QUALITATIVE ANALYSIS OF THE SCREW LINER WEAR PREDICTION IN VERTICAL STIRRED MILLS BY THE DISCRETE ELEMENT METHOD

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ABSTRACT

Vertical stirred mills have been widely used in the regrinding process in mining operations for its efficiency over other conventional mills. Screw liner wear prediction in these regrinding operations is important for plant maintenance planning and for operational costs estimation. In this paper, a Metso Vertimill VTM-1500, located in an iron ore operation in Brazil, had its screws liners worn compared to the simulated screw liner worn by Discrete Element Method (DEM). The net power for different lifetime screw liner worn was estimated to understand the effect of the screw liner wear on the grinding efficiency. The results show that the simulated screw liner wear profile is similar to the industrial screw liner wear and this qualitative analysis can be used to help the maintenance planning team to forecast the liners lifetime.

KEY WORDS
Vertical stirred mill, Vertimill, Discrete Element Method, Liner, Wear.

1. Introduction

The vertical stirred mill is more efficient than the horizontal ball mill in regrinding applications (Mazzinghy, et al. 2015; Morrison et al. 2009; Rosa et al. 2014). The vertical stirred mills have a screw agitator centrally located in the mill chamber, which promotes the grinding action by stirring the media and circulating it throughout the mill (Morrison et al. 2009). The liner of the screw agitator is worn because of its contact with the ore and the balls. Screw liner wear predictions are important for planning plant maintenance and for estimating operational costs (Allen e Noriega 2011). One big disadvantage of the vertical stirred mill is the impossibility to inspect the screw liners without unloading the balls of the mill completely, this procedure normally consuming time and effort of the operational team. One way to estimate this screw liner wear is monitoring the power draw of the mills and another tool that could be used is DEM simulations to estimate the liner wearing (Esteves et al. 2018).

The present work shows a comparison of the screw liner worn from an industrial operation with Vertimill Metso's model VTM-1500, an iron ore operation in Brazil, to the estimated screw liner worn by a Discrete Element Method (DEM) carried out using ROCKY software.

2. Discrete Element Method (DEM)

Cundall e Strack (1979) were the first to detail all the steps necessary to describe mathematically the contacts between particles to show arrangements and particulate systems behaviors. Each particle is represented in three dimensions and is governed by mass, the radius and the moment of inertia. The normal and shear forces (tangential) according to Newton's second law can be described by the contact between particles elements.

The discrete element method is being used in many industries including mineral processing, cement, food processing, pigments and pharmaceuticals (Cleary et al. 2008). In mineral processing, the grinding charge motion was the firstly described by Mishra e Rajamani (1992, 1994). Many contributions using DEM were made to the science of comminution (Weerasekara et al. 2013). Vertical stirred mills was described in terms of its energetic performance by Sinnott, et al. (2006), the charge motion and collisional structure were described by Cleary, et al. (2006) and the media shape and properties by Sinnott (2011a). The inclusion of hydrodynamic effects of the slurry is presented by Sinnott (2011b) and Cleary (2015) using the Smoothed Particle Hydrodynamics (SPH) (Hoover 2006). Modeling multiphase in mineral processing systems continues being a big challenge (Neethling and Barker 2016; Neethling 2017)

3. Methodology

The screws liners worn considering different operation lifetime was compared to the estimated screw liner worn by DEM simulations using the Rocky software.

In order to reduce the simulation time and computational effort, a 1/10th scaled down version of the 3-D geometry of the VTM-1500 was built using CAD tools. Figure 1 show the screw 3-D geometry of the 1/10 scaled down Vertimill VTM-1500.

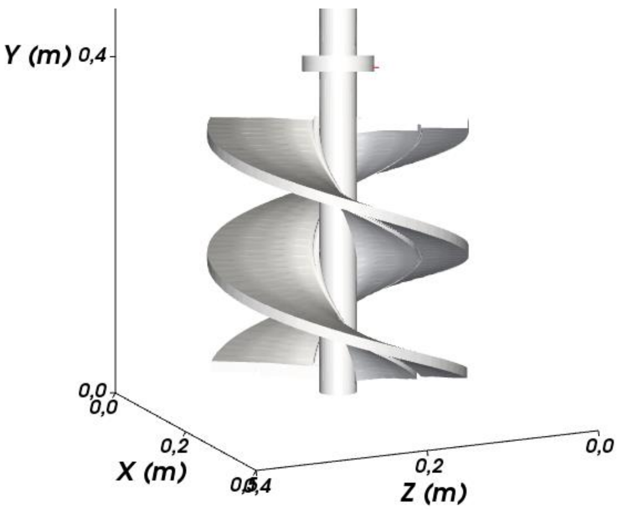

Figure 1 - Vertimill VTM-1500 screw 3-D geometry

Table 1 presents some parameters for the VTM-1500 and the simulated vertical stirred mill in 1/10 scale.

Table 1 - Dimensions and operation parameters of VTM-1500 and its scaled-down version considered in the DEM simulations

Mill	**VTM-1500**	**Scaled down (Simulated)**
Scale	1/1	1/10
Screw Diameter (mm)	3300	330
Rotation Speed (rpm)	19	190
Ball load (kg)	80000	80

The discrete element method simulations in this work were performed using ROCKY software considering only the steel balls as the charge in the DEM environment. This kind of approximation is normally considered valid (Tavares 2017).

The contact model used was Linear Hysteresis for Normal Forces and Elastic Coulomb for Tangential Forces (Rocky 2018). The Rolling Resistance Model used was the elastic-plastic spring-dashpot. A summary of the parameters used in the simulations is presented in Table 2.

Table 2 - Material and contact parameters used in the DEM simulations

Variable	Value
Young's Modulus (Pa)	$11x10^{11}$
Density (kg/m^3)	7850
Coefficient of Restitution	0.3
Coefficient of Static Friction	0.5

The value of the shear modulus was reduced to consider that the ore and slurry interactions make the contact between balls softer when compared to steel-steel contact (Steel: 200GPa).

The net power for different lifetime screw liner worn was also compared to understand the effect of the screw liner wear on the grinding efficiency.

4. Results and discussion

Figure 2 shows the balls velocities colored as a function of their kinetic energy in the vertical stirred mill. The grinding media charge on the left side of figure 2 shows the balls and the right side shows the streaming lines.

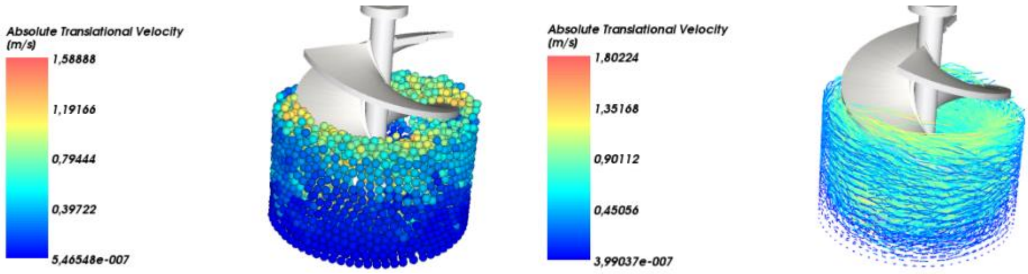

Figure 2 - Charge motion velocities

The simulations were carried out until 6 seconds and the screw liner worn are shown in Figure 3.

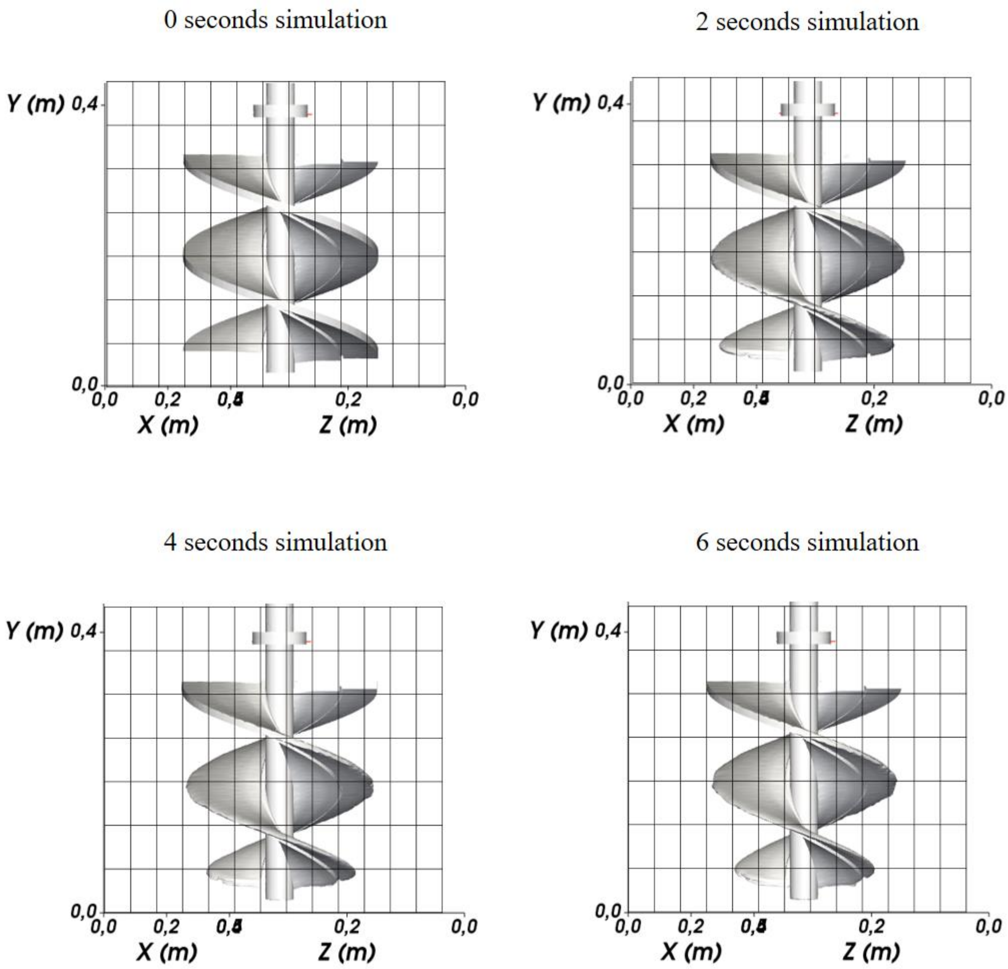

Figure 3 - Screw liner worn by DEM simulations

The screw on the left side of Figure 4 shows a liner with intensive wear and the right side shows a new liner in the bottom of the mill. This wear caused a great decrease in the bottom screw liner and so the grinding media accumulated at the bottom of the mill reducing the grinding performance. From the Figure 4 it is conclusive that liner wears trends to the external and bottom surfaces, as proposed by computational simulation (Esteves et al. 2017).

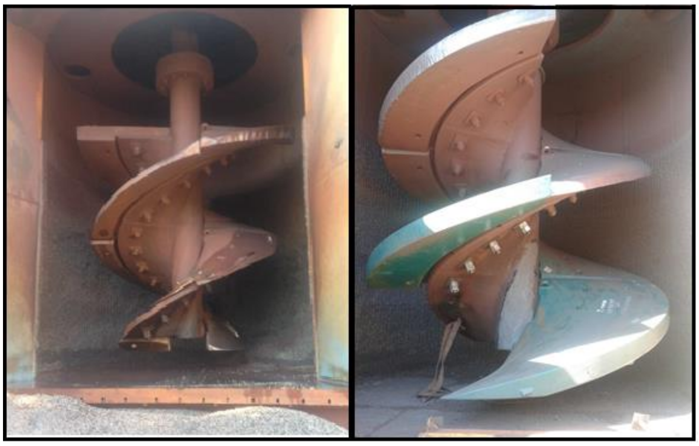

Figure 4 - Left: screw liner with intensive wear at the bottom. Right: new screw liner (Esteves et al., 2018).

Allen and Noriega (2011) show, using computational simulations, that shear power intensity is much more intensive not only outer in the screw, but also in the bottom of the mill. The industrial screw liner worn shows results that agree with Allen e Noriega (2011) founds.

Figure 5 presents the overlay of the laboratory 1/10 scale mill after simulated wear together with the VTM-1500 worn profile picture. It is possible to note that both screw profiles present similar format after wear. For both mills wear is intensive at the bottom and at the edge of the screw, such as described by literature and operational practice (Allen and Noriega 2011; Cleary et al. 2006; Esteves et al. 2017; Radziszewski and Moore 2016).

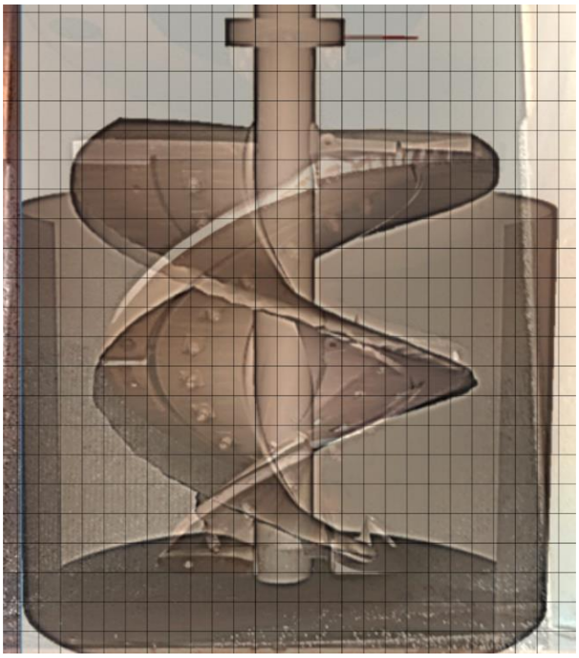

Figure 5 – Comparison between DEM simulation and a VTM-1500 liner worn

Figure 6 shows the net power obtained by DEM simulations. It is conclusive that power decreases with liner wear. It happens due to two reasons, firstly because of the total screw weight reduction and secondly because of the decrease in media motion due to the reduction of screw surface area. Total power reducing is around 63%.

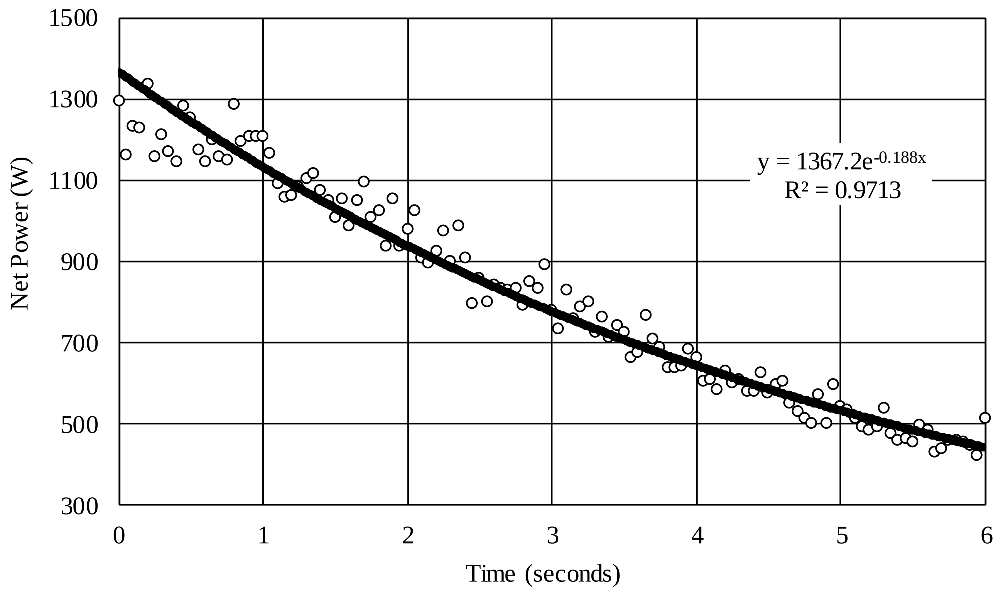

Figure 6 - Power estimated by DEM simulations

Figure 7 shows impact and shear energy obtained by DEM simulations during liner wear. It is possible to note that both impact and shear tends to reduce as the liner wears.

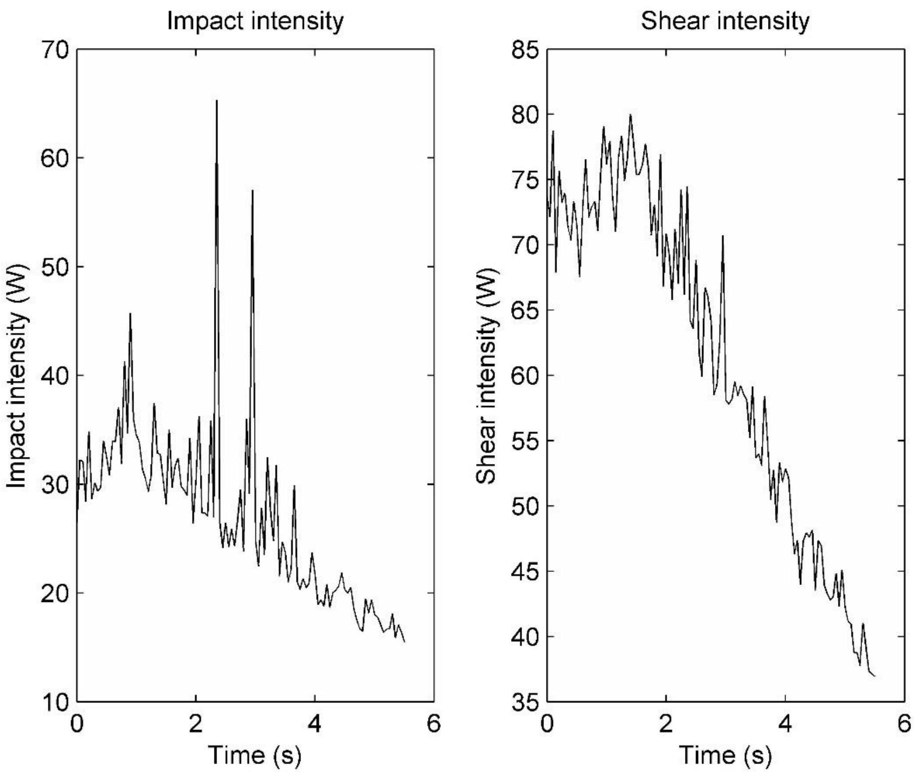

Figure 7 – Shear and impact energy estimated by DEM simulations

Once liner wear reduces breakage mechanisms it is possible to infer that grinding efficiency is also reduced and the liner becomes to wear slower as shown by Allen and Noriega (2011).

5. Conclusions

The results showed that it is possible to reproduce the screw liner wear by computational simulations and this tool can help the operational team to plan the maintenance to replace the liners worn and also can help to estimate the operational costs. The current work did not consider the slurry (fluid), so as a future study is recommended use CFD (Computational Fluid Dynamics) or SPH (Smoothed Particle Hydrodynamics) to describe the mill charge in detail.

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