtained after high stress abrasion test (SiC) (**a**) showing deformed rims of the wear grooves indicating a fair degree of ductility, (**b**) showing a wear scars that is terminated abruptly due to carbide fracture.



(a) 925°C and air quenched (b) 1000°C and air quenched

Figure 17. SEM micrograph of the worn surface (**a**) showing deformed rims of the wear grooves (**b**) showing a wear track terminated probably due to fracturing of the abrasive particle.



(a) 1050°C and air quenched (b) 1100°C and air quenched

Figure 18. SEM micrograph of the worn surface, (**a**) showing the wear track interrupted by a carbide particle resisting the cutting action of the abrasive, (**b**) micro cracking and wear grooves indicating fair degree of ductility.

4 DISCUSSION

The experimental results show that there is a clear influence of retained austenite (γ_{ret}) on microstructure, hardness and abrasion resistance of high chromium white cast iron. Micrographs of the alloy, subjected to destabilization heat treatments at different temperatures show a varying degree of %RA, martensite with dispersed secondary carbides. Following the heat treatments at 875 and 925°C, the matrix of the alloy appears to transform to martensite with less amount of %RA. The presence of secondary carbides within the matrix is apparent. An austenitic microstructure was formed upon air cooling from 1100°C. The structure of the HCWCI consists mainly of the hard carbide (i.e. M_7C_3) and austenitic and/or martensitic matrix.

The hardness of the abraded material (H_m) relative to that of the abrasive (H_a) is an important factor in the resistance to wear of a material. It has been found that the wear of material in a pin on belt test is greatly reduced when the hardness of the test material exceeds 0.8 the hardness of the abrasive. When SiC (2600Hv) is used as the abrasive the ratio of H_m/H_a is 0.54 which is below 0.8, the value taken by Richardson(17) to be the limit of the ability of the abrasive to scratch the material.

The hardness values of some metallic phases and other common materials are given in Table 5. Thus silicon carbide (SiC) will readily cut all the material in Table 5, garnet will not cut the M_7C_3, silica may cut M_3C but it will cut all of the other softer material.(17) The above statements depend on the ratios of the specific materials in contact and it must be noted that Table 5 listed the values relative to SiC. In this Table it can be seen which material is abrasive to others or which resist abrasion of the other in pin on belt wear test the hardness ratio of eutectic carbides to abrasive H_m/H_a has a great action on wear resistance. When using a soft abrasive material such as garnet (1360HV), a martensite matrix performed better than austenite.

Table 5. Comparison of hardness of different constituents (SiC as abrasive)(17)

Abrasive	Hardness (Hv)	H_m/H_a
SiC	2600	-
M_7C_3	1400	0.54
Garnet	1360	0.52
Silica	1100	0.42
M_3C	1000	0.38
Martensite matrix	800 max	0.31
Austenite matrix	600 max	0.23
0.2% Carbon steel	120	0.05

The hardness after abrasion can be traceable to factors like work hardening and the presence of strain induced martensite (SIM), which also influences the wear resistance. There are some cases in which low hardness has higher wear resistance.(17) Therefore, it is not always correct to estimate wear resistance of a material only by bulk hardness.

At higher austenitizing temperatures the increase in the dissolution of carbides leads to higher wear resistance although it simultaneously lowers the hardness by increasing retained austenite content.(18) A further increase of austenitizing temperature further reduces wear resistance again. The observation that maximum hardness appeared at intermediate destabilisation temperature is consistent with the earlier results of Maratray and Poulation.(18)

Maratray and Poulation(18) argued that this is due to the competing effects of the increasing retained austenite content at higher destabilisation temperature which tends to reduce hardness. In addition the higher carbon martensite which forms following higher destabilization temperatures tends to increase hardness.

The data in Table 4 show a minimal increase in the retained austenite content between 875°C and 950°C. However, after destabilisation at 1000°C, the retained austenite of the air-quenched structure increased to 22% and this is also shown in Figure 7.

In this work the increase in destabilization heat treatment temperature and retained austenite content resulted in a marginal increase in mass loss. According to the literature,(13) it has been shown that increasing the retained austenite content decreases the abrasive mass loss. The abrasion results in Table 4 highlight that, for all conditions, the mass loss of the specimen destabilised at 925°C was less than that of the other temperatures. This study has shown that increasing the retained austenite content increases the abrasive mass loss. This is different to what the other authors have found.

Following the destabilisation treatment, the austenite contents relative to 875°C and 925°C heat treatment temperatures were generally low. During air cooling carbon partitioning to the austenite will take place from the “ferrite” (martensite). Since retained austenite would be expected to be of relatively low carbon content the hardness of any martensite that formed through deformation induced transformation would also be low due to its low carbon. Indeed, Table 4 shows that transformation to martensite does occur for the high destabilisation temperature.

The X-ray diffraction diagrams of those specimens that were destabilised at higher temperatures before and after the test are different. There was a decrease in retained austenite after testing indicating that transformation had occurred. Pin-on-belt wear tests by others, using garnet as an abrasive material have produced conflicting results.(13) Several studies cite superior abrasion resistance for martensitic matrixes(18) while others found the austenitic matrix to be superior. This study has found an increase abrasion mass loss results when using a harder abrasive material (i.e. SiC). According to the results, a superior abrasion resistance was obtained for martensitic matrixes.

The SEM investigation showed clearly that micro-machining was the dominant wear mechanism in this test. Worn surfaces studied under SEM revealed ploughing on those specimens that had a high retained austenite content. Scratching was observed on the low retained austenite content specimens (Figures 15b and 16(a-b). Scratching and ploughing was seen on all the SEM images. The deformed rims shown in Figure 17(a-b) of the wear grooves indicate a fair degree of ductility in the matrix. Several published studies on the effect of matrix structure on gouging abrasion resistance suggest that a martensitic matrix offers better wear resistance than an austenitic matrix.(18,20,21)

5 CONCLUSIONS

The conclusions that can be drawn from the results are as follows.

- Destabilizing at higher temperatures had a variable effect on structure and properties. The alloy softened considerably with increasing austenitizing temperature and exhibited substantial increase in retained austenite
- The pin on belt test showed a significant change in the amount of retained austenite (%RA)
- It was found that the bulk hardness of the alloy tested was indicative of the abrasion wear resistance with the material having the highest bulk hardness wearing the least. The relative wear ratio is proportional to the hardness
- The alloys obtain the best abrasion resistance when the retained austenite content is about 10%
- The SEM investigation showed clearly that micro-machining was the dominant wear mechanism in this test
- The matrix removal mechanism occurs regardless of whether the matrix is soft austenite or harder martensite, however, lower wear rates are associated with martensitic matrices.
- The harmful effect of retained austenite may be explained in terms of it reducing the hardness of the matrix thus decreasing its abrasion wear resistance

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