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Development of a preliminary media wear measurement test procedure for cement ball milling applications

Serdar S. Çolak [a], Okay Altun [a,*], Hakan Benzer [a], Zeki Gencer [b], Harun Koçak [b]

[a] Hacettepe University, Mining Engineering Department, 06800 Beytepe, Ankara, Turkey
[b] Cemas Dokum Sanayi, 40100 Kırsehir, Turkey

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ABSTRACT

The paper initially focusses on developing a test procedure for measuring the wear of grinding balls and then correlating the results with the wear obtained in industrial scale cement ball milling applications. The cost of grinding media is one of the major items and it needs to be optimized by testing different types of media. Since industrial scale trials are time consuming, there is a need for an easy, accurate and fast media wear testing procedure for cement ball milling applications. Such a procedure enables cement plants to compare wear results of different types of media and choose the optimal one for the economy of the grinding operation. Within the scope of the study, 6 types of 30 mm media having different chemical compositions were subjected to wear measurements at different time intervals by utilizing laboratory scale ball mills. The studies showed that reproducible results can be obtained from the test apparatus hence the methodology is said to be consistent. The wear results concluded that the order of the media wear from the highest to the lowest was the same independent of the mill dimension and whether the material is inside the mill. The results also implied that the chemical composition or the microstructure of the media was an influencing parameter on the wear therefore there is room for improvement with regards to the quality of media. This study proved that the media wear measured at industrial scale cement ball mills was in good agreement with the laboratory scale results.

1. Introduction

In a comminution process, the choice of the grinding media is of great importance. Therefore, wide range of products should be compared and the economy of the application i.e., cost of media, media wear, grinding performance of media etc. should be evaluated in details. In the economy of the grinding operation, media consumption is one of the primary items. Literature reports that the wear of liners together with the grinding media accounts for about 15–25% of the mining operating costs [1]. The wear costs of the grinding media given in the literature is mostly collected from wet grinding operations. There is limited data on dry cement grinding circuits. However, during communications with the plant people it is found out that grinding media consumption constitutes 3–8% of the total operating comminution costs depending on the composition of the media and the type of cement production. Consequently, it is important to make thorough and reliable evaluations on media consumption so that the overall operating costs can be optimized [2]. In this context, long term observations should be made and detailed studies should be conducted for specific applications so that the behaviour of the media can be understood more clearly [3].

Literature reports that there are 3 basic wear mechanisms that are abrasion, impact and corrosion, which can be correlated with the mass losses of the grinding media. In a grinding system, owing to the nature of the operation, the complex synergies of these mechanisms can arise [2]. For instance, decreasing rotational speed of the ball mill results in cascade action or abrasion wear mechanism be more dominant hence the influence of impact mechanism is reduced [4]. Consequently, the operating conditions of the mill should be considered initially and then the focus should be given on media selection.

Until so far, the variations in media wear have been attributed to several parameters. In wet milling, pulp coating on ball surfaces, which is the function of rheology, reduces the media wear [2]. It can be concluded that the solid loading and viscosity modifiers can influence the wear characteristics of the media [5]. During the wet milling, the resistance of media to corrosive action should also be considered. The wear of the media is supposed to be increasing as a result of the interactions between corrosive and abrasive components [6]. Hardness of the media is another parameter. In case of having increased hardness number, the media resists more to impact mechanism rather than the abrasion [2]. As a conclusion of the media wear studies, although the individual effects of these parameters have been summarized, which of the action is more predominant still remains controversial [7].

* Corresponding author.
E-mail address: okyaltun@hacettepe.edu.tr (O. Altun).

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Table 1
The chemical compositions of the media tested.

Name	%C	%Si	%Mn	%Cr	%Mo
A1	2.15	0.78	0.88	12.9	–
A2	2.21	0.73	0.87	12.8	0.54
A3	2.27	0.53	0.67	12.1	1.98
B1	3.04	0.74	0.8	12.93	0.52
B2	2.94	0.55	0.65	12.72	1.9
C1	2.2	0.83	0.83	17.54	–

There have been several studies conducted in laboratory scale to imitate at least some of the ball to ball or ball to material interaction that occurs in the industrial mills [3,8]. The common characteristic of these studies is, they were all accomplished in wet conditions. For dry conditions, the research is found to be limited. A study was performed by Rivera Madrid et al. [9] who studied on different types of ceramic media where their wear rates were determined in dry environment. They developed a media selection methodology based on a population balance model. They concluded that the wear rate of the media was constant and also determined the time necessary to recharge the media inside the mill.

The objective of this study is to fill the gap in the field of steel grinding media regarding to the wear rates and in this context cement grinding area where dry grinding prevails was chosen. Within the context of the study, a laboratory scale media wear measurement test procedure was developed for dry environment by utilizing 3 different mill dimensions. Briefly, 6 types of high chromium white cast iron grinding balls having 30 mm diameter were subjected to tumbling action at different time intervals. Experiments were conducted with and without material to be ground inside the mill. For each time interval, the loss on weight of media was measured and the differences between the media compositions were discussed. In the final stage of the study, long-term observations were made at 3 different cement plants during CEM I 42.5R production where one of the tested grinding balls was charged. For these plants, the media wear rates were measured and then correlated with the laboratory results. The study concluded that the media qualities can be improved hence the cost of cement grinding operation can be optimized by conducting laboratory test works.

The outcomes of the study are believed to be benefitted from both media and cement manufacturers side. Since the grinding media is one of the most important parameters for the efficiency of the grinding process, determining the media wear from a laboratory scale tests can also help predicting the time necessary to recharge the media into the mill. Such a procedure can improve the control on the milling operation to ensure the sustainability of the overall process.

2. Materials and methods

2.1. Media types

Within the scope of the study 6 different media types having 30 mm diameter were manufactured by Cemas and then the tests were undertaken. The types of media were characterized by their chemical composition, microstructure and Rockwell hardness values so that the

Table 2
The volumetric fractions (%) of the elements found in the microstructure.

Name	Martensitic matrix	Primary carbides	Secondary carbides
A1	60	40	6
A2	50	50	5
A3	60	40	15
B1	40	60	6
B2	40	60	12
C1	50	50	10

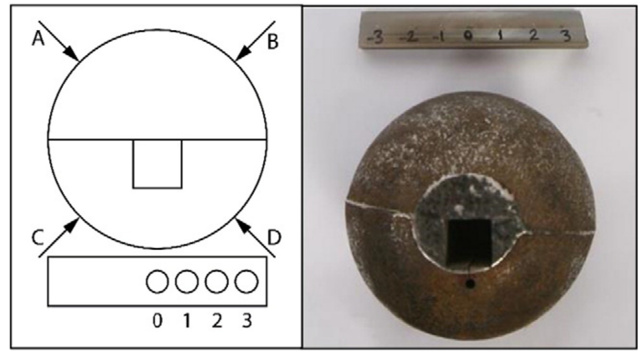

Fig. 1. The points of the hardness measurements.

correlations could be developed with the wear rates. The chemical compositions are summarized in Table 1.

In addition to the chemical composition, microstructures of the media were investigated under the microscope. In this context, volumetric fractions of martensitic matrix, primary and secondary carbides were measured and given in Table 2. It should be emphasized that all of the media was manufactured via oil quenching heat treatment procedure. As can be understood, the sum of martensitic matrix and primary carbide is 100% and the secondary carbides are found in martensitic matrix.

Final characterization technique was the determination of Rockwell hardness values of each type of the media. Both surface and volume hardness measurements were undertaken so that the overall assessment of the hardness values was completed. Fig. 1 depicts the points of the measurements of the media by surface (A, B, C, D) and by volume (0, 1, 2, 3) from core towards the surface. Table 3 summarizes the hardness values in Rockwell C scale. As the three measurements were undertaken from each location, the average values are given.

As can be understood from Table 3, the hardness values measured from different points of the surface show a little change. However, it is

Table 3
The results of the hardness measurements in Rockwell C scale.

	Surface hardness				Volume hardness			
	A	B	C	D	0	1	2	3
A1	61	62	61	61	57	58	59	61
A2	61	61	60	61	58	58	59	60
A3	61	62	60	61	57	58	59	60
B1	60	61	61	61	59	59	60	61
B2	60	61	61	61	58	59	60	60
C1	61	62	61	61	57	57	58	60

Table 4
The chemical composition [8] and Bond work index value of the granulated blast furnace slag.

Component	%
Fe	0.93
SiO_2	33.98
Al_2O_3	13.03
CaO	29.87
MnO	2.37
MgO	12.18
P_2O_5	<0.01
SiO_2	0.65
Na_2O	0.37
K_2O	0.84
TiO_2	0.9
Bond work index (kWh/t)	20.01