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RESEARCH NOTE

A New Procedure of Impact Wear evaluation of Mill Liner

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ABSTRACT

The wear of mill liner has the unwanted economic effects in mineral processing in the form of labor costs, price of material and shut down periods. Therefore, the study of liner wear is economically important to optimize the mill operating conditions and liner profile designto decrease the wear rate. There is no universally accepted and applicable research on impact wear evaluation of mill liners. In the present work, a procedure is presented for evaluation of impact wear of mill liners. A test machine is used to do impact wear experiments in different conditions of ball size, velocity and impact angle.A single relation of wear evaluation can be extracted from the experimental data. This relation is used to evaluate the liner wear due to impacts. The procedure is validated by measured liner wear of a laboratory mill. In the laboratory mill, a plate is positioned in front of the cataract regime to eliminate it and enable us to measure the abrasion and impact wear separately. The comparisons show the acceptable accordance of evaluated and measured data; so, the liner wear of an operating mill can be evaluated by the procedure. The operating mill is in Sarcheshmeh copper complex in Iran.These studies help us to have appropriate liner designs in order to postpone the liner wear and shut down periods while maintaining the mill performance.

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NOMENCLATURE

m_{wkN}	Impact mass loss of liner element *k*	V_f	Percent of mill filling
n_x	Number of liner elements	V_m	Mill total volume
R	Mill radius	y_k	Height of liner element *k*
r	Ball radius	Δy_k	Height of element face
v	Ball velocity	**Greek Symbols**	
K_w	Wear coefficient	ρ_s	Steel density (kg/m^3)
m	Ball mass	θ	Incidence angle
		θ_{sk}	Surface tangential angle of element k

1. INTRODUCTION

In tumbling mills, liners raise grinding media and ore to transfer energy from mill to load. During the course of mill operation the lifters wear and thus affect the mill performance through loss of lifting action; [1] in addition extensive down-time is required to replace worn liners. Furthermore, random breakage and replacement of the liners can cause many unwanted interruptions of the SAG mill. Investigation of the primary parameters that drive the wear process can lead to increased mill efficiency. Wear is the loss of material of contacting surfaces due to relative motion and frictional interaction. There are numerous factors influencing wear; the relative strength and hardness properties of the material surfaces, sliding distance, sliding velocity, normal force or pressure and history of loading. Approaches have been proposed to predict the lifter wear. Radziszewski [2-4] proposed a correlation with laboratory data for the prediction of lifter wear. Cleary [5] described how in principle DEM could be used to predict the wear of lifters. Kalala et al. [6] investigated the wear of lifter profiles in dry coal grinding mills. Banisi and Hadizadeh [7] used a

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mechanical lifter wear monitor to measure the mass loss due to the wear in a real SAG mill.

2. CHARGE PROFILE

The charge profile of operating mill is not visible and there are generally three ways to estimate the load behaviors: theoretical models [8-10], DEM simulations [11, 12] and laboratory mills. Here, a *1m* diameter laboratory mill is used to determine the charge profile. It can be equipped by 60 liners and has a speed controller that ranges between 0 to 120% of critical speed[2]. The laboratory mill is a scaled model of operating mill and many of its data can be generalized to the real-scale mill [13]. It has been long established that the charge in a tumbling mill moves in two modes: cascading and cataracting [14, 15] . The *en masse* load is a semi-static section in which particles roll on each other. A typical charge profile obtained of DEM models [16] is illustrated in Figure 1. Radziszewski [2] proposed a relation for mass loss in a tumbling mill. Teeri et al. [17] investigated the impact wear of the different materials. Farahani et. al. [18] proposed a new smoothed particle hydrodynamics (SPH) algorithm for simulation of elastic-plastic deformation of solids. Kalala et al. [19] investigated the influence of lifter wear on the load behaviour of an industrial dry tumbling mill using DEM. Rezaeizadeh et al. [20] determined the mass loss of face and top of the liner using a laboratory mill. All of these provide an insight into lifter wear, but none provide the relationship of mill operating parameters, lifter profile, and lifter material with lifter wear rate. There are studies in the field of wear processes [21, 22] but the results could not be reliably generalized to different cases. In the present work by using a pilot-scale experimental mill, the charge profile of the operating mill is determined. A procedure is presented to evaluate the liner wear due to impact. A small specimen is inserted in laboratory mill liner to measure the mass loss due to mill operation and validate the predictive model. The cataract regime is eliminated using a mechanism in laboratory mill and the abrasion and impact wear portion in specimen is determined separately. Comparisons show that the suggested procedure well predicts the liner wear of mill elements.

3. WEAR MODEL

Liners wear due to two mechanisms: liner movement under the *en masse* load and impacts of cataract regime.

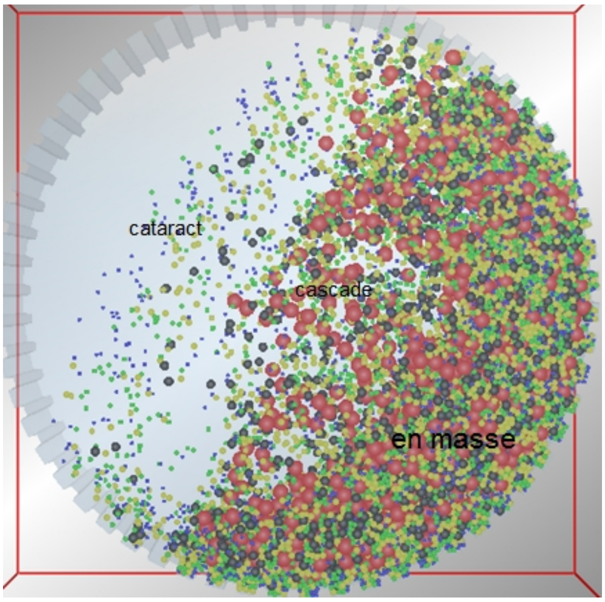

Figure 1. Charge profile in tumbling mill

Here, the impact is only evaluated and abrasion wear is currently explored by another team in our research group.

4. IMPACT WEAR TESTER

Wear data is generally lacking for impact wear situations any way [23]. Here, a tester is designed such that the balls obtain the required velocity and impact the specimen consecutively. The mass loss of specimen is measured after a number of impacts to investigate the effect of impact parameters on wear. The balls are positioned in front of the rotating wheel, move through an inclined hose toward the specimen and impact it. After this, they fall in the ball container to repeat the process. The schematic of the rotating wheel, ball path and specimen are illustrated in Figure 2. The magnet piece fixes the balls on their place to properly gain velocity.

4. 1. Impact Wear Evaluation

Using the wear test machine we would be able to measure the wear of any specimen due to ball impacts. We can do several tests for any specimen at the different conditions of ball size, velocity and impact angle. After this, a single relation can be extracted to evaluate the specimen wear due to impact. Such experiments are performed on a piece of liner at the conditions listed in Table 1. The equation which gives the wear measurements of Table1can be considered as follow:

$$w = K_w V^{\alpha} r^{\beta} \exp(\theta\gamma) \tag{1}$$

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[2] Speed in which the eccentric force is equal to weight

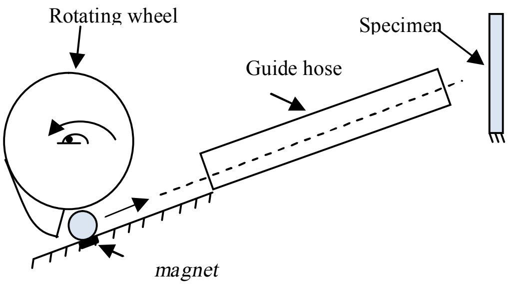

Figure 2. Schematic of the rotating wheel, ball path and specimen position in wear test machine

Figure 3. Measuring the cataract load mechanism

TABLE 1. The wear measurements at different impact conditions

Test No.	Velocity (m/s)	Diameter (mm)	Angle (dg)	Worn Mass (g)
1	2.5	15	10	0.0002
2	5	15	15	0.0007
3	7.5	15	20	0.0013
4	2.5	25	15	0.0015
5	10	15	30	0.0016
6	5	25	10	0.0027
7	2.5	20	20	0.007
8	7.5	25	30	0.0054
9	10	25	20	0.0084
10	2.5	30	30	0.0123
11	5	20	30	0.014
12	7.5	20	10	0.017
13	5	30	20	0.0306
14	10	20	15	0.03
15	7.5	30	15	0.043
16	10	30	10	0.047

TABLE 2. The parameters of Equation (12)

Parameter	K_w	α	β	Y
θ≤30	100	1.3	2.66	0.94
Θ>30	100	1.6	2.4	-2.4

In which, w is the worn mass in gram, V is the ball velocity in m/s, r is the ball radius in meter and Θ is the incidence angle. Similar experiments are performed for the impact angle greater than 30°. It is due to that the wear variation is different at the impact angles less than 30° and larger than it [24, 25]. The best values of parameters K_w, α, β and ʏ which fits the evaluations of Equation (1) to the measurements of Table 1 are listed in Table 2. The parameters of Table 2 are the adequate parameters which gave wear values. These values are matched with the experimental results obtained from wear tests. They give us a relation for evaluating impact wear for the materials of presented case and for the range of parameters given here. We use Equation (1) to evaluate the liner wear due to ball impacts in laboratory mill.

4. 2. Cataract Load Measuremen

The cataract load should be determined to evaluate the liner impact wear. The laboratory mill which is a scaled model of operating mill is used for this aim. Cataract load in laboratory mill is measured using the plate illustrated in Figure 3. It collects the falling cataract load and we can measure it after a number of mill rotation. This method gives the cataract loading about 0.4% of mill filling.

4. 3. Evaluation of Liner Impact Wear

An impact sensor is inserted in a liner of laboratory mill to record the ball impacts during mill rotation. It gives the impact diagram as illustrated in Figure 4. The high values correspond to the impacts of cataract load. Zero on horizontal axis corresponds to the highest position in mill. The impact-wear of liner elements is evaluated by Equation 1 which is re-written as follow:

$$\text{Cataract mass} = 0.004 V_f V_m,$$

$$\text{Number of impact} = \frac{0.004 V_F V_M}{m} \tag{2}$$

$$m_{wkN} = \frac{0.004 V_F V_m}{m n_x} K_w V^{\alpha} r^{\beta} \exp(\theta\gamma)$$

In which, m_{wkN} is the mass loss of element k due to the impact of cataract regime during revolution N, V_F is the percent of mill filling, V_m is the mill interior volume, n_x is the number of liner elements and m is the ball mass. The velocity parameter in this equation is the ball falling velocity at the point it impacts the mill wall. It is evaluated using the free falling equations of motion.
The reduction in element height then will be:

$$y_{k(N+1)} = y_{kN} - \frac{m_{wkN}}{\rho_s \Delta x} \tag{3}$$

In which, y_{kN} is the liner height on element k (refer to Figure 5) at revolution N, ρ_s is the steel density and Δx is the element width. The liner profile then could be re-build after each revolution. Thus, we have the worn liner profile after N revolution (due to impact only).

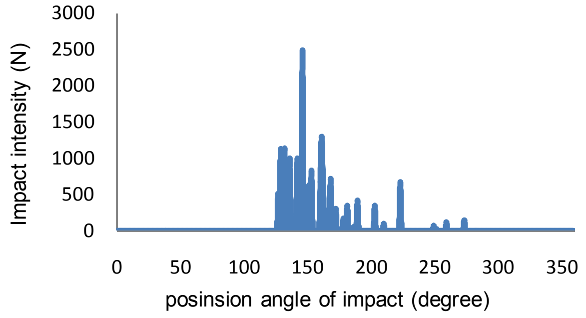

Figure 4. A sample diagram of impact intensity in laboratory mill over one mill revolution

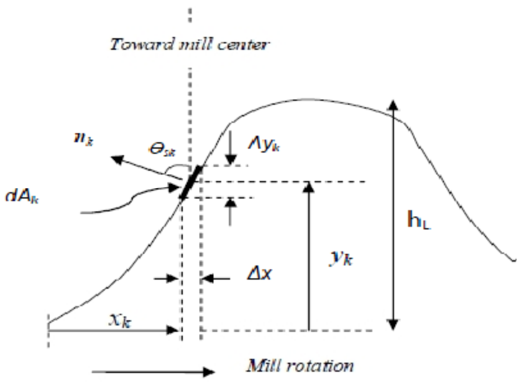

Figure 5. liner element specifications

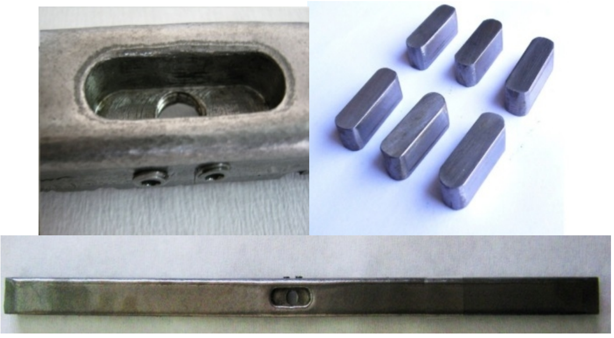

Figure 6. Specimens and their positions in liner face

4. 4. Materials and Methods

At first, the laboratory mill liner wear is evaluated by the procedure. For comparison purposes, the liner wear is measured and evaluated. A specimen is inserted in the liner face to measure its wear. The 30×30×10mm AISI1040 steel specimens, as illustrated in Figure 6. With Brinell hardness 65HB is used for this aim. They are completely cleaned and inserted in the mill liner and are withdrawn after specific mill revolutions. The mass loss is measured by weighing the specimens before and after the experiments.

The mill load is 25mm steel balls and experiments are performed at the different mill filling and mill speeds. Each experiment is performed twice: one without the cataract elimination mechanism and other with the mechanism. The first experiment gives the abrasion-impact wear and the second one gives only abrasion wear. The wear difference of these two cases will be the impact wear.

5. RESULTS AND DISCUSSION

5. 1. Wear Evaluation of Laboratory Mill

The measured and evaluated wear results, corresponding to 1000 mill revolutions are listed in Table 3.

The results of Table 3 have been illustrated in Figure 7.

Noting the enormous reasons which may cause errors in milling studies, the results will be acceptable. However, there are almost differences between the evaluated and measured data in some cases but the data variation behaviors are the same. It justifies the procedure as the first stages of impact wear phenomenon study in operating mill.

5. 2. Evaluation of Operating Mill Liner Wear

Operating conditions of real mill are listed in Table 4. The liner worn profile after 600,000 revolutions (about 925 h) is illustrated in Figure 8. Measurement of the worn liner after this period shows more wear than the current evaluations. It confirms that the major part of liner wear is due to abrasion wear.

TABLE 3. Laboratory mill liner wear: measured and evaluated

Number of tests	Mill filling%	Mill speed%	Imp. Wear (mg/m^2)	
			Evaluated	Measured
1	18	75	126	180
2	18	80	230	340
3	24	75	276	500
4	24	80	889	1000
5	30	75	250	400
6	30	80	237	383

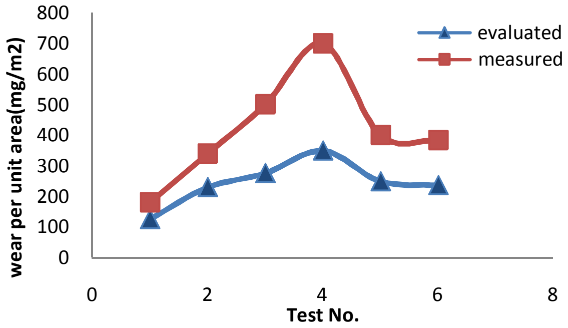

Figure 7. Comparison of measured and evaluated impact wear in laboratory mill

TABLE 4. Operating conditions of real mill

Mill radius	Mill length	Mill speed	Mill filling	Nom. of liners
4.75m	4.75m	77%	About33%	60

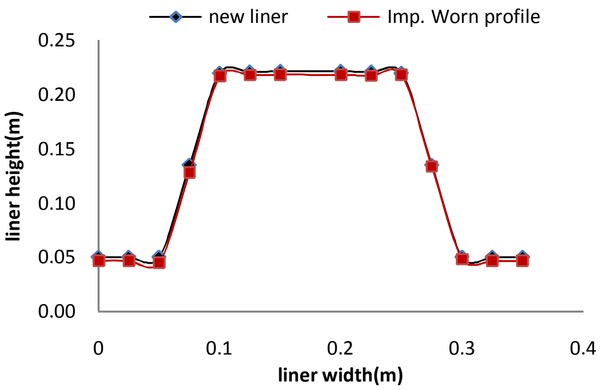

Figure 8. Worn profile of operating mill liner after 600,000 revolution(about 925h)

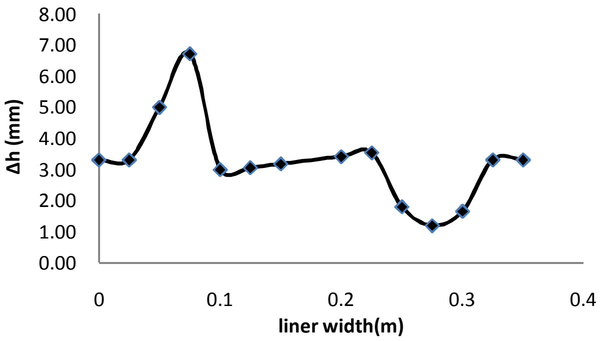

Figure 9. Height decrement of liner elements

Figure 9 shows the height decrement of liner elements due to impact wear. As we can see the Impact wear maximizes on the back elements where the impact angle of cataract regime with liner face is about 30°, the critical impact angle. These data will be helpful in liner design stage to optimize the liner profile toward the minimum material scatter and optimized operation of liner during its lifetime onto its replacement. Studies on this field are currently done by the research centers of Sarcheshmeh copper complex and Shahid Bahonar university.

6. CONCLUSIONS

- An impact wear tester is used to extract a relation for calculating the wear of specimens due to ball impacts
- The liner wear of laboratory mill is measured by weighing a small specimen inserted in liner face before and after mill operation.
- The abrasion and impact portions of specimen wear are measured separately by eliminating the cataract regime in laboratory mill.
- Evaluations show that the impact wear is a minor part of liner wear in operating mill.
- Evaluations show that the impact wear maximizes on back elements of liner.
- The data will be helpful in liner design stage to optimize the liner profile.

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چکید

سایش آسترهای آسیا هزینه های زیادی بر فرآیندهای فرآوری معدنی تحمیل می کند که شامل هزینه نیروی انسانی، هزینه خریداری آسترها و هزینه توقف تولید است. بنابراین مطالعه این فرآیند جهت بهینه سازی عملکرد آسیا و طراحی آستر در جهت کاهش نرخ سایش بسیار اقتصادی است. تحقیق مناسب و کاربردی در زمینه سایش ضربه ای آسترآسیا انجام نشده است. در کار حاضر روشی برای محاسبه سایش ضربه ای آستر ارائه شده است. یک دستگاه آزمایشی برای انجام آزمایشات سایش ساخته شده که قادر به انجام آزمایشات سایش ضربه ای در شرایط مختلف اندازه گلوله، سرعت و زاویه برخورد است. یک معادله محاسبه سایش، برگرفته از داده های آزمایشی استخراج می شود. این معادله برای محاسبه سایش آسترها مورد استفاده قرار می گیرد. این روش با اندازه گیری و مقایسه سایش آسترهای یک آسیای آزمایشگاهی اعتبارسنجی می شود. صفحه ای در برابر جریان آبشاری درون آسیا تعبیه می شود که جریان آبشاری را مانع شده و امکان اندازه گیری سایش ضربه ای و سایش اصطکاکی را بطور جداگانه فراهم می کند. از آنجا که نتایج محاسبه شده و اندازه گیری شده انطباق قابل قبولی دارند از این روش برای محاسبه سایش ضربه ای آسترآسیای واقعی در مجتمع مس سرچشمه استفاده می شود. این روش به بهینه سازی طراحی آستر جهت به تعویق انداختن سایش و دوره های توقف آسیا همزمان با حفظ عملکرد مناسب آسیا کمک خواهد کرد.

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