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A coupled DEM and FEA analysis of bulk material flow on the bottom plate of excavator bucket

Excavators operate in hazardous mining environment are subjected to extreme load and complex wear mechanism. The main purpose of this work is to analyze the pressure and force distribution over the bottom plate of the excavator bucket, which basically experiences dry sliding wear due to flow of granular earth material. In this work a numerical model based on both discrete and finite element model has been proposed to analyze the pressure distribution, stress strain and deformation phenomenon in order to prevent/ reduce the equipment failure and maintenance cost.

Another important aspect of this numerical analysis is to compare the change in the pressure and force distribution on bottom plate both in the presence and absence of wear reduction bars. The results exhibit that the bottom plate having wear bars offers better resistance to the complex loading conditions that occur in mining environment.

Keywords: *Discrete element method, finite element method, excavator bucket, wear*

I. Introduction

Material removal from the surface due to abrasion follows two mechanisms i.e. two body abrasion and three body abrasion. When the abrasive grit or the harder particles remove the surface from opposite direction, two body abrasion occurs. Three body abrasion occurs when a third body trapped between two surface and causes material removal from both the surface [1]. In this work two body abrasion phenomena has been considered. It has been reported that consideration of the two body abrasion phenomena is the best suited method to simulate the wear mechanisms that occur in mining industry in laboratory condition [2].

In this paper a discrete element method (DEM) has been used to simulate the problem related to the flow of granular material over the bottom surface of excavator bucket. Initially an experimental set up was designed and explained in our previous work [3], in which we observed some changes in wear volume for the bucket having wear bar with respect to the bucket without any wear bar. Using the same experimental parameter as boundary condition the entire DEM analysis has been performed to simulate the pattern of contact pressure and compressive force over the bucket surface. The results obtained from DEM analysis are then imported into the finite element software to analyze the result.

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II. Methodology

According to the earlier works done experimentally through some prototype of excavator buckets, we have got some wear data on those bucket prototypes for different run time [3]. Now, the goal of this job is to analyze the pattern of total deformation, equivalent strain and von mises stress through numerical simulation under different condition. Here, a FEA and DEM coupling simulation have been carried out to predict the behaviour of the buckets due to the loading during rotation.

As excavator buckets in mines generally handles earth material, coal, ore etc. and which is nothing but bulk material, so it is chosen to model that bulk material handling through discrete element method. And to analyze the structural behaviour changes finite element analysis (FEA) has been used by importing the simulation data from DEM software.

A. Bucket modelling

A simple CAD software Pro-E has been utilized to model 2 types of bucket, one is with clean base plate and other with parallel projected bar in it (Figs.1 and 2). Geometry specifications are as per prototype used in the experiment mentioned earlier.

B. DEM model

The DEM numerical simulation was performed to investigate the interaction between the bucket and bulk material. A simplified contact model was developed to implement the DEM numerical simulation and we hypothesize that the test specimen is in rotational motion and the particles are stationary in a container like as our experimental set up.

Particles were modelled with the combination of sphere of

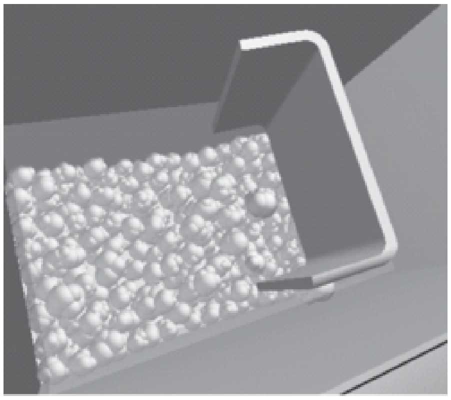

Fig.1 Bucket without wear bar

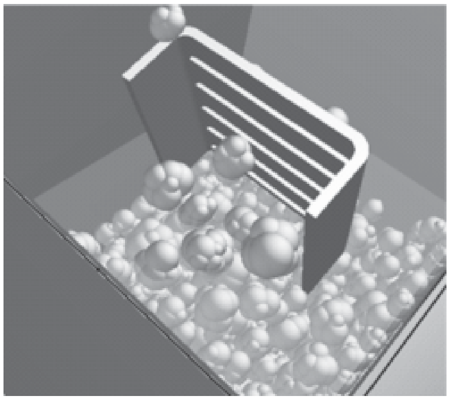

Fig.2 Bucket with wear bar

TABLE I: BOUNDARY CONDITIONS

Materials			
Component	Bucket	Particle	Container
Material	Structural steel	Granite	Structural steel
Material properties			
Properties	For steel	For granite	
Poisson ratio	0.3	0.25	
Shear modulus	79.3 GPa	26 GPa	
Density	7800 kg/m^3	2600 kg/m^3	
Work function	4.4 *ev*	0 *ev*	
Contact parameters			
Contacting material	Co-efficient of restitution	Co-efficient of static friction	Co-efficient of rolling friction
Steel - granite	0.2	0.5	0.2
Granite - granite	0.1	0.545	0.22
Bucket speed		30 rpm	

C. DEM SIMULATION

DEM simulation was carried out on two different types of bucket, in which one bucket have some wear bars welded on its surface and another bucket is without any bar. Simulations have been performed considering all other parameters and conditions as same for both the cases and at a certain interval of time during the loaded condition of bucket the average pressure data on buckets were exported for FEA analysis.

D. FEA SIMULATION THROUGH DEM COUPLING

For 3-D finite element modelling and analysis a commercial programme, ANSYS, was used to solve the problem and its structural changes were observed. DEM exported pressure data was imported in ANSYS with a coupling add-in and solved by keeping side edge of the buckets as fixed. Although the bucket geometry was simplified, care is taken to ensure smooth contact pressure variations by dividing the contact surface in to fine triangular finite element mesh. This result indicates how stress and strain will be induced in 2 types of bucket geometry if it is loaded with bulk material.

different radius at different orientation. The properties and parameters of the components used in this model are given in Table 1.

In the given boundary conditions the value of coefficient of static and rolling friction, poison ratio, shear modulus and density has been taken from open literatures [4-7]. The work function is the minimum energy required for electrons to escape from the Fermi level inside a metal to a point just outside the metal [8]. In our simulation, the value of work function has been considered only for the bucket plate, as the work function is not a characteristic of a bulk material, so it is taken as zero, but rather a property of the surface of the material. Another important parameter of this simulation is coefficient of restitution (COR) and can be defined as the ratio of the rebound and incidence velocities of two impacting bodies (or small sphere) in normal direction [9]. Value of COR varies between 0 for perfectly plastic collision, to 1 for perfectly elastic collision [10]. In our simulation we have considered very less value of COR, as the bucket prototype digging inside the particle (Fig. 3) and the chances of particle rebound back is very less.

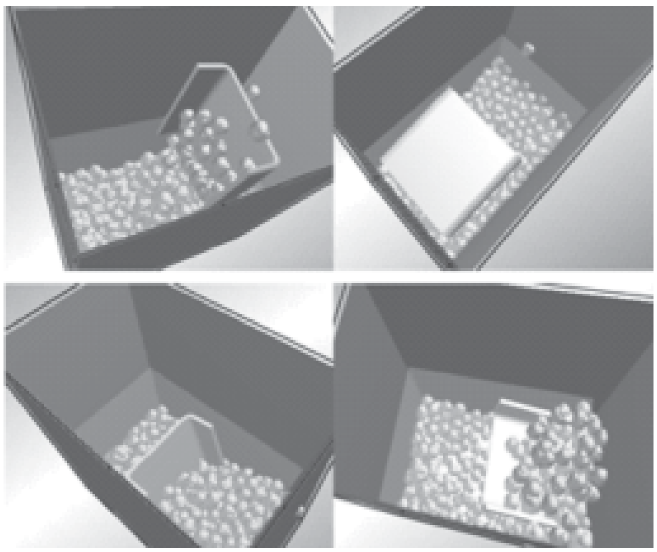

Fig.3 Bucket digging simulation

III. Result and discussion

It has been observed from the simulation results obtained for both the bucket plates, that application of wear bar on the surface has remarkable impact on the total deformation, von mises stress and equivalent elastic strain.

A. BUCKET WITH WEAR BAR

Fig.4 shows the simulation result of equivalent elastic strain. Result indicates that at the front end of the plate intensity of equivalent elastic strain is maximum. The value is higher at the two front extreme corner of the surface and minimum at the end of the plate. Maximum and minimum values with the proper indication has been shown in the simulated figures.

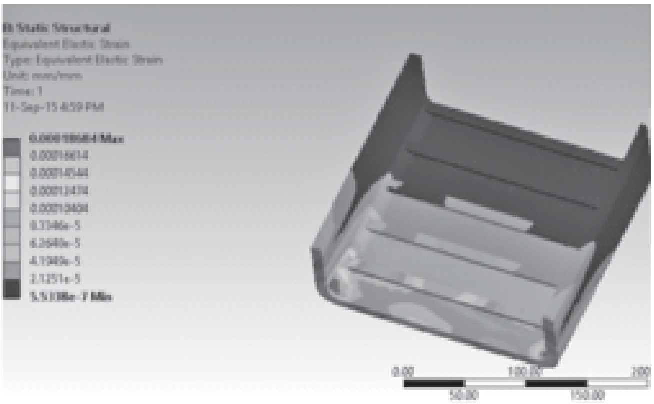

Fig.4 Equivalent elastic strain simulation

Similarly Fig.5 shows the simulation data for von mises stress. Result reflects the similar effect like the previous analysis with the proper values at respective areas.

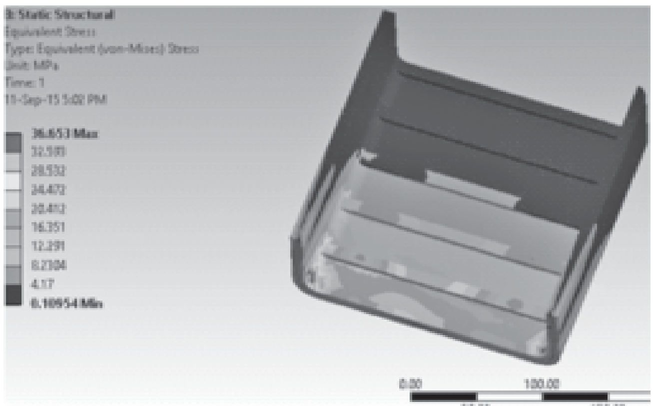

Fig.5 Von mises stress simulation

Fig.6 shows the pattern of deformation over the surface. Intensity of the deformation is higher at the front end as compared to the back end of the surface, where no deformation has been observed.

B. BUCKET WITHOUT WEAR BAR

Fig.7 shows the simulation result of equivalent elastic strain for the bucket surface without any wear bar. Result indicates that at the front end of the plate intensity of equivalent elastic strain in maximum as it was for the bucket surface having wear bar. In this case also the value is higher

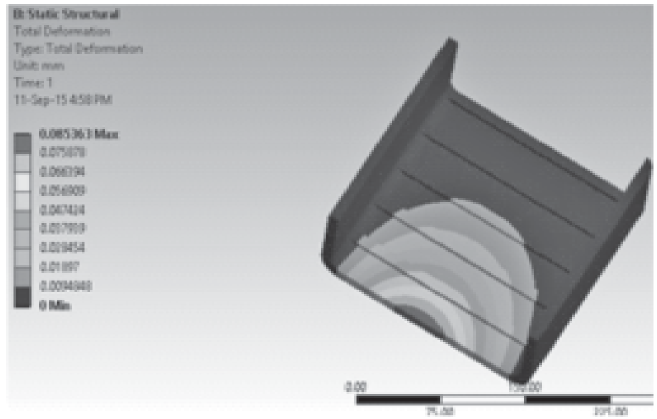

Fig.6 Total deformation simulation

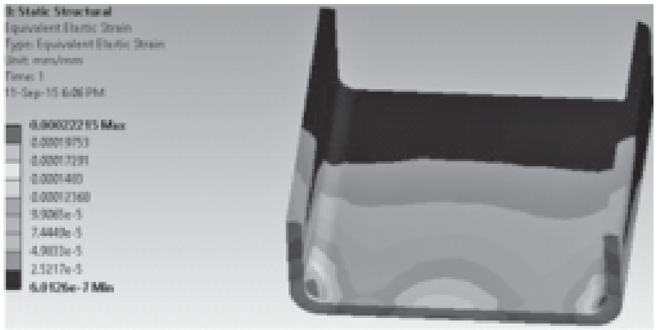

Fig.7 Equivalent elastic strain simulation

at the two front extreme corner of the surface and minimum at the end of the plate, but the values are higher in every position of the surface as compared to the bucket having wear bars. Maximum and minimum values with the proper indication has been shown in the simulated figures.

Similarly, Fig.8 shows the simulation data for von mises stress. Result reflects the similar effect like the previous analysis with the proper values at respective areas. From the Fig. 5 and Fig. 8 it is clear that the values of von mises stress is high as compared to the bucket with wear bar.

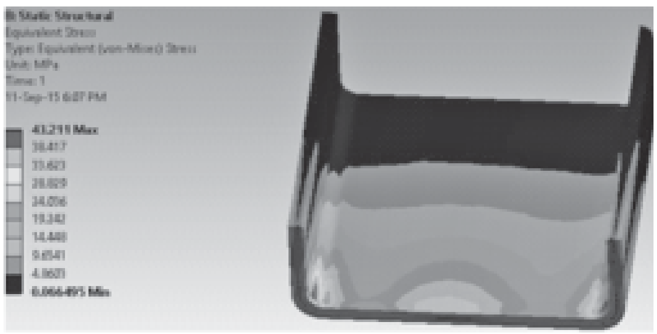

Fig.8 Von mises stress simulation

Fig.9 shows the pattern of total deformation over the surface. Intensity of the deformation is higher at the front end as compared to the back end of the surface, where no deformation has been observed, and the pattern is similar to the previous analysis. Like other result deformation values are also higher for the bucket having no wear bar as compared to the bucket having wear bars welded on its surface.

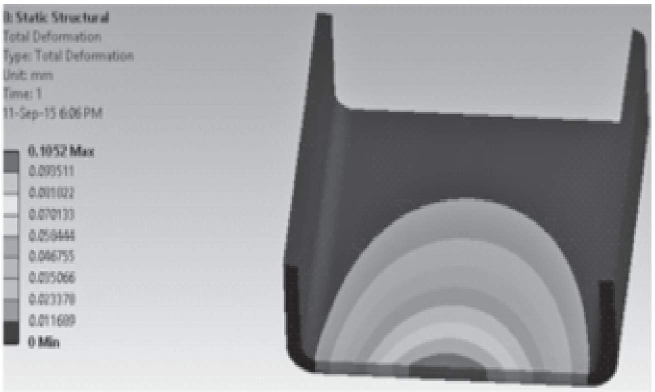

Fig.9 Total deformation simulation

IV. Conclusions

Above simulation results demonstrates the effect of wear bar on the strain, von mises stress and total deformation has been observed. From the entire analysis following conclusions have been made:

- The coupling of FEA with DEM is a good simulation process to model the interaction between continuous structure and bulk material. The entire simulation has been performed considering the actual experimental conditions.
- FEA results clearly shows that the bucket with the projected bar is capable of withstand higher pressure and load than the bucket with clean surface, with lower deformation. And it also adds a structural strength to the base of bucket geometry.
- Wear bar offers better resistance to the complex loading conditions that occur in mining environment.
- As the unprotected bucket surface is more vulnerable to loading conditions that occur in mining environment, thus more prone to breakdown and also a costly affair and serious concern about the equipment reliability.

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