Investigating the contribution of wear caused by impact and abrasion in semi autogenous grinding mills

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Abstract

Milling is one of the most important operational stages in steel and copper processing. Liners and lifters are used inside mill to extend their life and to enhance the grinding and crushing efficiency. The wear of lifters is influenced by a range of parameters such as: media charge level and mill speed. In this work, the researcher used a pilot mill of 1m diameter and 0.5m length to investigate the influences of ball filling and the mill speed on the impact wear of lifters under wet condition. The contribution of impact wear and abrasive wear from the total wear was investigated with new mechanical test method. A copper ore smaller than one inch was used to prepare slurry at 60% solids concentration of mass and slurry filling U=1. The ball filling is 10%, 20% and 30% of mill volume at different mill speeds from 60% to 100% of the critical speed. It was found that while there is an increase in ball filling the wear impact decreases. The wear rate was maximum when the mill speed varied between 80% and 90% of the critical speed. To find out the role of impact on the wear, a mechanism was devised and installed on the pilot mill to prevent the cascade motion.

Keywords: Semi autogenous grinding mill, Wear of lifter, Impact wear, Abrasive wear, Wet grinding.

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1. Introduction

Milling is one of the most important operational stages in processing the minerals. Ball mills and semi autogenous grinding (SAG) mills are of the common types. SAG mills include a rotary cylindrical pipe that made of steel plates. Inside a mill, materials change from large dimensions into small due to impact and abrasion processes. For wear protection, the inner surface of the mill is covered by liner. The wear of lifters/liners has dramatic effects on the mill performance due to the loss of lifting. Also the replacement of the worn lifters takes a long time. Besides, unsystematic breakage and the lifters replacement would cause several undesirable downtime of the mill. Therefore, the recognition of the effective parameters on the wear may improve the efficiency of the mill [1-3]. The mechanism (or processes) of wear is in five categories; adhesive wear, abrasive wear, surface fatigue, fretting wear and erosive wear [4-7]. Also, it should be noted that the impact wear (type of erosive wear) happens particularly in the SAG mills. Fig.1 shows the exterior view and interior view of a SAG mill. Fig.2 shows the load behavior in a wet SAG mill.

To predict the lifter/liner wear, different methods have been proposed. To anticipate the lifters wear, Radziszewski [9] suggested a correlation with laboratory data. Cleary have explained how the Discrete Element Method (DEM) could be used for the wear prediction [10]. The wear of lifter profiles in dry coal grinding mills was stud-

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ied by Kalala et al. [11]. In order to measure the mass loss due to the wear in a real SAG mill, Banisi, Yahyaei and Hadizadeh [12, 13] employed a mechanical lifter wear monitor. Moreover, Radziszewski has proposed an equation for mass loss in a tumbling mill [14]. In order to examine the forces in the mill charge region, a theoretical model was exploited by Rezaeizadeh et al. [15]. They employed the DEM model to compute the balls velocity profile in the mill.

In another work carried out by Rezaeizadeh et al. [16], an experimental mill with the possibility of working under both dry and wet conditions was exploited to investigate the influence of mill speed, ball filling, size of ore and the material of the lifters on the wear. Also, they studied the distribution of particles in the mill using DEM. They found that the effect of impact in the toe region is higher on the liner wear [17]. In addition, Teeria [18] studied the wear impact of different materials. The effect of lifter wear on the load behavior of an industrial dry tumbling mill [19], and then the effect of lifter shape and number of lifters on lifter wear, were investigated [20, 21]. It is important to note that a few studies have been published for the assessment of wear of lifters in tumbling mills under the wet condition and available data in this area are rather limited and scarce [22, 23]. However, some articles reported experimental results of impact forces, slurry concentration and slurry filling on the wear of lifters in tumbling mills [8, 24]. The impact wear and abrasive wear of lifters in dry SAG mill were studied experimentally by Bahiraei in his master thesis [25].

The previous works reported that the wear impact provides a negligible contribution to the wear of lifters in SAG mills. Hence, it was proposed that abrasion wear provides the prime contribution to the lifter wear in tumbling mills. Therefore, in this study, abrasive wear and the effect of the impact forces are considered. The wear of lifters in this work is due to a combination of corrosion, impact and abrasive wear. To find the contribution of wear due to impact and abrasion a mechanism was devised and installed on the pilot mill to prevent the cascade motion under wet condition.

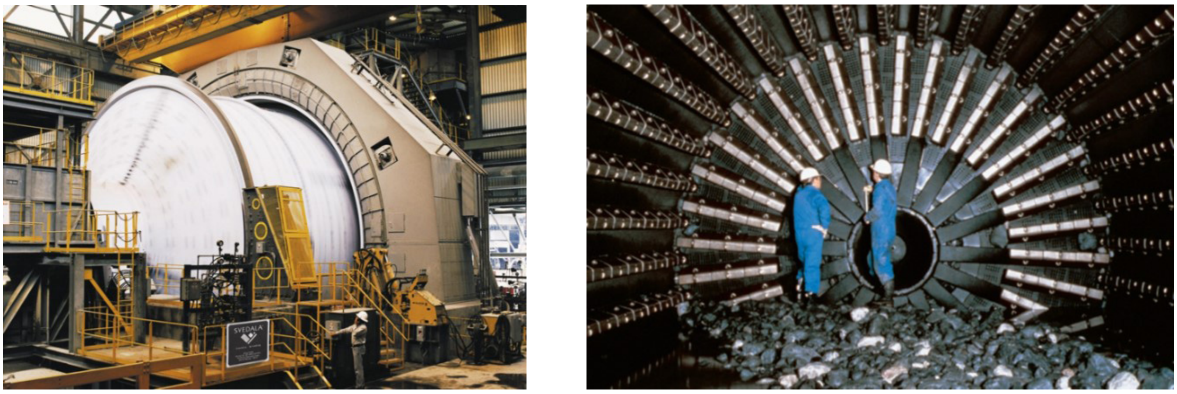

Fig. 1. Exterior view and interior view of a SAG mill [2].

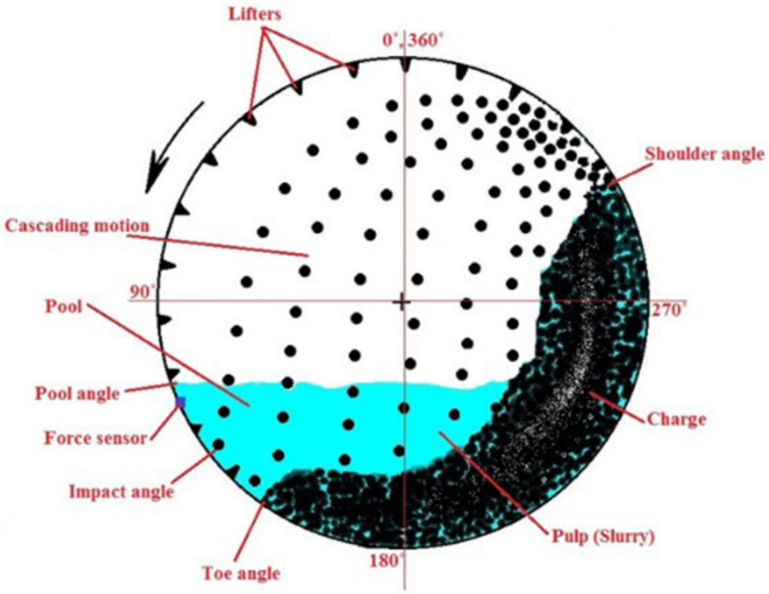

Fig. 2. Definition of the load behavior in a wet tumbling mill [8].

2. Materials and Methodology

A schematic view of the experimental pilot mill is illustrated in Fig. 3. In the rig, there are 15 lifters with 50mm height and face angle of 30˚. In the present work, the combination of the balls (40% of the balls with 60mm diameter, 40% of the balls with 40mm diameter and 20% of the balls with 25mm diameter) was used as grinding media with 10%, 20% and 30% of the total volume of the mill. The mill motor was capable of adjusting its rotation up to 100% of critical speed. The critical speed is defined as the rotational speed where centrifugal forces equal gravitational forces at inside surface of the mill's shell. This is the rotational speed where balls will not fall away from the mill's shell. The applied speeds to this study were 60%, 70%, 80%, 90% and 100% of the critical speed. In Table 1, the mill characteristics and grinding conditions are listed.

To find out the role of the wear occurred because of impact and abrasion a mechanism was invented (Fig. 3). This device was installed on the pilot SAG mill to prevent the cascade movement under the wet condition. This device can be adjusted to different angles for various speeds to the specified direction. The device consists of a curved plate which was connected through a shaft to a fixed anchor out of the mill. To adjust the angular position of the curved plate, a scaled plate was employed.

Fig. 3. Lateral device that installed in pilot SAG mill to prevent cascading motion.

Table 1. Mill characteristics and grinding conditions.

Mill	
Diameter	1000 mm
Length	500 mm
Speed	25, 29, 34, 38 and 42 rpm
Fraction of critical speed (Φ_c)	0.6, 0.7, 0.8, 0.9 and 1
Lifters	
Number	15
Height	50 mm
Face angle	30 degree
Shape	Trapezoid, leg thickness 50 mm
Grinding media	
Material	Chrome alloy steel
Ball diameter	40% of the balls with 60mm, 40% of the balls with 40mm, and 20% of the balls with 25mm diameter
Density	7800 kg/m^3
Ball filling (J_b)	0.1, 0.2 and 0.3 fraction of mill volume
Total ball mass	176, 352 and 528 kg
Feed	
Material	Copper ore
Particle size	$F_{100} = 25.4$, $F_{80} = 12.7$, $F_{50} = 8$ and $F_{10} = 0.3mm$
Ore density	2700 kg/m^3
Slurry concentration (C)	0.6 (mass fraction of solid in slurry) or 35 (vol.% solid)
Slurry density	1610 kg/m^3
Slurry filling (U)	U=1 (as volume fraction of ball bed voidage)

In order to investigate the wear, the wear specimens are installed in two of the lifters. These lifters have special location for the specimen placement which was able to protect the specimens. The specimens are mounted in a slot on the top of the lifters they are screwed in their place (Fig. 4). The specimens were made from ductile steel (120 HB). To prevent the overheating and the variation of surface properties, during their production, cold-working processes were used. To improve the surface finishing, the specimens were completely polished. Also, in order to assess the effect of size and shape of the specimens, one of them was chosen with a larger size and another one with a smaller size. Since the thickness and density of the specimens is constant, the mass difference between them can be a suitable criterion for the wear measurement. So, to measure the wear, the mass of specimens is quantified before the test by an accurate scale (GR-200) with the precision of 0.1mg. After the test, the specimens are weighted again. Using the difference between the mass before and after the test, the wear can be obtained. According to Eq. (1), to make the wear independent of surface and density, a parameter called "rate of wear" is used which states the ratio of mass variation to the initial mass in a given time.

$$rate\ of\ wear = \frac{\Delta m}{m_1 \Delta t} \qquad \text{Eq. (1)}$$

The feed of the mill is copper ore smaller than 1 inch, which F_{80} and F_{50} of them are 1/2" and 5/16", respectively. The slurry concentration used in the tests was 60% (mass % solid). The amount of slurry is increased till the slurry volume becomes 1 time of the balls bed voidage. The concept of the slurry filling (U) in the mills was first introduced by Austin et al. [26]. In a pilot mill with 1m diameter, in cascading motion, the ball velocity rapidly approaches 4m/s and it has impacts at high speed in the toe region [14]. The kinetic energy of the balls with 60mm diameter and 0.88kg mass is approximately 7J. The energy of balls to grinding the copper ore feed with dimensions less than 1 inch and the average hardness is enough [27]. The mill grinding mechanism is a combination of both impact and abrasion mechanisms [28].

The experiments will be performed once without the device to prevent cascading motion (to calculate the total wear) and once with the device (to calculate the abrasion wear). The difference in the value of these two tests shows the wear caused by impact. For each experimental condition, the mill is allowed to rotate for 15 minutes, and then the specimens are taken out from the mill to be weighted and eventually the rate of wear is calculated. During the experiments, the slurry temperature was regularly monitored and the changes were observed to be 20-23˚C. All experiments are repeated and in order to measure the experimental error, one experiment was repeated three times, and their variability is seen to be within ±0.00002 1/hr at 98% confidence level.

3. Results and Discussions

In Fig. 5, contribution of wear due to impact and abrasion for different speeds and ball filling 10% are presented in the wet condition. As Fig. 5 indicated, initially with the increase of speed, the wear increases, then after approaching the peak point, the wear decreases. The pick point relies on the speeds range from 80% to 90% of the critical speed. When the mill speed increases, the shoulder of load moves up, and the falling height of particles is increased in the cascading motion and as a result, the materials which impacted on the toe region with more speed and more energy, leads to the increase of the impact wear. At the speeds higher than 90% of the critical speed, the cascade path is changed due to the lifting of shoulder angle and it moves toward the end of the toe. Therefore, the falling height, impact speed and impact force are lowered. Consequently, the particles and the balls have direct impact on the lifters, but due to the reduction of the speed, the wear caused by the impact is lowered. Moreover, the centrifugal forces are augmented as the speed got increased. As a result, the relative velocity between the materials and the balls increases and consequently this causes the increase of the abrasion wear rate.

Fig. 4. View of the holder liner and samples used in the research.

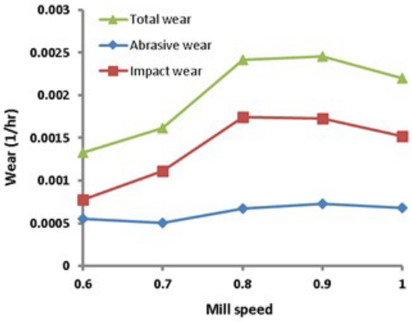

Fig. 5. Contribution of wear due to impact and abrasion at different mill speeds for ball filling 10%.

Figures 6 and 7 show contribution of wear due to impact and abrasion at different mill speeds for ball filling 20% and 30%. As observed from Fig. 5 to Fig. 7, the wear rate reduces when the ball filling increases. When the charge volume is small and the mill speed is high, the balls land upper than load toe and strike the lifters directly which causes the rapid failure and wear of them. With the rise of charge and transmission of the load toe to the top, direct impact between the balls and the mill shell reduces and the balls land on the toe region, consequently the impact wear decreases. With the increase of ball charge, the shoulder angle remains almost constant while the toe height increases, thus, the balls have short falling height and in turn, the wear due to the impact is reduced.

Contribution of impact wear and abrasive wear for different ball filling at 80% of critical speed is depicted in Table 2. According to Table 2, the impact wear decreases remarkably with the increase of the ball filling. When the charge volume is small and the mill speed is high, the balls land upper than load toe and strike the lifters directly which causes the rapid failure and wear of them. With the rise of charge and transmission of the load toe to the top, direct impact between the balls and the mill shell reduces and the balls land on the toe region, consequently, the impact wear decreases. However, with the enhancement of the ball charge, the abrasive wear increases slightly with the increase of normal forces.

4. Conclusions

In this study, an experimental method was used to investigate the effects of the mill charge and mill speed on the wear of lifters/liners in wet condition. The wear specimens were installed on the top of lifters in order to compare the mass loss under different conditions. It was found that the mill speed and the ball filling remarkably affect the wear rate of the liner. The following remarks can be drawn from this study:

- As mill charge increases the impact wear rate decreases.
- As mill speed increases to a certain value (about 80-90% of critical speed) the rate of impact wear increases to a peak value and thereafter it decreases.
- The contribution of impact wear and abrasive wear from the total wear depends on the mill speed and ball filling.

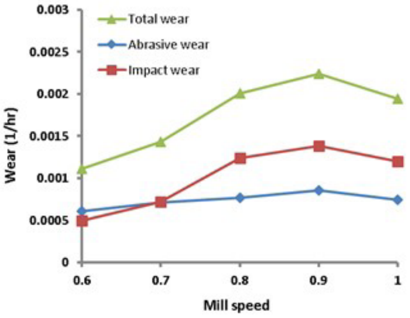

Fig. 6. Contribution of wear due to impact and abrasion at different mill speeds for ball filling 20%.

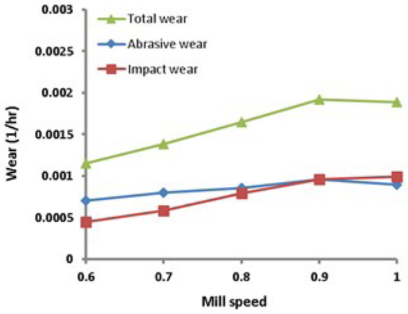

Fig. 7. Contribution of wear due to impact and abrasion at different mill speeds for ball filling 30%.

Table 2. Contribution of impact wear and abrasive wear for different ball filling (Φ_C=0.8, U=1, C=0.6).

Ball filling	Impact wear	Abrasive wear	Total wear
J_b=10%	0.001747 1/hr 72.34%	0.000668 1/hr 27.66%	0.002415 1/hr 100%
J_b=20%	0.001240 1/hr 61.75%	0.000768 1/hr 38.25%	0.002008 1/hr 100%
J_b=30%	0.000795 1/hr 48.18%	0.000855 1/hr 51.82%	0.001650 1/hr 100%

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