2024 ENGINEERING INSTITUTION OF ZAMBIA SYMPOSIUM

EFFECT OF CHROMIUM ON MICROSTRUCTURE, HARDNESS AND WEAR RESISTANCE OF WHITE CAST IRON GRINDING BALLS

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OUTLINE

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INTRODUCTION

- Ore minerals are finely disseminated and intimately associated with gangue minerals
- Grinding of ore liberates valuable ore from gangue minerals
- Grinding is performed in mills.
- Grinding media can be bars, balls, the ore itself or mixture of ore and balls
- Grinding of ore is one of the most expensive processes in mineral processing.
- Grinding medium consumption contributes significantly to the total milling cost

Figure 1: Balls and ball mills

INTRODUCTION (CONT..)

- Lowering grinding media consumption leads to reduction in production costs .
- The main materials used for grinding media are steel and high-chromium white cast iron (HCWCI).
- Steels are ferrous alloys with less than 2% wt C., while HCWCI have more than 2 % wt C (HCWCI are Fe–Cr–C ternary systems).
- In HCWCI the amount of carbon ranges from 1.8 to 4% while chromium varies from 12 to 30%
- HCWCI alloys are wear-resistant and are widely used in the manufacture of mill balls.
- The wear strength of HCWCIs is attributed to the presence of carbides in their microstructure

OBJECTIVE

To investigate the effect of chromium on the microstructure, hardness, and wear resistance of white cast iron mill balls with chromium content of 12 - 20%

EXPERIMENTAL

Materials

- High chromium white cast iron (HCWCI) scrap metal was used with composition shown in Table 1.

- Mould was a rectangular metal flask, 63 balls/cast
- Moulding sand was a mixture of sand, bentonite clay and yellow binder.

- Pattern was a 40mm diameter metal ball
- Melting was performed in an induction furnace

Table 1: Chemical composition of the initial white cast iron metal

Type of ball	Elements (wt %)						
	C	Si	Mn	P	S	Cr	Cu
40mm_HC1	2.44	0.45	0.36	0.03	0.09	12.89	0.20
40mm_HC2	2.53	0.44	0.37	0.03	0.09	12.89	0.22
40mm_HC3	2.51	0.46	0.37	0.03	0.09	12.89	0.23

EXPERIMENTAL (CONT..)

Grinding Ball Casting Procedure

- Sand was mixed and compacted with a machine.
- Cr was added to HCWCI scrap metal to obtain balls with 12.89%, 14.90%, and 16.10% Cr.
- Induction furnace was used to melt metal to about 1630 ^{o}C.
- Molten metal was poured into the moulds within 15 minutes,
- After cooling for 1.5 hours the balls were taken for heat treatment

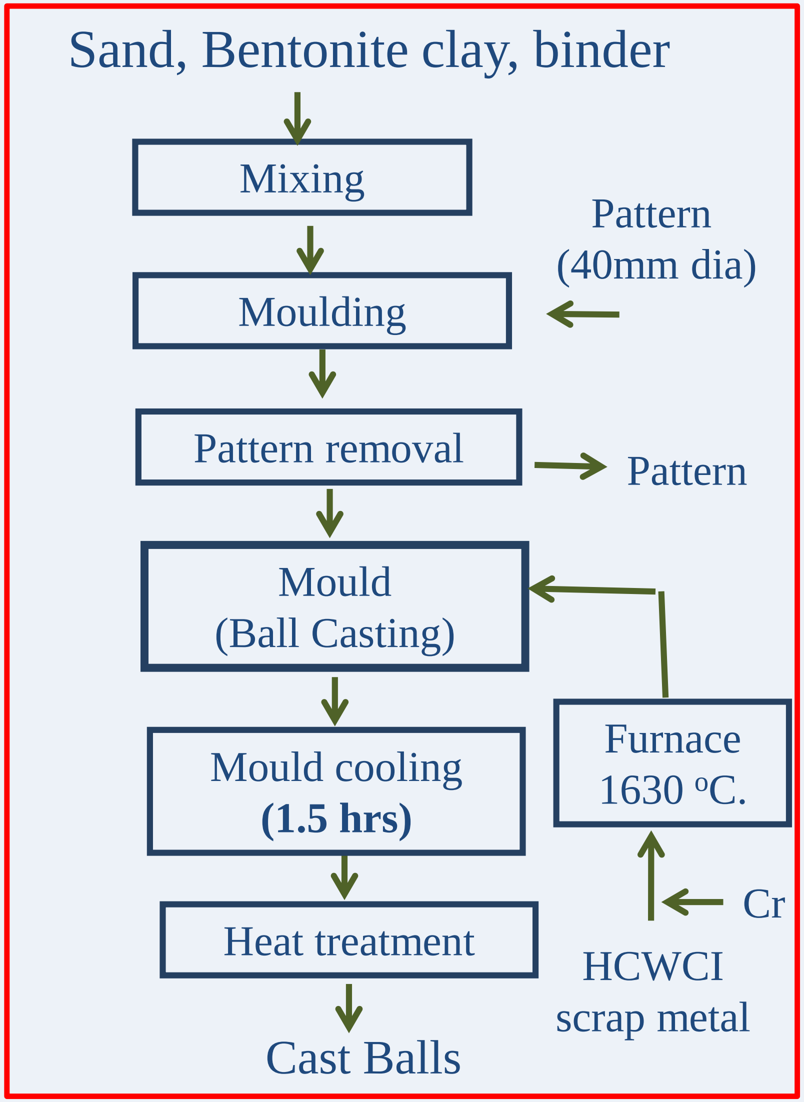


Figure 2: Ball casting procedure

EXPERIMENTAL (CONT..)

Cast Ball Heat Treatment Procedure

- The cast balls were charged into the induction furnace at 700 °C
- Temperature was gradually increased over 420 minutes from 700 °C until austenite temperature of 880°C
- Then quenching was done in oil to transform austenite into martensite structure.
- Tempering of the balls was done at 200°C - 220°C for 150 minutes to relieve thermal stress.

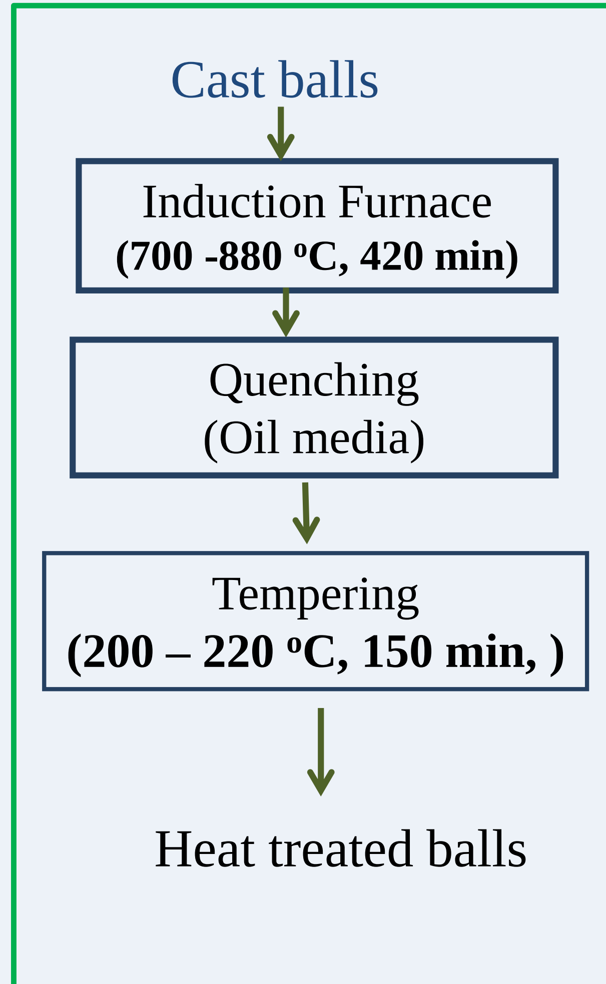


Figure 3: Ball heat treatment procedure

EXPERIMENTAL (CONT..)

Chemical analysis and mechanical properties test procedures

1) **Chemical Analysis:** was done using spark emission spectrometry
2) **Microstructures Analysis:** a cross section of the cast balls was cut, ground, polished and etched with glyceregia. Then optical microscope was used.
3) **Brinell Hardness:** measurements were performed on the cross-sectioned balls at 0, 5, 10, 15 and 20 mm positions from the surface to the centre using a load of 750kg.
4) **Abrasive Wear Tests:** were conducted in a laboratory ball mill, using SiO_2 sand as charge.

   Each wear test was conducted for 25 hours with stoppages every five hours to measure mass loss of the balls. 10 balls were used per test.

RESULTS AND DISCUSSION

Chemical composition of the cast grinding balls

- Three sets of HCWCI balls were cast with different chromium content of about 12.89%, 14.90% and 16.10% Cr (Table 2)
- Variation in the %C content was not studied as it was marginal and had minimal effect on the mechanical properties of the grinding balls.
- Variations in the content of other elements were also minimal

Table 2: Chemical composition of the cast grinding balls

Type of ball	Elements (wt %)						
	C	Si	Mn	P	S	Cr	Cu
HC1 (12.89% Cr)	2.44	0.45	0.36	0.03	0.09	12.89	0.20
HC2 (14.90% Cr)	2.53	0.44	0.37	0.03	0.09	14.90	0.22
HC3 (16.10% Cr)	2.51	0.46	0.37	0.03	0.09	16.10	0.23

RESULTS AND DISCUSSION (CONT..)

Effect of Cr on the microstructure of the grinding balls

- Balls with **12.89% Cr** (HC1 balls) showed eutectic carbide (EC) within martensite (M) and retained austenite (RA) matrix (Fig.4).
- Balls with **14.90% Cr** (HC2) showed similar microstructure but more martensite (M) and eutectic carbide (EC) due to increased Chromium content(Fig. 5).

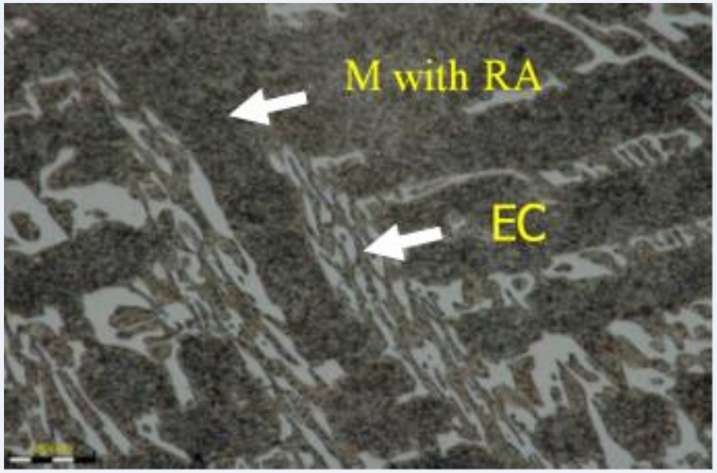


Fig. 4: Micrograph of HC1(**12.89 % Cr**) balls (M = Martensite, RA = Retained Austenite, EC = Eutectic Carbide)

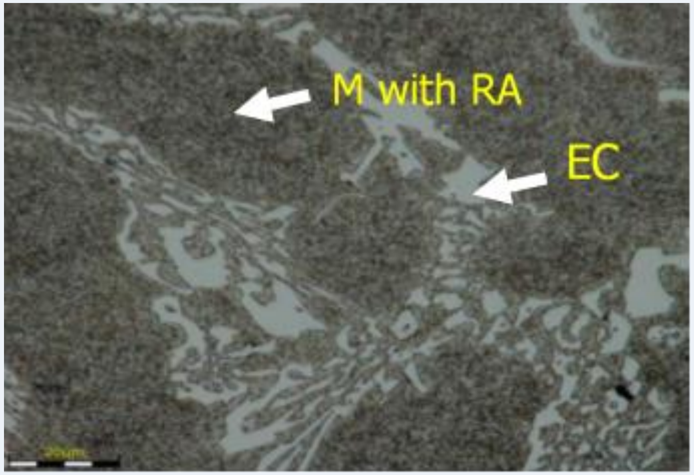


Fig. 5: Micrograph of HC2 (**14.90 % Cr**) balls (M = Martensite, RA = Retained Austenite, EC = Eutectic Carbide)

RESULTS AND DISCUSSION (CONT..)

Effect of Cr on the microstructure of the grinding balls

- Balls with **16.10% Cr** (HC3) also showed similar microstructure and even more martensite and eutectic carbide (Fig. 6)

- The carbides in white cast iron are mainly present as Fe_3C and Cr_7C_3.

- Different amount of carbides and metallic matrices can be produce by varying chemical composition and heat treatment variables

- Due to carbides HCWCI have excellent wear resistance, impact toughness, and hardenability

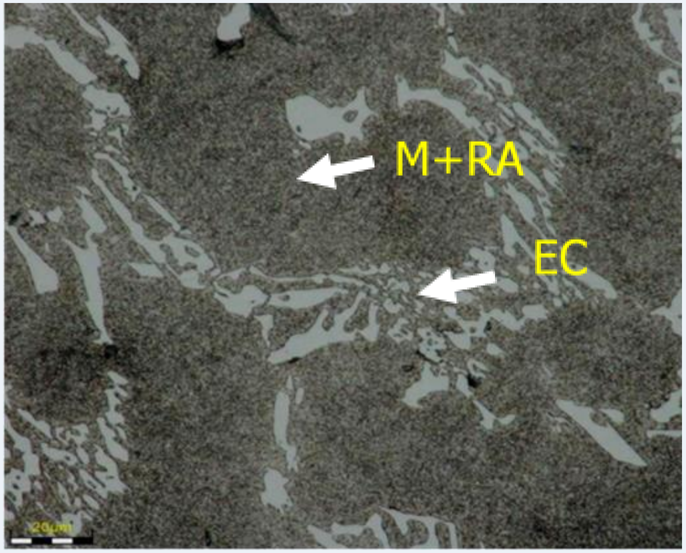


Fig. 6: Micrograph of HC1**(16.10 % Cr**) balls (M = Martensite, RA = Retained Austenite, EC = Eutectic Carbide)

RESULTS AND DISCUSSION (CONT..)

Effect of Cr on the microstructure of the grinding balls

- The carbide volume fraction (%CV) of balls increased with increase in the Cr content (Table 3).

Table 3: % Carbide Volume (%CV) of the balls before and after increasing Cr content

Type of ball	%C		%Cr		%CV	
	Before	**After**	**Before**	**After**	**Before**	**After**
HC1(12.89% Cr)	2.44	2.44	12.89	12.89	21.98	21.98
HC2(14.90% Cr)	2.53	2.53	12.89	14.90	23.08	24.19
HC3(16.10% Cr)	2.51	2.51	12.89	16.10	22.84	26.58

- The carbide volume (%CV) can be calculated approximately using the empirical relationship:

$$\%CV = 12.33(\%C) + 0.55(\%Cr) - 15.2$$

RESULTS AND DISCUSSION (CONT..)

Hardness of the cast and heat treated grinding balls

- Hardness increased with increase in chromium content due to increase in carbide volume fraction (%CV) (Table 4 and Fig. 4)
- Hardness decreased towards the centre of the ball

Table 4: Brinell Hardness of the heat treated grinding balls

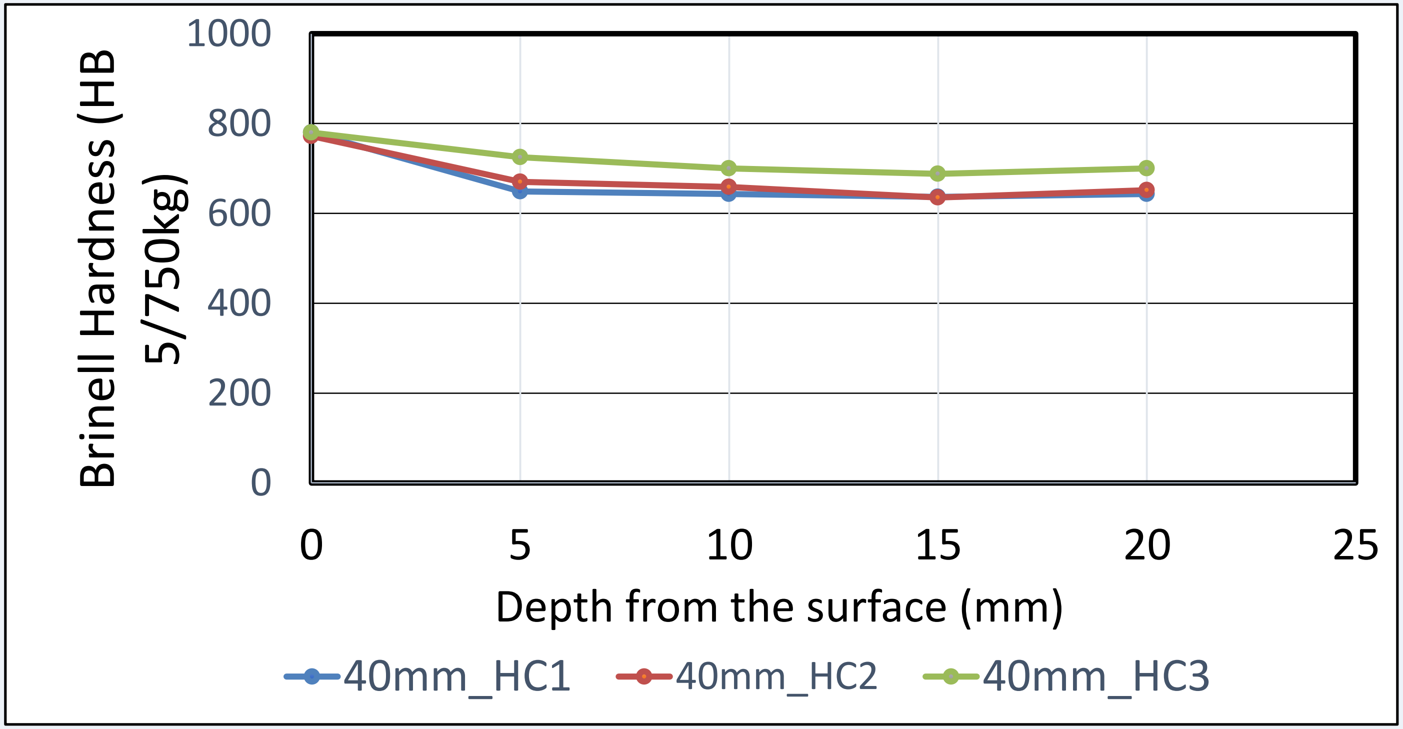
Depth from the outer surface (mm)	Brinell Hardness (HB)		
	(12.89 %Cr) HC1	(14.90%) HC2	(16.10%) Cr) HC3
0	780	779	780)
5	649	670	725
10	643	659	700
15	637	635)	688
20	643	652	700

RESULTS AND DISCUSSION (CONT..)

Hardness of the cast and heat treated grinding balls

Hardness decreased towards the centre of the ball because more martensite and carbide structures were formed on the surface as the rate of cooling and solidification is faster on the surface.

Figure 4: Hardness of the cast and heat treated balls



RESULTS AND DISCUSSION (CONT..)

Wear resistance of cast grinding balls

- Wear resistance was reported in terms of mass loss of the balls during milling of SiO_2 sand in a ball mill for 25 hours
- Mass losses were measured every five hours (1 Run was 5 hrs) and are shown in Table 5 and Figure 5
- The higher the Cr content the higher the wear resistance

Table 5: Mass loss of the grinding balls per run and total mass loss

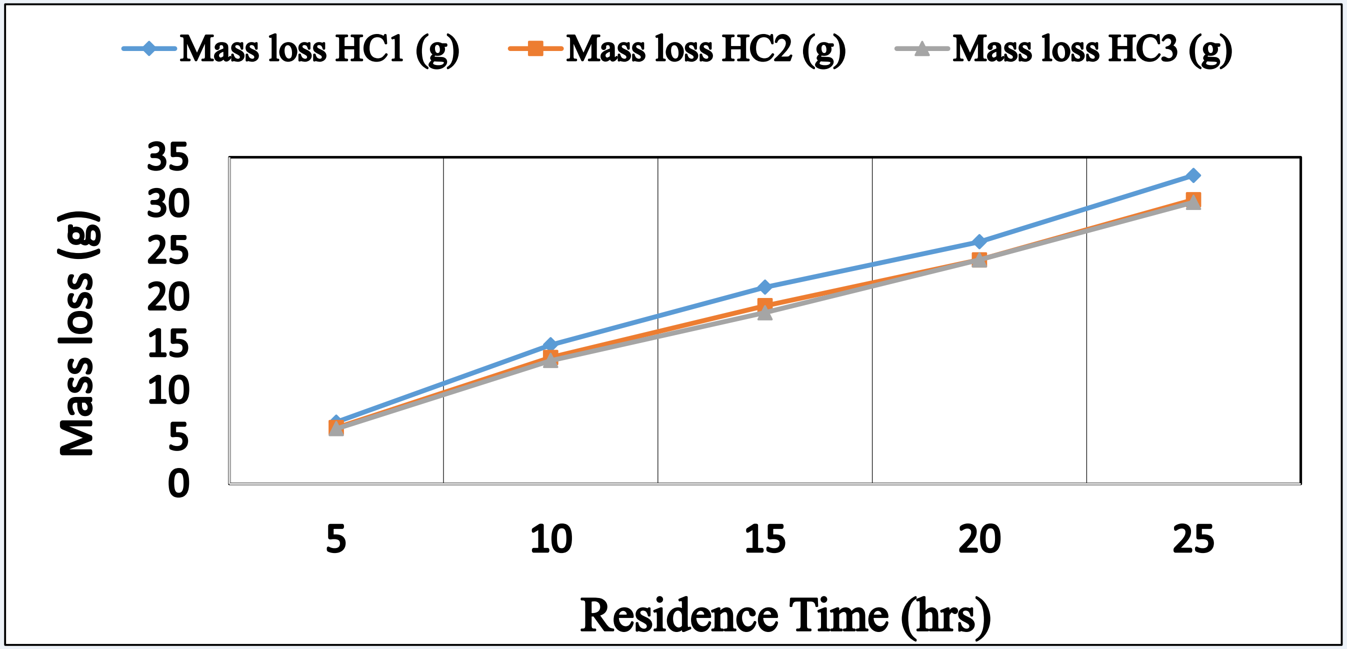
Type of ball	Original Mass (g)	Run 1	Run 2	Run 3	Run 4	Run 5	Final Mass (g)	Total Mass loss (g)
		Mass loss (g)	Mass loss (g)	Mass loss (g)	Mass loss (g)	Mass loss (g)		
HC1 12.89%Cr)	2998.90	6.63	8.28	6.18	4.88	7.1	2965.85	33.05
HC2 14.90%Cr	3006.00	6.03	7.53	5.53	4.93	6.45	2975.54	30.46
HC3 16.10%Cr	2957.55	5.93	7.29	5.14	5.65	6.17	2927.38	30.17

RESULTS AND DISCUSSION (CONT..)

Wear resistance of cast grinding balls

- The balls with the highest chromium content (16.10%Cr) had the lowest cumulative mass loss.
- Mass loss for each run was different, this showed that eutectic carbide was not evenly distributed in the martensite matrix.

Figure .5: Cumulative mass loss for the three types of cast balls



CONCLUSIONS

- The microstructure of the cast grinding balls composed of eutectic carbide within martensite and retained austenite matrix.
- The carbide volume fraction (%CV) of the balls increased with increase in the Cr content.
- Thus hardness of the balls increased as Cr content increased.
- Wear resistance of the balls also increased as Cr content increased.
- Quality of grinding balls employed in the milling of ores can be improve by varying Cr content and heat treatment variables to produce optimum carbide volumes and metallic matrices

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The End

THANK YOU OFR YOUR ATTENTION.