ISSN: 2277-9655
Impact Factor: 1.852

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Quality Improvement in the Production Process of Grinding Balls

Andrew Muzinda[*1], Rumbidzai Muvunzi[2], Catherine Maware[3]

[*1] Chinhoyi University of Technology, Department of Production Engineering, P Bag 7724Chinhoyi, Zimbabwe

[2]Chinhoyi University of Technology , Masters in Manufacturing Systems and Operations Management (NUST), BSc Production Engineering Hons (CUT) , Zimbabwe

[3]Chinhoyi University of Technology , Masters in Manufacturing Systems and Operations Management,, Btech Hons Production Engineering (CUT) , Zimbabwe

amuzinda@cut.ac.zw

Abstract

The paper outlines how experiments were carried out to determine the optimum chromium/carbon (Cr/C) ratio that brings the required hardness of 65HRC and to establish a quenching technique for the grinding balls. Matlab was also used to develop a mathematical model for the ball wear rate and its cost effectiveness basing on surface theory and volume theory. From the experimental results, the Cr/C ratio in the chemical composition 18:2 gave the required hardness. Also water quenched grinding balls gave the required hardness. The mathematical model was validated for both volume and surface theories using correlations of coefficients. The correlations of coefficients for both volume and surface theorems were 0.9994 and 0.9985 respectively and are all close to unity, which shows that both theories provide good descriptions of the way in which the masses of the balls decrease as a function of the amount of material milled.

Keywords: quenching, grinding balls, wear rate

Introduction

In Zimbabwe grinding balls are produced from scrap metal and are used as grinding media in gold processing. For the production of grinding balls, incoming scrap metal is segregated according to the chemical composition. Visual inspection, bending and sonic tests are used in grading the metal and these methods do not accurately determine the chemical composition of the scrap. As a result, carbon or chromium is added to the metal bath after melting to achieve the required hardness of the grinding balls (steelmedia,2013).Variation in composition due to raw materials used and heat treatment negatively affect service performance of the grinding balls (Moema J. S. et al 2009).The elements added (Carbon or chromium) to correct the bath chemistry are manually mixed using metal rods by stirring the molten metal hence uniform mixing is not achieved since the heat emanating from the molten metal disturbs the operators to perform the mixing well. Therefore, it is difficult to achieve homogeneity of the bath metal chemistry. The scrap metal used makes it difficult to achieve compared to ferro alloys (virgin metals which have never been recycled). This result in most batches of grinding balls manufactured with a value of an average hardness of 36 HRC far less than the expected value of 65 HRC(J.O. Agunsoye et al, 2011). Dirty, greasy and rusty scrap contributes to slag in the ball castings. Some slag remains in the metal to be casted causing gas porosity to the balls hence lowering the hardness (Hisyamudin N et al, 2009). Analysis of the current production process of grinding balls in Zimbabwe showed that rust, grease and dirt reduce the expected output metal by 24% by weight because they are removed as slag. The heat treatment employed for the grinding balls in Zimbabwean industries is normalizing. The process involves the balls heated to a temperature of 800 $^{\circ}$C, above their critical point for 5 hours in the oven and then removed from the oven for air cooling in an open space. Generally air quenching has a tendency of causing premature cracking to materials in which they quench due to its physical properties such as heat flux, viscosity, and vaporizing temperature (Ruglic T, 1990). Air quenching has the minimum cooling rate as compared to water and oil. The production of cast grinding balls has seven steps which are segregation of scrap metal, melting, skimming and degassing, sand casting, heat treatment, quenching and quality control. The scrap metal is segregated from the scrap yard and charged into the induction furnace for

ISSN: 2277-9655
Impact Factor: 1.852

melting. Molten metal is transferred to hand ladles where the degassing process is done. After degassing, slag is then skimmed off from the molten metal followed by the casting process. After being casted the grinding balls are then quenched, this involves the controlled cooling of a metal from a high temperature to a cooler temperature to facilitate the formation of the desired microstructure and physical properties. Finally quality tests such as metallurgical microscopic observations, experimental ball mills test, impact testing and hardness tests are carried to check if the hardness of the balls is within the acceptable hardness standards. Leakage, impact and fatigue tests can be applied for some produced grinding balls as other types of quality control step. The objectives of the study are to determine the optimum Cr/C ratio and establish a suitable quenching technique for the manufacturing of grinding balls using scrap metal that gives the required hardness of 65 HRC.

Methodology

The Taguchi method for experimentation was used due to its emphasis of a mean performance characteristic value close to the target value within certain specification limits required for the grinding balls, thus improving the product quality (Fraley S, 2007) In this research it was used as it narrows down the scope of a research project or to identify problems in a manufacturing process from data already in existence

Experiments carried out

Experiments carried out were to determine the optimum Cr/C ratio that brings the best hardness for the balls, the amount of slag for the charged scrap metal and the effect of varying quenching technique to the wear resistance of the grinding balls. Measurement of the hardness of grinding balls was done with a hardness testing machine. A mathematical model was also developed using MATLAB 2010 to determine ball wear rate for the grinding balls.

To determine the optimum Cr/C ratio that brings the best hardness for the balls

The chromium/ carbon variations were done by using ferro alloys with a maximum chrome content of 24% and carbon content of 2.5%. By using a weight based charge calculation method different carbon and chromium levels were achieved. Trace elements of the chemical composition of the grinding balls were also maintained at recommended concentrations. For reliability the variations were then measured by a maxx spectrometer.

To determine the amount of slag for the charged scrap metal

A BY 31 series Slag skimmer was employed as it offered a safe, clean and efficient way to remove the slag. Because of its long arm, the operator is not exposed to extreme heat; hence there its less susceptibility to accidents (Magnalenz, 2008). The frequency of skimming was a once off so as to minimize the skimming time hence maintaining the cast temperature.

The effect of varying quenching technique to the hardness of the grinding balls

For experimentation a portable quench tank (2000 mm x 1500 mm x 1200 mm) was used for quenching. The tank has two compartments, one for oil and the other for water quenching. Each compartment has a drain plug, a screen in the bottom to catch scale and other foreign matter, and a mesh basket to hold the grinding balls.

Mathematical model of ball wear rate for different grades of grinding balls

The mathematical model was used to show ball wear rate and their cost effectiveness basing on surface theory and volume theory. The model was used to give predictions of ball wear and its cost effectiveness. For the surface theory the shapes of balls must remain constant during the period of test so that the cube root of the ball mass will vary linearly with the tonnage of gold ore milled. The steel consumption is established in terms of the model parameters, and simulations for the effect of a change in the grades of grinding balls are to be shown graphically using MATLAB simulation software.

Modeling the grinding ball wear in milling

The conventional procedure employed in ball mills illustrates the scale and cost of a test aimed at measuring the durability and cost-effectiveness of a particular type of ball. If *M* is the total mass of the charge within a mill and *dM/dt* is the rate at which the balls are consumed, the time constant of a mill is

$$\theta = -\frac{Mt}{dM/dt} \qquad \textit{(Eqn. 1)}$$

The ball charge used was 22 tones. The mass of material milled is *T* hence the ball consumption in kilograms per ton milled becomes:

$$\frac{dM}{dt} = \frac{dM/dt}{dT/dt} \qquad \textit{(Eqn. 2)}$$

A tonnage constant' for the mill, j_m, can be defined as follows:

$$j_m = -\frac{M}{dM/dt} \qquad \textit{(Eqn. 3)}$$

Since dM /dt is negative, j_m is positive. The relation between j_m and θ is:

$$j_m = \theta\frac{dT}{dt} \qquad \textit{(Eqn. 4)}$$

Where dT/dt is the mass of material milled per unit of time; j_m is measured in tons or; kilotons. The cost-effectiveness of balls is measured by the use of an index, E, given by:

$E = C[\frac{dM}{dt}]$ *(Eqn. 5)*

2.2.1 The Volume Theory

The volume theory states that:

$-\frac{dM}{dT} = \frac{m}{j}$ *(Eqn.6)*

Where the proportionality constant, j,is called the 'tonnage constant' of a ball; j is measured in the same units as T. From equation (6),

$m(T) = m_o \exp(-T/j)$ *(Eqn. 7)*

From equation *7* of the volume theory, after T tons of material have been milled, the mass of a ball was reduced by a factor of e^{-1} (e being the 'base' of natural logarithms), so that m (j)= $m_o e^{-1}$ (approximately 37 per cent of m_o*)*. Also, if m_l and $m_2$are the respective ball masses before and after T_o tons of material have been milled, then j, the tonnage constant, was given by:

$j = \frac{To}{ln(\frac{m1}{m2})}$ *(Eqn 8)*

The equations were later coded in MATLAB.

The Surface Theory

The surface theory states that wear rate is proportional to the surface area, the formula is written as:

$\frac{dm}{dT} = bm^{2/3}$ *(Eqn. 9)*

Where *b* is a constant, from *(**Eqn. 9)***, we obtain

$m^{1/3} = m_o - \frac{1}{3} b T$ *(Eqn. 10)*

The equations were later coded in MATLAB.

Results and Discussion

The results of the experiment are illustrated in the sections below. These results assist in coming up with improvements to improve hardness and quality of the grinding balls.

Effect of variation of chromium carbon ratio on hardness of grinding balls

The effect of quenching temperature on the hardness of grinding balls is shown in Fig.1below. The hardness of grinding balls increased with the increase of quenching temperature. When the quenching temperature reached 200◦C, the peak of hardness appeared. When the quenching temperature increased further, the hardness decreased as shown from the graph. Hence the graph shows that Cr/C ratio 18:2 (9) gave the optimum and required hardness of 65 HRC at a temperature of 200◦C

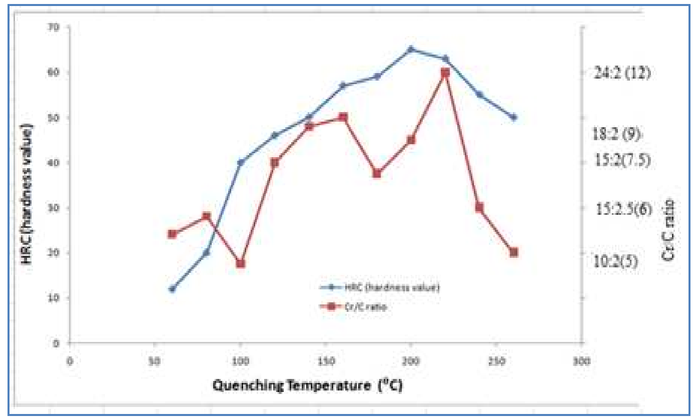


Fig 1 : Effect of quenching temperature on mechanical properties of grinding balls

Amount of slag skimmed from the molten metal of the charged scrap metal

Five heats were done and the minimum amount of slag skimmed was 14 kg on heat number two and the maximum was 20 kg in heat number five. The amounts of slag skimmed were all in the tolerated amount of slag range of 15 – 20 kg as shown in figure 2 below

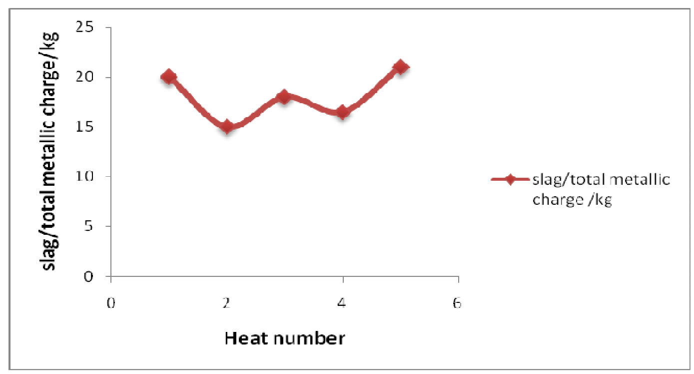
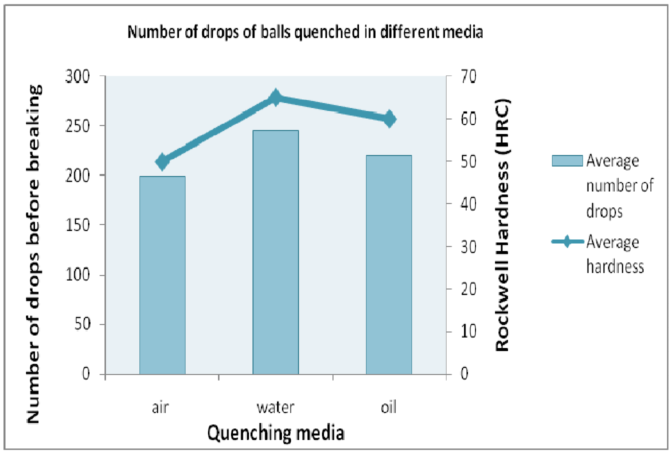


Figure 2: Amount of slag collected as a function of the number of heats

Quenching the grinding balls in different media

Figure 3 shows that the air quenched grinding balls had minimum level of hardness of 47 HRC, then the oil quenched with 52 HRC, with the water quench being the hardest with 65 HRC. Due to the sequence of hardness water quenched grinding balls had an average of 254 drops just above the required of 250, followed by oil quenched with 248 and lastly air with 200 drops. Water quenched grinding balls had the hardest balls.



Number of drops before failure made by balls quenched in different media

Results for volume theory to the wear data for Cr/C ratio 18:2 grinding balls

In Fig. 4, the graph shows ***In*** (ball mass) versus the tons milled for 18:2 Cr/C ratio balls. It can be shown that the points were distributed linearly. The correlation coefficient is 0, 9985. The line is a least-squares fit to the experimental points and yields a value for ***In*** $m_o$of 8.3, corresponding to m_o= 4100 g. The reciprocal of the slope of the line is the tonnage constant. For 18:2 Cr/C ratio grade of balls, the researcher found that j = 898 kt.

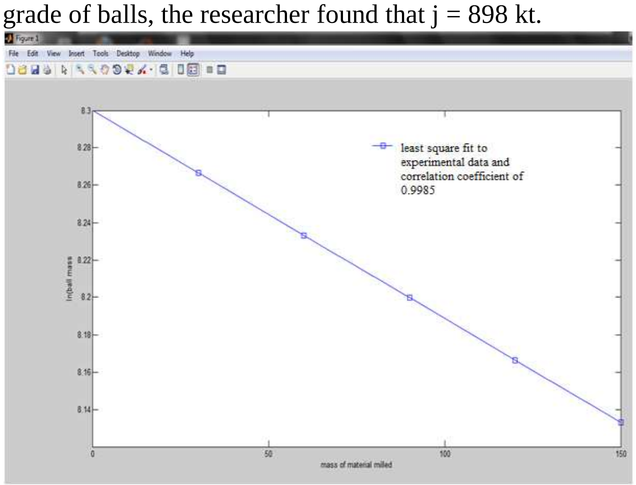


Fig Error! No text of specified style in document.**: Fit of the volume theory to the wear data for Cr/C ratio 18:2 grinding balls by a plot of $m^{1/3}$versus T**

It can be concluded that the function

m (T) =1400 exp (-T/898) ***(Eqn. 11)***

is a good description of the way in which the mass of a Cr/C ratio 18:2 ball varies with the tonnage milled by the given mill.

Results for volume theory to the wear data for Cr/C ratio 18:2 grinding balls

Fig 5 shows the cube root of the ball mass versus the tonnage milled, it can be seen that the points are distributed linearly. The correlation coefficient is 0, 9994. The line, which is the least-squares fit to the data, yields a value for $m_o$of 4100 g that is in agreement with the known initial mass. From the slope of this curve, the following value for the surface-wear constant of chromium carbon ratio balls was obtained:

b = 3, 69 x $10^{-2}g^{1/3}$. kt-^{I}.

It can be concluded that the function

m (T)= (11.187- 1.23 x 10^{-2}) ***(Eqn. 12)***

is a good description of the way in which the mass of Cr/C ratio 18:2 balls varies with the throughput of the given mill.

Conclusions

The grading methods of scrap metal used makes it difficult to control the chemical composition as per customer specification compared to ferro alloys (virgin metals which have never been recycled). This result in most batches of grinding balls manufactured with a value of an average hardness of 36 HRC far less than the expected value of 45 HRC. From the experimental results, it can be concluded that the variation of chromium/carbon ratio in the chemical composition of balls affects the hardness. From experiments carried out water quenched grinding balls with Cr/C ratio 18:2 had the required optimum hardness of 65 HRC. From the mathematical model of grinding balls, the kinetics of ball wear were considered, and formulae for the dependence of the mass of a ball on the amount of material milled by a ball mill were derived from the volume and surface theories of ball wear.

References

[1] J. O. Agunsoye1, V. S. Aigbodion and O. S. Sanni, Effect of Heat Treatment on Microstructure and Mechanical Properties of NF6357A Cast Alloy for Wear Resistance Application, Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No.11, pp.1077-1086, 2011.

[2] DRA Mineral projects tutorial, The milling process, Mining Review Africa, issue 4, 2003, http://www.drasa.co.za, accessed in 2013.

[3] Hwang, K.C., Lee, S. and Lee, H.C., 1998, "Effects of tempering temperature on wear resistance and surfaceroughness of a high speed steel roll: Part I. Microstructural analysis", Mater Sci Eng A Struct Mater Prop MicrostructProcess, 254:282.

[4] John Udodua, Quality Control Report Nigerian Foundry Limited. Vol 2, No 6, 20-21, July 1996.

[5] Slabbert, G.A, Paton r, Moema, J.S, Papo, M.J, and Zima J, Grinding media in comminuting, MTC Brochure, 2007

[6] Factors involved in the selection of grinding media, http://www.miningbasics.com, and http://pauloabbe. com, accessed in 2013.

[7] Dennis, M.V. and Purdue, J.D, Development of alloy steel grinding balls for semi- autogeneous grinding, Advances in autogenous and semiautogenous grinding technology volume. 2, pp. 461–471, Canada.

[8] Pattyn, R.L., 1988, “Heat treatment of high-Cr white irons”, AFS Trans., 93 (1): 161–167.

[9] Moema, J.S., Papo, M.J., Slabbert, G.A., and Zimba, J, Grinding media quality assurance for the comminuting of gold ores. World Gold Conference 2009, The Southern African Institute of Mining and Metallurgy, 2009.

[10] B.M.N. Nik Hisyamudin, S. Yokoyama, and M. Umemoto Absorption of CO2 in EAF Reducing Slag from Stainless Steel Making Process by Wet Grinding World Academy of Science, Engineering and Technology 32, 2009

[11] Zhang MX, Kelly PM, Gates JD, Journal of materials science, Vol 36 ,No16, 3865-3875. 2001

[12] Ruglic Thomas 1990, Normalizing of steel, ASM Handbook, Volume 4, Heat treating, 1990.

[13] Slabbert, G.A, Paton R, Moema, J.S, Papo, M.J, and Zima J, Overview of grinding media consumption in comminuting, World Gold 2007, Cairns, Australia, 22- 24 October 2007.

[14] John Udodua, Quality Control Report Nigerian Foundry Limited. Vol 2, No 6, 20-21, July 1996.