CHARGE AND STRUCTURE BEHAVIOUR IN A TUMBLING MILL

Pär Jonsén¹, Bertil I. Pålsson², Kent Tano³, Andreas Berggren⁴

¹Division of Solid Mechanics, Luleå University of Technology, SE-97187 Luleå, Sweden
²Division of Mineral Processing, Luleå University of Technology, SE-97187 Luleå, Sweden
³Technology and Business Development, LKAB, SE-98381 Malmberget, Sweden
⁴Technology and Development, Boliden Minerals, SE-93681 Boliden, Sweden

The grinding process in tumbling mills is complex and to include all phenomena that occur in a single numerical model is today not possible. This paper presents the results of a study in which the deflection of a lifter bar in a pilot ball mill is measured by an embedded strain gauge sensor and compared to deflections predicted from finite element (FE) simulations. The flexible rubber lifter and the lining in a tumbling mill are modelled with the finite element method (FEM) and the grinding medium modelled with the distinct element method (DEM). The deflection profile obtained from DEM-FE simulation shows a reasonably good correspondence to pilot mill measurements. The approach presented here is a contribution to the validation of DEM-FE simulations and an introduction to the description of a bendable rubber lifter implemented in a DEM-FEM mill model. It opens up the possibility to predict contact forces for varying mill dimensions and liner combinations. FEM is especially valuable in this case, since there are readily available libraries with material models. This is a follow-up work to previous preliminary result from a mono-size ball charge interaction study.
INTRODUCTION

The behaviour of tumbling mills is complex and several parameters do significantly influence the effectiveness of the grinding operation. Many of these parameters are either difficult or laborious to measure. Understanding of the charge motion within the mill is of importance in mill optimisation. Both the breakage of ore particles, deformation of the lining and the wear of liners/ball media are closely linked to the charge motion. To study these phenomena in a physically correct manner, suitable numerical models for the different parts of the mill system is required.

To model charge motion and its interaction with the lining, the grinding balls are modelled with DEM and the mill structure modelled with FEM. All parts of the mill system will affect its response and a DEM-FEM model gives the opportunity to study the influence of the mill structure. The validation of this task is done by comparing numerical results with experimental measurements from pilot grinding with an instrumented rubber lifter. This work is a continuation of previous preliminary work on DEM-FEM modelling of tumbling milling processes, see Jonsén et al. [1].

EXPERIMENTAL SETUP

The pilot mill is 1.414 m in diameter and 1.22 m in length. It is a grate-discharge mill, equipped with 12 rubber lifters of square size 0.1 m and a face angle of 45 degrees. Steel balls with a diameter ranging between 10-30 mm and a density of 7800 kg/m³ were used in the experimental tests. The test material, a hematite pellet feed with d50 around 35µm and a solids density of 5200 kg/m³, was chosen to obtain stable grinding conditions with respect to feed size variations. Feed rate was kept constant at approx. 1.5 tonne/h.

One of the lifters has a strain gauge mounted on the leaf spring that converts this deflection to an electric signal. The signal is then amplified, filtered and transmitted to a computer. The sensor system is marketed by Metso Minerals under the name Continuous Charge Measurement system (CCM). As the mill rotates and the lifter with the sensor dips into the charge, the force acting on the lifter increases, which in turn, causes a deflection.
MODELLING

The model of the mill is a combined DEM-FEM model; the charge consists of DEM particles and the mill structure is modelled with FEM. The mill structure consists of rubber lifter and liners and a mantel made of solid steel. For the elastic behaviour of the rubber a Blatz-Ko hyper-elastic model is used [2]. Experimental data for the rubber was provided by the supplier of the lining. The mill mantel is modelled as a rigid material. The original length of the mill is 1.22 m, however, in the model only a slice of 0.10 m is modelled. Fully integrated eight node solid elements with a reduced integration of the pressure part are used to model the structure.

![Fig 1](image_url)

Fig 1. In a. the non-graded charge with 20 mm diameter particles and in b. the graded charge with a diameter distribution of 15-25 mm.

A total number of 9401 solid elements are used to model the structure. The friction coefficients of the particle-particle contact was set to $\mu = 0.5$ and for the particle-wall contact to $\mu = 0.9$ based on values published by Rajamani [3]. For the contact between the particles and the structure a “nodes to surface” contact is used. A viscous damping of 60% is used in this contact based on the particle-particle bouncing collision behaviour observed in the current calculations. Be-
cause of the two-dimensional representation, the balls in the numerical mill are represented by rods rather than spheres. In this case, the disk thickness is set equal to the length of the pilot mill model, 0.1 meters. In order to mimic the mass and inertia of a string of charge balls rather than a solid rod, the density of the particles representing the charge was lowered accordingly. The consequence of this two-dimensional representation is that any single particle impacting the lifter within the two-dimensional model is actually simulating the simultaneous impact of a string of charge balls running the full length of the mill. Such simultaneous impact is not likely happening in reality and so this should be considered when interpreting deflection results from the 2D model.

![Graph showing displacement of the lifter during passage through the charge. Comparison between graded charge, non-graded charge calculations and measurements.](image)

**RESULTS**

In the numerical study the mill fill was $J = 25\%$ and speed $73\%$ of critical rotational speed. Two different ball charges are used in the study. One with a constant particle diameter of 20 mm and one with a particle diameter distribution from 15 to 25 mm, one third of each type, also called graded charge. In Fig 1 the two cases are shown at steady state. The graded charge tends, according to the simulation to
have more voids in the packing pattern of the particles and the toe angle is smaller.

Fig 3. A snapshot of the von Mises’ stress field for a part of the mill model during its passage through the charge.

To study the charge impact on the mill structure during the milling process one can study forces and deflections of a lifter in the system. To observe the forces that go through the system of liners a section plane is introduced in the liner behind the studied lifter. The structure will respond to deformation upon the incoming load from the charge. The deflection of the lifter is also analysed and compared to the experimental measurements, see Fig 2. These deformations will give rise to strains and stresses which are dependent on the material properties of the structure. A snapshot of the von Mises’ stress field for two lifters and the liner in between and during their passage in the charge is shown in Fig 3. This is one of the additional properties that are available from the FE-program.
CONCLUSION

The DEM-FEM model can predict the classical DEM results, but can also predict responses from the mill structure like, e.g., stress and strain. The model gives the opportunity to optimize the material selection of the mill structure. Critical response values for e.g. stress and strain can be identified during the milling process. Forces and mechanical waves in the mill structure can be found. The major difference between DEM only and DEM-FEM models is that the latter give a direct coupling between force, stress and displacement for the whole mill system.

To include the mill structure response in the numerical models gives more information regarding charge motion and results in better correlation between experimental measurements and numerical models.

ACKNOWLEDGMENTS

For financial support of the project ModPulp project number P341106-1 within Gruvforskningsprogrammet are Vinnova gratefully acknowledged.

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