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Investigating the controllable factors influencing the weight loss of grinding ball using SEM/EDX analysis and RSM model

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ABSTRACT

This study was aimed to investigate the effects of individual variables and their interactions on weight loss of grinding ball using the SEM/EDX analysis and RSM model. The results SEM/EDX analysis indicated that corrosion mechanism type for steel balls is pitting. In addition, abrasive corrosion was observed on high carbon chromium steel ball surface. It was also found that steel balls were formed from corrosion phases of Fe, O, S and Si. The results of RSM model showed that the linear effects of all factors and the quadratic effects of solid concentration and charge weight of balls were significant parameters on wear rate. Also, it was observed no interactions between factors. Furthermore, results indicated that degree of influence of factors on the wear rate was in the order of ball type > solid percentage > pH > solid percentage^2 > charge weight^2 > grinding time > rotation speed of mill > charge weight > throughout.

1. Introduction

Ball mills are the most common and versatile type of grinding mills. They are remarkable in that they can operate over a very wide range of conditions and geometries. Ball mills may be used for primary, secondary, tertiary and regrind applications. In a mineral processing plant, they are often used for a secondary grinding duty, which directly links with downstream recovery processes such as flotation [21,22]. Mild steel or stainless steel balls are generally used as grinding media in ball mills for processing of sulphide ores to achieve the required liberation size. Grinding circuit operators have long been aware of the significant impact of grinding media consumption on the cost of grinding. It is estimated that comminution includes 30–50% of typical mining operating costs, and of these, liner wear and media consumption account for roughly 50% of the cost [1,19]. Therefore consumption of grinding media forms a significant part of the operating cost in mineral processing industry. According to Ref. [11] grinding medium wear can constitute up to 40–45% of the total operation cost in comminution process.

Total media wear in ball mills is a product of three recognized wear mechanisms including abrasion, corrosion and impact [20]. Also, the contributions to total media wear of each of these wear mechanisms has not been well established [24]. Abrasion and impact wear is metal loss due to mechanical force on the grinding media. Erosion wear results from the friction between grinding media and particles. Corrosive wear is defined as metal loss due to chemical and/or electrochemical reactions of grinding media with the solution and/or other electrochemical conductive particles [6,16].

There are many different factors which could influence on the mass losses of grinding media. These factors can be summarized under five headings [1,2,4–7,9,10,13,15–18,23,24]:

(1) The grinding media: where composition and metallurgical properties of the grinding media, grinding media size, grinding media size distribution, hardness, shape, charge weight and media selection methodology are the most important parameters.
(2) The ore: where particles sizes, hardness (abrasiveness), work index, density, shape and ore mineralogy and lithology are the most important parameters.
(3) The mill: where size, speed and discharge type are the most important parameters.
(4) The grinding environment: where pH, percent solid, viscosity, Eh, gas purging (air, oxygen and nitrogen), temperature, rheological properties, water chemistry and galvanic interaction between grinding media and mineral in wet grinding are the most important parameters.

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Table 1
Characterization of Sarcheshmeh ore representative sample.

Chemical compositions	SiO_2	Al_2O_3	CaO	MgO	K_2O	MnO	Na_2O	P_2O_5	TiO_2	Fe_2O_3	SO_3	Cu	Mo	LOI
Weight, %	59.47	14.35	0.96	2.39	3.72	0.06	0.74	0.18	0.54	6.2	7.62	0.74	0.032	2.17

Table 2
Chemical compositions of the grinding media.

Ball type	Chemical compositions (weight, %)							
	C	Si	S	P	Mn	Cr	Mo	Cu
High carbon chromium steel (HS)	2.28	0.698	0.049	0	1	13.25	0.177	0.044
Low alloy steel (LS)	0.249	0.173	0.024	0.018	0.586	0.019	0.002	0.012

(5) The grinding circuit: where throughout (input feed to ball mill), circulating load and grinding time are the most important parameters.

Based on these observations and the importance of wear in milling costs, this paper was aimed to investigate some of controllable factors affecting the mass loss of grinding ball. These factors were pH, solid percentage (pulp density), throughout of ball mill, rotation speed of mill, charge weight of balls and grinding time.

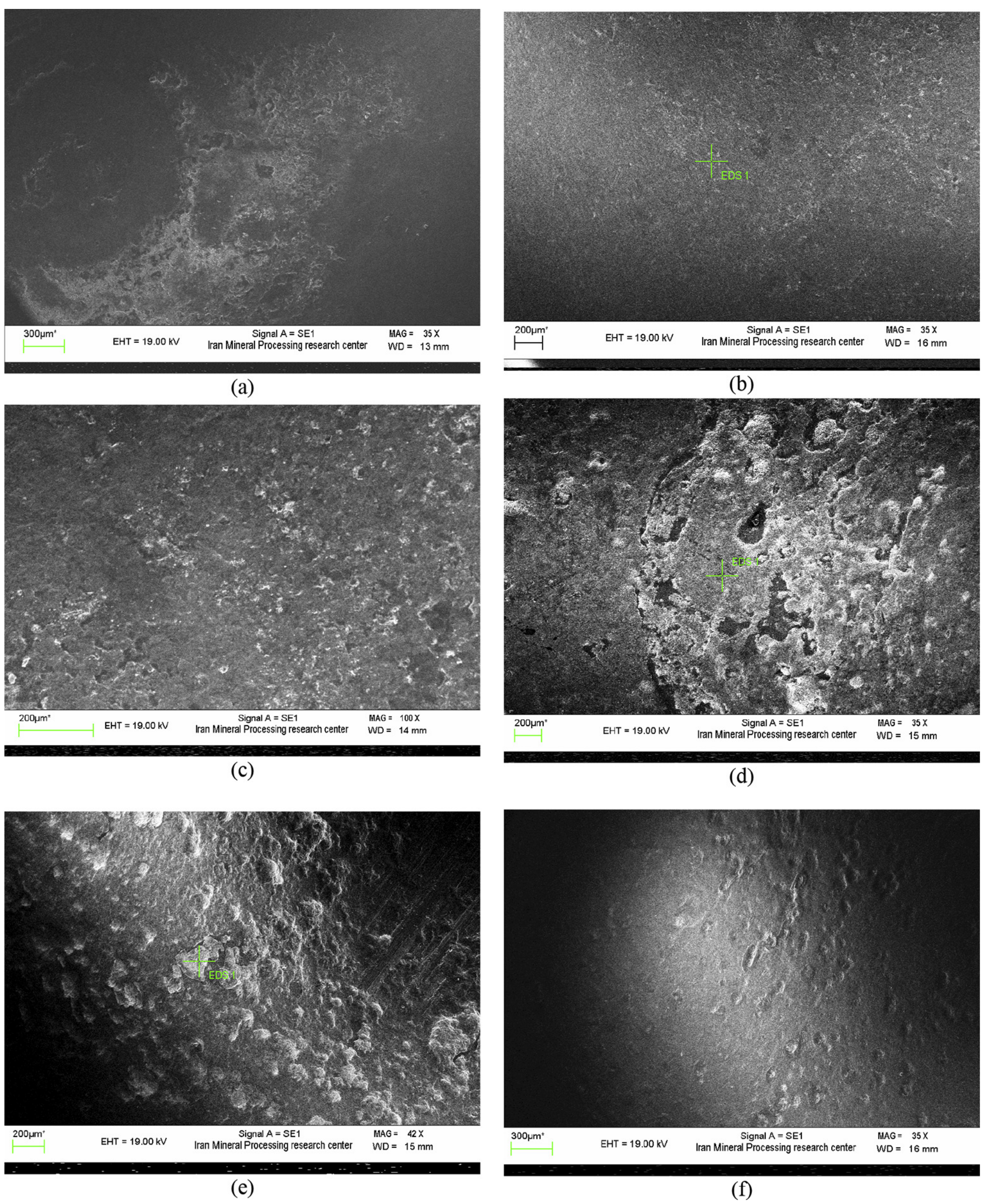

Fig. 1. SEM images of steel balls under grinding different conditions; pH: 7, percent solid: 35, grinding time: 60 min, mill speed: 75 rpm and ball type: low alloy steel (a); grinding time: 90 min (b); grinding time: 90 min and mill speed: 85 rpm (c); grinding time: 300 min (d); grinding time: 300 min and ball type: high carbon chromium steel ball (e); pH: 10, percent solid: 55 and ball type: high carbon chromium steel ball (f).