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Propose a New Model for Prediction of the Impact Wear Using an Experimental Method

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ABSTRACT

Impact wear can be defined as the wear of a solid surface that is due to percussion, which is a repetitive exposure to dynamic contact by another solid body. It generally has the devastating effects on the mechanical elements and causes the equipments to shift away from their normal performance. Impact wear has not been studied as extensive as other wear mechanisms and as a result information on the causes and actual impact wear data is quite scarce. Knowing how the impact parameters affect the wear intensity would be helpful to have the more optimal designs. Having an experimental apparatus would be a reliable way for this aim. In the present work, a new impact tester was designed to explore the consecutive impacts between balls and a flat plate as a wearing specimen. Measurements of the plate mass loss after a number of impacts at the different impacting conditions revealed the effect of parameters on the impact wear. Design of experiment is carried out regarding the impact velocity, ball size and impact angle as the variables. An impact wear model is extracted based on the experimental data. The obtained results suggest that the model can be used as a predictive way to study the practical design problems and to explain some phenomena associated with impact erosion.

Keywords: Impact wear; Contact ; Wear modeling, Steel, Indentation

1 INTRODUCTION

INDUSTRIAL machinery components may subject to the mechanical impacts during their useful life. While component stresses safely remain under the yield point, practical usefulness of the machine element depends on its resistance to fatigue and wear. Fatigue may be virtually eliminated by maintaining the part under the endurance limit but wear phenomena apparently persist even at low stress levels. In many mechanical devices impact wear poses a severe problem to the useful life of components which are otherwise carefully designed for performance in the elastic range. Since preventive measures are mandatory, a basic understanding of the wear process and the factors influencing it must be sought. Very little engineering information has been established in this area. Studies [1, 2, 3] revealed that the normal load and relative velocity of contact points are the main causes of the mechanical wear. Steady state wear mechanisms have been solved theoretically for the different wearing geometries but the compound impact wear evaluation is so complicated. [4]. There are several theories for describing the impact. The most convenient model includes the Hertz relations which is limited in the elastic deformations. Mindlin [5] improved the Hertz theory for the case that the plastic deformation occurs. Researchers [6, 7, 8] theoretically and experimentally analyzed the variation of the tangential and normal forces due to impact of a ball on the flat plate.

Empirical models have been proposed to evaluate the wear rate in different modes of erosion due to solid particle interactions [9–13]. Talia et al. [14] established a theoretical analysis based on a new laboratory technique for solid

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particle erosion. They could evaluate the effect of particle velocity components (normal and tangential) on the wear rate. Since many parameters affect the impact wear, generalizing the results of one case to other ones is rarely reliable and so, each wearing case should be studied separately. Our desired case of study is the wear of mill liners due to the impacts of mill charge (ball and ore). For this aim, a new impact wear tester is designed to study the effect of kinematical parameters on the impact wear intensity. Experimental procedure is such that a flat plate is impacted consecutively by the steel balls and its worn mass is measured after a number of impacts. Measurements are used to extract a predictive wear model in terms of the impact parameters. The results could be used to have the optimal designs where the impact wear occurs.

2 IMPACT

Impact of mechanical elements conjugates with transferring the high level forces due to the small periods of time and causes the mass loss of elements. However, the impact is a complicated process to be completely analyzed but at least it can be said that the response of bodies depends on the impact initial conditions and material properties. In the case of the impact between a ball and a flat plate, as schematically is illustrated in Fig. 1, the ball impacts the plate by the initial velocity of v_i at the angle θ_i and leaves it by the final velocity of v_f and the angular speed of ω_f at the angle θ_f . Impact studies generally include the attempts of providing the procedures to determine the material responses and final impact parameters. [5-8] A simple way of this aim is the rigid body analysis whose many aspects are valid for practical impacts when the small elastic deformations are involved. [8] However, at the high impact velocities the elastic or elastic-plastic deformations are involved and the rigid body theories have the notable deviations from the practical observations so, the more accurate analyses are required that include the variation of the force and displacement during the impact process. [15] Mass loss of impacting bodies is one of devastating effects of the impact phenomena and makes the elements away of their normal performance so, it would be obviously desirable to accommodate the level of impact wear. To this aim, the influence of impact parameters and material properties on the wear intensity should be studied. It requires the incorporation of the contact and wear theories and will be obviously a complicated process. A simple and reliable way is using the empirical apparatus. Some machines have been manufactured for this aim [1, 16, 17, 18] and, here a new wear tester is designed to determine the effect of impact parameters on the impact wear.

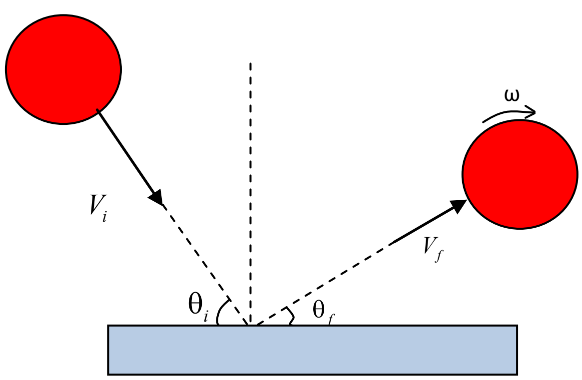

Fig. 1
Schematic of the ball impact on a flat plate.

3 IMPACT APPARATUS

As mentioned, the impact wear analysis is rather complicated and may not give the reliable results. So, the empirical apparatus would help us to study the process reliably. Here, the impact between balls and flat plate is simulated because that our focus is on determining the effect of ball impacts on the wear of mill liners. Regarding our issue, tester is designed such that the balls get the required velocity and impact the specimen (a flat plate) consecutively. The balls are positioned in front of the rotating wheel, get the velocity, move through an inclined hose toward the specimen and impact it. After that, they fall in the ball container to repeat the process. The schematic of the rotating wheel, ball path and specimen are illustrated in Fig. 2 and an image of the impact apparatus is illustrated in Fig. 3. A ball of 25*mm* in diameter is illustrated in this figure to show the real size of the machine. Machine design considerations are to provide a variety of testing conditions: impact angle in the range of 0-90 degrees, impact velocity up to 30m/s and the ball size of 10-50mm. ball velocity is calculated using the following dynamic equations.

$$H_{01} = H_{02} \tag{1}$$

$$\bar{I}\omega_1 = \bar{I}\omega_2 + mvR_1 \tag{2}$$

$$e = \frac{\int f_r dt}{\int f_d dt} = \frac{m(v - v_0)}{m(v_0 - 0)} \tag{3}$$

$$e = \frac{\int M_r dt}{\int M_d dt} = \frac{\bar{I}(\omega_2 - \omega_0)}{\bar{I}(\omega_0 - \omega_1)} \tag{4}$$

$$v = \frac{\bar{I}R_1\omega_1(1+e)}{\bar{I} + mR_1^2} \tag{5}$$

e is the coefficient of restitution which is determined experimentally. H is the angular momentum, I is the rotating wheel mass moment of inertia, ω_1 and ω_1 are the rotating wheel angular velocity before and after impact respectively, R_1 is the rotating wheel radius and v is the ball velocity.

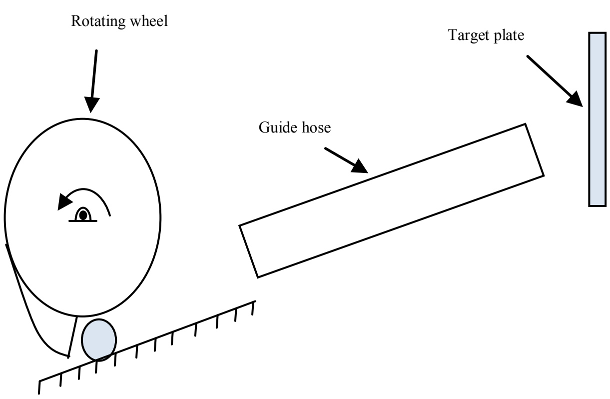

Fig. 2
Schematic of the rotating wheel, ball path and impacted plate position.

Fig. 3
Impact wear tester.

4 EFFECT OF IMPACT PARAMETERS ON THE WORN MASS

Since the ball velocity and its size are two important parameters in mills, from the liner wear point of view, the tests are devised in such a way to investigate the effect of these parameters on the impact wear. Tests have been performed at the variable velocity and constant ball size. The 25mm steel balls impact the specimen in different impact velocity and impact angles. Specimens are the plates of alloy steel of dimension $40 \times 40 \times 5$ mm. Variation of the impact wear with respect to impact velocity is illustrated in Fig. 4. The sensitivity of the impact wear intensity to the ball size variation is illustrated in Fig. 5. The tests are done for the different values of ball size by the impact velocity of 10 m/s, near the maximum velocity of ball-liner impacts in our case mill. Comparing Figs. 4 and 5, it can be inferred that the impact wear is more sensitive to the ball size variation contrast to the ball velocity variations. It is investigated in more details in the next section. Impact angle highly affects the normal load and sliding distance on the contact area and so on the impact wear [19]. It is seen, as illustrated in Fig. 6 that the maximum wear occurs when the impact angle is about 30degrees. The FEM study of the wear due to a flow of particles also upholds this conclusion [19].

The empirical apparatus greatly helps us to deeply understand the effect of impact parameters on the impact wear intensity. Such insight of the impact wear would be a vital knowledge at the design stage. For our case, the liners of mills, the present data would be helpful, at the design stage, to devise a balance between the appropriate comminution and acceptable liner wear rate.

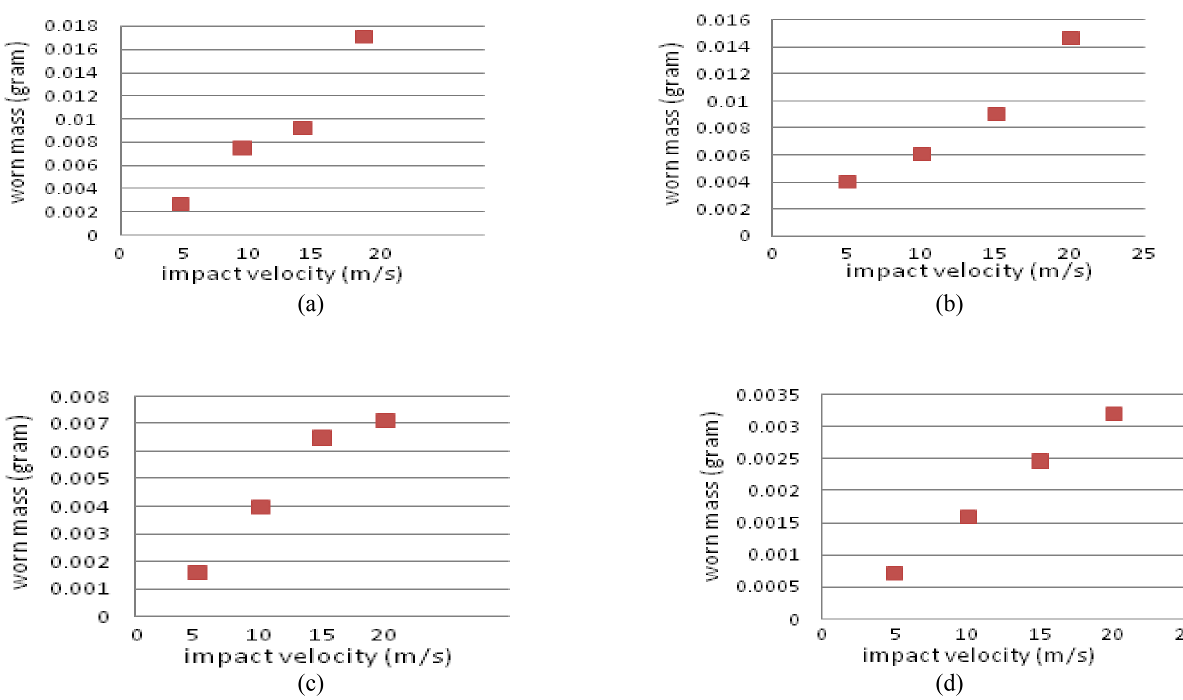

Fig.4
Experimental results of worn mass versus the impact velocity at the different impact angles, (a) 10, (b) 30, (c) 45 and (d) 60 degrees.

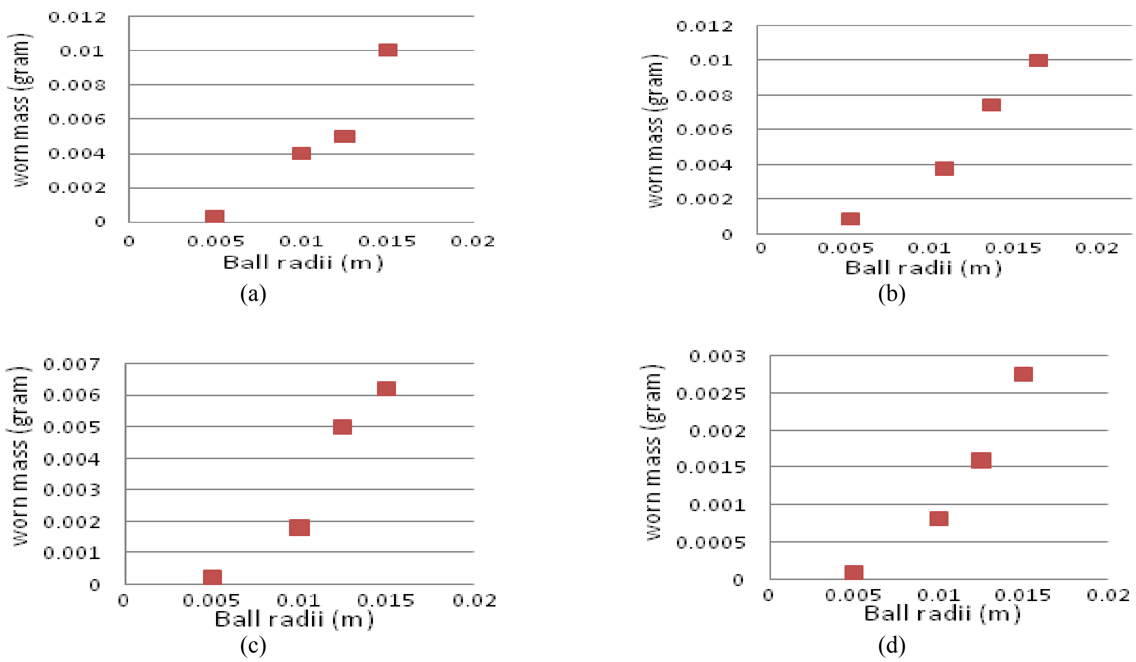

Fig. 5
Experimental results of worn mass versus the ball size at the different impact angles, (a) 10, (b) 30, (c) 45 and (d) 60 degrees.

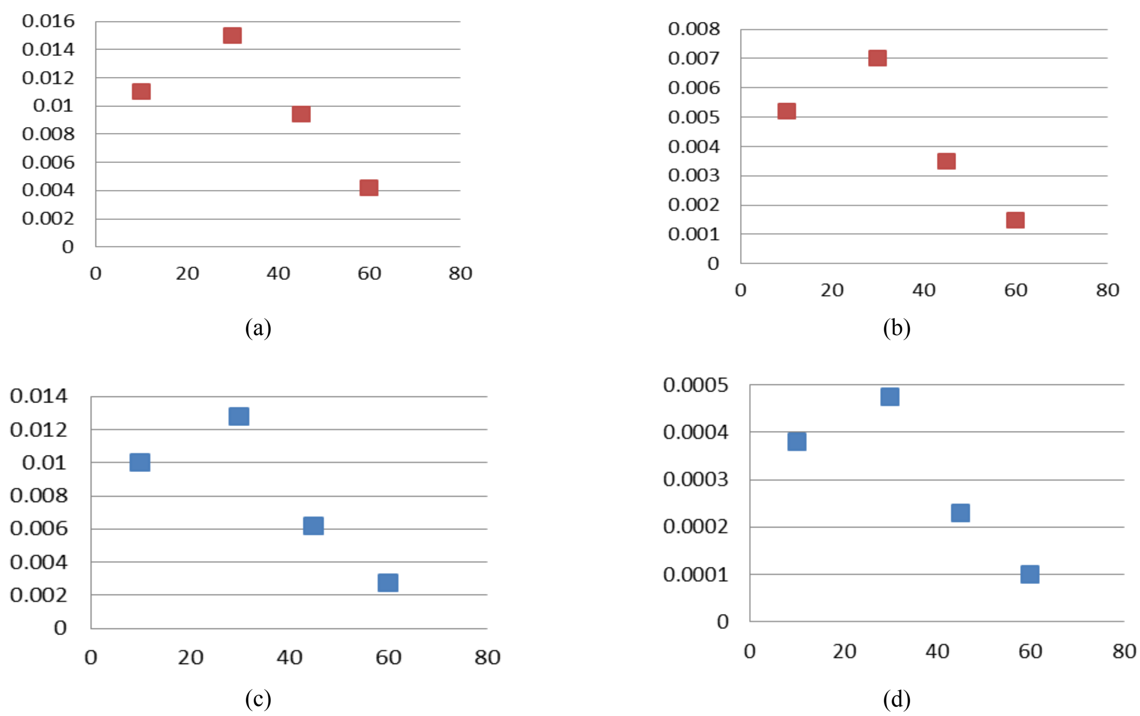

Fig.6
Experimental results of variation of the worn mass in gram (vertical axes) with respect to the impact angle in degree (horizontal axes). a) v20m/s, R12.5mm, b) v10m/s, R12.5mm, c) v10m/s, R15mm, d) v10m/s, R5mm.

5 DESIGN OF EXPERIMENT

It is desired to extract an impact wear model to predict the mass loss of flat plate in terms of the impact velocity, ball size and impact angle. A taguchi DOE (design of experiment) technique was performed. As mentioned, the wear increases as the impact angle increases up to 30 degrees and then decreases as the impact angle increases. So, two sets of tests are designed: first one for the impact angle lower than 30 degrees and the second one for higher than it. Impact velocity, ball size and impact angle are considered as the effective kinematic variables and levels of Table 1. are selected. We have three factors including ball radii, impact velocity and impact angle. For these factors, a 4-Level taguchi design of experiment gives a L16 design.

Since the worn mass due to one impact is not practically measurable, 600 ball impacts are made for each test to have the measurable results. DOE is carried out for two sets of data levels: impact angles under 30 degrees and upper it. 16 tests are devised for each set. A model is extracted based on the effective kinematical variables and is presented in the form of Eq. (6).

$$w = Kv^{\alpha} r^{\beta} e^{\theta\gamma} \tag{6}$$

In which w is the worn mass in gram, v is the impact velocity in m/s, r is the ball radii in meter, e is the impact angle and α, β, γ and K are the constant parameters. The best values of constants that make the predictions of Eq. (6) appropriately coincident with the experimental results are listed in Table 2. The values of coefficient K depends on the properties of the specimen and impacting balls and is not more discussed here. The comparison between the experimental measurements and predictions of Eq. (6), along with the constants of Table 2. , is illustrated in Figs. 7 and 8. The model results are in good agreement with the experimental measurements. It means that the model of Eq. (6) well predicts the impact wear of the balls on the flat plate. The power of ball radii (β) is greater than the power of impact velocity (α) in Eq. (6). So it can be inferred that for the presented case (steel balls on the alloy steel specimens) the effect of ball size variation on the impact wear is more than the ball velocity variation.

Table 1
Level of variables for the DOE process

variable	Levels
Impact velocity (m/s)	2.5-5-7.5-10
Ball Radii (mm)	7.5-12.5-20-25
Impact angle (degrees)	10-15-20-30-35-45-60-75

Table 2
The constant parameters of the wear model

parameter	k	α	β	γ
$\theta \le 30$	100	1.127	2.811	0.970
$\theta > 30$	100	1.422	2.545	-2.580

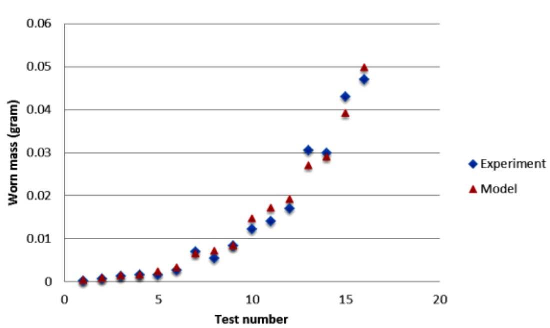

Fig. 7
Comparison between the experimental measurements and predicted results, Impact angle lower than 30 degrees.

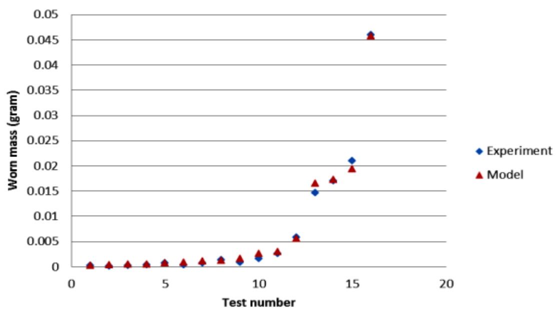

Fig. 8
Comparison between the experimental measurements and predicted results, Impact angle higher than 30 degrees.

6 RESULTS AND DISCUSSION

Investigation of the effect of impact parameters on the wear of mill liners using an impact wear tester is of interest. Different values of impact velocity, ball size and impact angle are tried. A plate is impacted consecutively by balls and the worn mass is measured after a number of impacts. Results show that the wear increases with increasing the impact velocity and ball size. The maximum wear occurs at the impact angle of about 30 degrees. Using a DOE process an impact wear model is extracted to predict the impact wear in terms of the impact parameters. Model revealed that the wear is more sensitive to the ball size variation in contrast to the impact velocity variations. The results will be helpful in more optimal designs where the impact wear is unavoidable. More studies in this field are currently processing by use of the present impact tester. The effect of specimen and ball materials, plate thickness, hardness and other influencing parameters are to be more investigated.

7 CONCLUSIONS

1. The impact wear effectively depends on the impact velocity, impact angle, and ball size.
2. Based on the experimental measurements, a model is extracted that well predicts the impact wear in terms of the impact parameters.
3. For the case that studied here, impact wear due to ball impacts is more sensitive to the ball size in contrast to the impact velocity.
4. The highest wear rates occur at around the impact angle of 30 degrees.

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