Study on Liner wear in Single Toggle Jaw Crushers: A Review

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Abstract—This article presents a review and discussion of the causes of liner wear in single toggle jaw crushers. Literatures from different authors were sorted, reviewed and discussed. The various articles considered showed that the main cause of the rapid wear of jaw liners is the sliding interaction between the crushed material and the jaw liners during the crushing operation. Reducing the sliding interaction will therefore relieve the rapid wear of the jaw liners. Though some researchers have attempted to resolve the rapid wear problem by altering the material constituents of the jaw liners, it has not been able to yield much results. This is because the key aspect in resolving wear failures is to recognize wear as a system property or characteristic and not only a material property[1]. The sliding of the crushed material on the surfaces of the jaw liners can be reduced by changing the surface profile of the jaw liners.

Index Terms—Sliding; jaw liner; single toggle jaw crusher; abrasive wear

1 Introduction

ONE major challenge faced by quarrying and mineral processing industries is the comminution process. This is because most materials that are dealt with are hard and abrasive, thereby rapidly wearing away the comminution machines. Single toggle jaw crusher, one of the popular comminution machines used in mines and quarries, is faced with this problem of rapid abrasive wear of its jaw liners. Much has been done by researchers to solve the problems surrounding jaw liners to some extent, but most of these researchers did not give attention to the reduction of thethe rapid abrasive wear associated with the crusher liners. This article presents a review of what researchers have done in the quest of identifying the causes of the rapid abrasive wear surrounding jaw liners of the single toggle jaw crusher.

1.1 Overview

The commonly utilized primary crushers in the mining and aggregate production industries are of the jaw type. Jaw crushers can be categorized into three. These are: Blake, Dodge and Universal jaw crushers. They are classified according to the location of the pivot point of the swinging jaw, as shown in Figure 1 [2].

A jaw crusher consists of a fixed jaw and a swing jaw. The swing jaw, which is inclined at an acute angle to the vertically fixed jaw, swings with the help of a pitman mechanism that is mounted on an eccentric shaft. The inertia force for crushing the material is provided by two heavy flywheels mounted at both sides of the eccentric shaft. The opening between the fixed and the moving jaws (the crushing chamber) tapers vertically downwards, thus gradually reducing the size of rock as is moves down through the crushing chamber.

The Blake jaw crusher was originally designed by Eli Whitney Blake in 1857 [3]. The Blake jaw crushers are of two types: double toggle Blake and single toggle Blake as shown in Figure 2. The double toggle machine, though robust and power consuming, can crush very hard rocks without abrasive wear. This is because its mechanism of operation is such that there is no rubbing action between the surface of the jaw liner and the material being crushed. The single toggle machine which is a later development of the double toggle, on the other hand, though very compact in design and power efficient has a very short jaw liner life, especially when used for hard and abrasive materials[4].

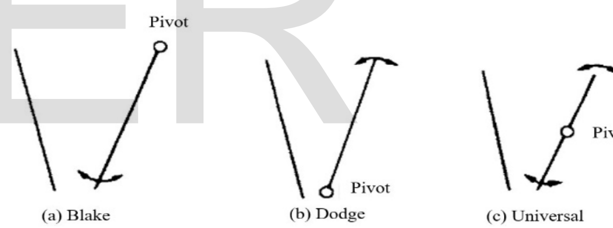

Figure 1: Classification of jaw crushers [2]

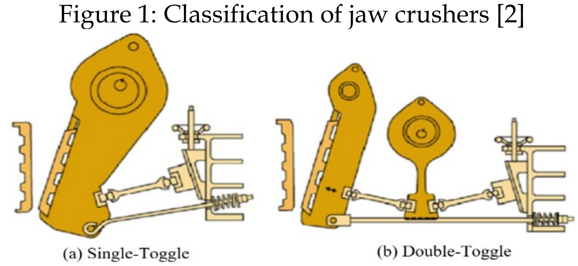

Figure 2: Two types of Blake jaw crushers [5]

The general service life of a typical jaw liner has been estimated to be three months[6]. The high wear rate of the liner is due to the kinematic characteristic of the liner, which generate a rubbing action between the jaw liner and the crushed material at the crushing interface domain [7]. Figure 3 compares the crushing action of the single and the double toggle Blake jaw crushers.

The single toggle jaw crusher has some special main features as illustrated in Figure 4. This type of jawcrusher pro-

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vides compression forces to break rock particles. Under the action of the eccentric shaft and the toggle, very powerful compressive forces are generated. To break a particle, the crushing forces (compressive) must be high enough to exceed the fracture strength of the particle. When a particle is nipped between the plates of a jaw crusher, tensile stresses are induced in the particle. Thus, the compressive force applied by the jaw plates causes the rock particle to fail in tension, as shown in Figure 5 [2].

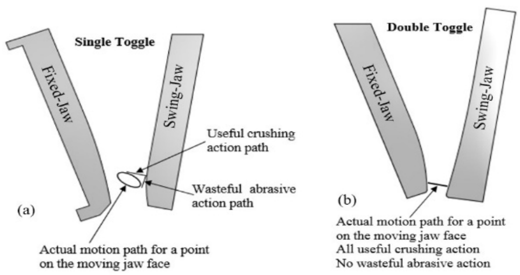


Figure 3: Crushing actions [4]

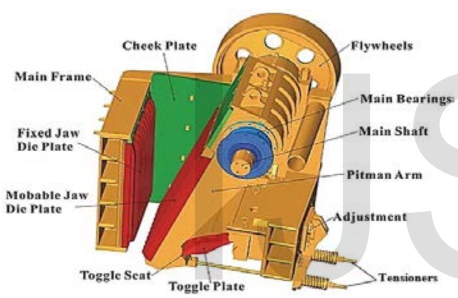


Figure 4: Single toggle jaw crusher [8]

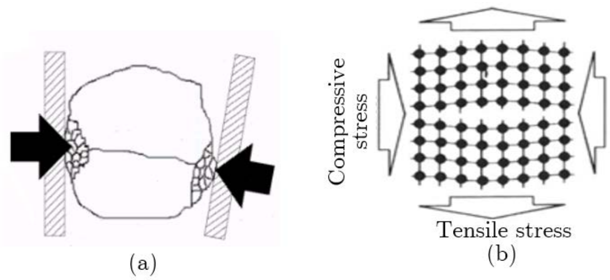


Figure 5: Fracture of rock particle under jaw-liner loading[2]

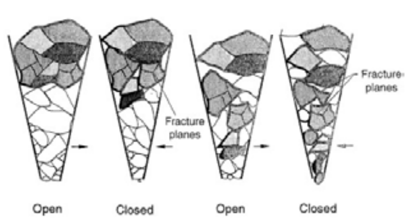


Figure 6: Breakage classification in a jaw crusher [9]

After a particle is nipped and fails in tension, the resulting fragments drop down to new positions within the crushing chamber before being nipped again. Particles continue to drop down and are either repeatedly nipped by the jaws or pass through the discharge opening (when small enough). This is referred to as arrested crushing, where crushing is done by the jaws only. The increasing stroke of the swing jaw at the discharge end allows material to leave at a rate higher enough to leave space for the particles above, preventing choking of the crusher. Since particles smaller than the discharge opening are free to pass through the crushing chamber at any time, the breakage process within the crusher operates simultaneously with a classification process, as illustrated by Figure 6 [9]. It is the crushing process that causes the wear of the jaw liners.

2 Types of Jaw Liner Profiles

The profiles of crushing plates of a jaw crusher and the comminution processes are closely related. This is because, the jaw liners interact directly with the crushed material during the crushing process. That notwithstanding, problems surrounding crushing plate design about wear have been neglected by designers [10]. The working surface and shape of the crushing plates have remained unchanged since compression type crushers were introduced into the comminution industry [10].

The three different types of cross-section profiles of jaw plates: flat, ribbed and corrugated, as shown in Figure 7, are most frequently used. The applicability of these three profiles depends on the material being crushed [10]. With flat profiles going for very hard rocks (hardness greater than 7 on the Mohs' hardness scale), corrugated for medium hard (hardness between 5 and 7 on the Mohs' hardness scale), and ribbed for softer ones (hardness below 5 on the Mohs' hardness scale) [11].

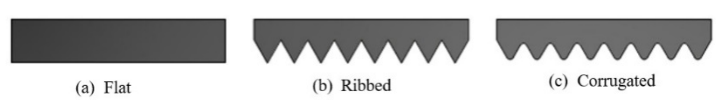


Figure 7: Jaw plate profiles [3]

3 Wear of Single Toggle Jaw Crusher Liners

A work published by Shyam[12] reveals that, the two main factors affecting the rapid wear of jaw plates include: squeezing and sliding. Manganese steel which is the dominating material in the manufacturing of jaw plates has an outstanding work hardening ability [13]. The high pressure generated through the squeezing action makes it harder. This increases the resistance of the liner to impact wear. After scanning worn jaw plates, the author observed that sliding is the main factor for jaw plates wear. This means that the work hardening ability of a manganese steel jaw liner cannot withstand sliding wear. Decreasing this sliding interaction between the jaw plates and the material can considerably increase the jaw plate life. Shyam[12]further observed that the wear in the inlet part of the crushing chamber was small, compared to the middle and exit sections. The author established that, since fewer particles are crushed in the edge parts of the jaw liners, the wear of the middle parts in the same crushing zone is more serious compared to the edge parts. It was also noted that for a typical jaw crusher, the sliding distance between the crushed particles and the fixed jaw liner is more than that between the crushed particles and the moving jaw liner, so the wear of the fixed jaw liner is more serious, relative to that of the moving jaw liner. The author was able to critically evaluate the causes of rapid wear of the jaw plates, but failed to provide a solution to the wear problem associated with single toggle jaw crushers.

Lindqvist and Evertsson[14]used a small jaw crusher to study the wear of the crusher liners for different settings of the crusher. In this work, the authors measured the crushing forces and tracked the motion of the crusher along with the wear on the crusher. Their test results revealed that the wear mechanisms are different for the fixed and moving liner. The authors also established that the sliding wear in a single toggle jaw crusher was three to six times more than the wear that occurs due to squeezing. However, the authors failed to devise a solution to the wear problem.

According to Deepak [15], the key factor for jaw plate wear is the sliding motion between the moving/fixed jaw liner and the crushed particles. The author outlined that the horizontal and vertical velocity of the moving jaw are variable during the crushing process, and hence the forces on the particle (consequently the reaction on the jaw plates) are also variable in different stages within the crushing chamber.

4 Kinematics of the Swinging Jaw

To understand the occurrence of rapid wear of jaw plates in single toggle jaw crusher, it is important to know the kinematics of the crushing mechanism of the crusher. Unlike the double toggle crusher in which the swing jaw only oscillates to transmit the crushing force, the swing jaw of a single toggle crusher oscillates and translates at the same time during operation.

Deepak [15] and Jinxi et al. [7] analyzed the kinematics of the swing jaw of the single toggle jaw crusher by considering the mechanism of the swing jaw as a four-bar link mechanism, as shown in Figure 8. Link AB is the crank, OA is the frame or fixed link, OC is the toggle link, and BC is the follower link. From the diagram shown in Figure 8, an expression was derived for the horizontal and vertical displacements of a point located on the swing jaw link (BC) given that crank AB rotates in the clockwise direction, and the position of any point in dynamic coordinate UCV is (u, v), and in global coordinates XOY is (x, y), as shown in Equations 1 and 2 respectively [15, 7].

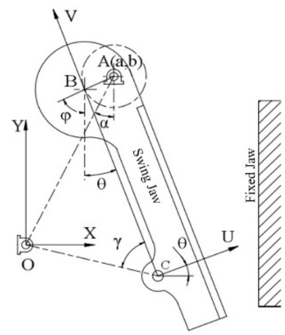


Figure 8: Swing jaw mechanism [7]

$$x = a - r\sin\phi + (l - v)\sin\theta + u\cos\theta \quad (1)$$

$$y = b - r\cos\phi - (l - v)\cos\theta + u\sin\theta \quad (2)$$

where,

ϕ is the crank angle measured clockwise from the negative Y -axis,
θ is the angle between the fixed and swing plates ≤ 90◦,
r is the length of crank link (AB) [mm],
l is the length of swing jaw link (BC) [mm],
a is the horizontal distance between origin (O) and center (A) [mm],
b is the vertical distance between origin (O) and center (A) [mm].

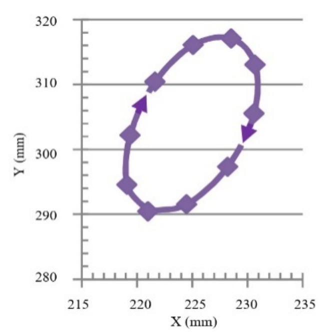


Figure 9: Motion path of a point on the swing jaw [7]

By analyzing the locus of some points on the swing jaw, it was revealed that every point on the swing jaw describes an elliptical path as shown in Figure 9, in one complete revolution [7]. This path consisted of vertical and horizontal displacements. It can be noted that this elliptical motion of the swing jaw is what produces the rubbing action between the jaw liners and the crushed material, hence the rapid wear of the liners [16]. It was established by Jinxi*et al.*[7] that, in the liner domain, a distance in the V-direction decreaseswith a decrease in U-component, which relieve the wear of the liner. Optimizing the surface contour of the jaw liners will therefore bring a relieve to the abrasive wear.

5 Energy Consumption in Jaw Crushers

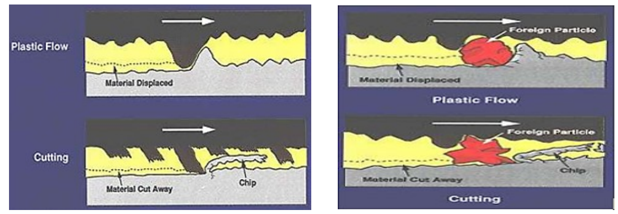
The comminution process in general, remains inherently inefficient, since 85% of the energy used is dissipated as heat, 12% is attributed to mechanical losses, noise and other factors account for 2% and only 1% of the total energy input is used in size reduction of feed material [17].

More [18] worked on design and analysis of the swing jaw plate of a jaw crusher. The author outlined that the recent concern for energy consumption has led to the consideration of decreasing the weight (consequently the stiffness) of the swing plate of jaw crushers to match the strength of the rock being crushed. In this work, the author employed point load deformability and failure relationship of the crushed material to calculate the jaw plate stresses, and consequently investigated the energy saving characteristic of the plate-rock interaction. Computer Aided Three-dimensional Interactive Application (CATIA) and Analysis System (ANSYS) software were employed by the author to analyze jaw liner models without stiffeners, and those with stiffeners. It was concluded that the stiffened plate models led to the reduction in plate weight which enhanced the efficiency of the jaw crusher. The author also observed that an increase in the number of stiffeners increases the strength-to-weight ratio of the jaw plates. It was finally estimated that stiffened jaw plates can lead to the saving of 35% in energy. The author however, failed to consider the wear aspect of the liner, since that also contributes to the high energy consumption in the single toggle jaw crusher [19].

6 Wear Modeling and Prediction

Wear is defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and contacting substance or substances [20]. Wear of materials is the result of many mechanical, physical and chemical phenomena. The main types of wear mechanisms observed in practical situations include: abrasive, adhesive, fatigue, fretting, erosion, oxidation and corrosion wear [21]. Wear of solid materials is usually treated as a mechanical process. Abrasive wear is the most important mechanical wear mechanisms from the technological point of view. It has been estimated that 80-90% of the total wear of machine elements is abrasive [21].

Abrasive wear is defined as wear due to hard particles or hard protuberances forced against and moving along a solid surface [22]. The abrasive wear process can be divided into two groups: two-body and three-body abrasive wear [20]. The two-body abrasion is caused by the sliding of a surface with hard protuberances on another surface. In three-body abrasion, particles are trapped between two solid surfaces but are free to roll as well as slide. The three-body abrasive wear is evidently the main cause of liner wear in the single toggle jaw crusher [12, 14, 23]. Schematics of these two types of abrasive wear mechanisms are illustrated in Figure 10.



(a) Two-body (b) Three-body

Figure 10: Schematics of two-body and three-body abrasive wear mechanisms [24]

A model for abrasive wear prediction was suggested byArchard[25]. This model assumed that wear is proportional to contact pressure and sliding distance as shown in Equation 3.

$$W = K\frac{Ps}{H} \tag{3}$$

where,

W is the wear increment [mm3/Nm],
P is the contact pressure [N/m2],
s is the sliding distance [mm],
H is the hardness of the material [BHN],
K is the wear coefficient [constant].

However, Lindqvist and Evertsson[14] argued that wear can still be recorded in crushing operations where there is no microscopic sliding between the crushed material and the liners, though the presence of sliding yields more wear. The authors therefore deduced a modified form of the Archard equation by including a second term which involves pressure and wear coefficient shown in Equation 4.

$$W = \frac{1}{w_1}\int_0^t Pvdt + \frac{P}{w_2} \tag{4}$$

where,

W is the wear increment [mm],
P is the contact pressure [Nm−2],
v is the sliding velocity [ms−1],
w1,w2 are the wear resistance coefficients [constant],
t is the time [s].

From the foregoing research, it has been discovered that to reduce the sliding wear of the jaw liners, the sliding interaction between the jaw liners and the crushed material must be reduced. This can be achieved by designing liner with a new liner surface profile.

7 Conclusions

It was concluded that little has been done about the design of jaw liner profiles. As such, the researches have not been able to provide a substantial solution to the rapid abrasive wear of the jaw liners. Because the focus of the authors was not on solving the rapid abrasive wear problem. It has been established that the sliding interaction between the jaw liners and the material being crushed is what influences the rapid abrasive wear of the jaw liners. Also, the surface profile of the liners has a direct influence on the abrasive wear characteristics of the liners.

It was therefore recommended thatan optimized jaw liner surface profile should be designed to reduce the abrasive wear of the jaw liners, by decreasing the sliding interaction between the crushed-material and the jaw liners.

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