Wear Model of an Excavator Bucket

Vladimir D. Sarychev[1,a)], Alexey Yu. Granovskii[1,b)], Sergey A. Nevskii[1,c)], Sergey V. Konovalov[1,2,d)], and Victor E. Gromov[1,e)]

[1] *Siberian State Industrial University, Novokuznetsk, 654007 Russia*
[2] *Samara National Research University, Samara, 443086 Russia*

[a)] sarychev_vd@mail.ru
[b)] nevskiy.sergei@yandex.ru
[c)] legatokun@gmail.com
[d)] Corresponding author: ksv@ssau.ru
[e)] gromov@physics.sibsiu.ru

Abstract. A mathematical model describing wear of the interior faces of the excavator bucket during the long-termed operation is proposed. The model is based on the Navier–Stocks equation and boundary conditions. The bucket was modeled as a rectangular parallelepiped; one of its faces is permeable for a granular material, whereas the others meet the conditions of impermeability and adhesion. In the approximation of viscous fluid, motion equations of a granular material in the excavator bucket were solved by the finite elements method. The velocity distribution curves of material particles along the bucket surface are obtained. A vortex structure is revealed at the bottom-back wall edge of the bucket, and it is thought to be the reason for high wear in these zones. As shown by the granular material pressure distributed along the bucket walls, its maximum is at the bottom-back wall edge of the excavator bucket. It is considered to be the reason for high wear in the operation process. Therefore, the bottom and back walls of the excavator bucket should be coated with a composite armouring mesh via arc surfacing.

INTRODUCTION

When operated in aggressive mining and geological conditions a bucket is subject to abrasion and impact wear [1]. To control these kinds of wear, a procedure of bucket plating with steel wear plates is currently used, which are highly resistant to wear and mechanical impacts [2].

The outer side walls of the excavator bucket are deteriorated mostly because of abrasion and impact wear of almost the whole surface area. The inner surface of the bottom back bucket receives impacts from rocks when the bucket is filled, being abraded due to uploading. The bucket bottom and inner surfaces of front and side walls also tend to abrasion. Taking into account sizes and capacity of modern buckets, appropriate wear-resistant plating can prolong maintenance intervals, making it possible to avoid unplanned downtimes of the excavator because of bucket repairing [2]. Some authors propose coating a wear plate with composite materials using flux-cored wire arc surfacing [3, 4]; this procedure offers a longer service life of wear plates and a possibility of repairing in field conditions. Wear intensity in real operational conditions is to be revealed for the scientifically grounded selection of a surfacing material. A prevailing damage type of coated parts is surface wear; in the case of relatively hard coatings, cohesion with the substrate can become deteriorated, resulting in their separation because of contact fatigue fracture [5]. For known stresses applied to the coating–substrate system, a stress-strain state can be determined in depth [6], thus identifying zones of contact fatigue fracture. Hence, it is important to know the distribution behavior of surface stresses arising due to the interaction of granular materials with bucket walls. Therefore, it is necessary to examine the character of rock movement in the bucket and distribution of stresses. To solve the above problem, a mathematical model based on concepts of granular material mechanics is required.

Proceedings of the International Conference on Advanced Materials with Hierarchical Structure for New Technologies and Reliable Structures 2017 (AMHS'17)
AIP Conf. Proc. 1909, 020186-1–020186-4; https://doi.org/10.1063/1.5013867
Published by AIP Publishing. 978-0-7354-1601-7/$30.00

To date, granular material mechanics is a rapidly developing scientific discipline [7–12]. Applied problems of granular material mechanics are reviewed previously [7], and its connection with the theory of plasticity, rock mechanics, synergy, and other sciences is shown. The author supposes that a promising field of granular material mechanics is the investigation into the complex stress-strain state of these materials [7], which might highlight new findings, e.g. a variant of non-Archimedean mathematical analysis, the main point of which is the scale hierarchy of temporal and spatial variables. Numerical studies of a granular material moving under vibration are carried out elsewhere [8]. It was found [8] that a convective current similar to Rayleigh–Bénard convection occurs in a granular material. Marinelli et al. [9] deal with the numerical data on compaction conducted with the help of a hydro-mechanical model outlined within the approach of numerical homogenization. This model features the two levels: a microscopic one where a material microstructure is described as a conglomerate of hyperelastic particles held by interfaces and a macroscopic one considering a material as a continuous medium where equations are stated using numerical homogenization into microscopic problems. Therefore, a total stress in a mixture, its density, mass flow of a fluid, and its mass share can be calculated. Schvab et al. [10] focused on the dynamics of highly concentrated free-pouring granular material in an upright mixing hopper. According to the investigation results, the proposed model can be recommended for describing the dynamics of highly concentrated flows of granular and grained materials in the inertial mode of movement as well as for simulating mixing processes or homogenized granular materials in powder technology machines. A micromechanical plasticity model of a porous granular material is proposed [11]; it is based on a new approach to the model of micromechanical friction strength for coherent granular materials. Tarantino et al. [12] examined the influence of hydrostatic pressure on deformation of composites by highly armoured particles. They pointed out that an external pressure contributes to the growth of yield stress. Consequently, the paper aims at the development of a flow model for granular materials, which takes into account the specifics of rock movement in the excavator bucket.

PROBLEM FORMULATION

We examine the behavior of a granular material in a moving bucket *ABDC* (Fig. 1). When the bucket is moving, there is an alteration of an angle $\alpha(t)$ between the gravity force and bucket bottom *AB*. We assume the bucket is stationary and will change a gravity direction:

$$\vec{F} = g\begin{pmatrix}\cos\alpha(t)\\ \sin\alpha(t)\end{pmatrix},\ \ \alpha(t) = -\frac{\pi}{2}t - \omega t, \tag{1}$$

where ω is the angular speed of the bucket rotation. To describe the flow of a granular fluid, we use the model of a viscous incompressible fluid [12]:

$$D_t\rho = 0,\ \ \rho D_t\vec{u} = -\nabla\rho + \mu\Delta\vec{u} + \vec{F}(t), \tag{2}$$

where ρ is the density, $\vec{u}$ is the velocity profile, $\vec{F}(t)$ is the vector of mass forces, $D_t = \partial/\partial t + \vec{u}\cdot\nabla$ is the substantial derivative. The *CD* line is open with a constant external pressure p_0, and the other lines of *ABCD* are with the boundary condition of adhesion. Numerical modeling was carried out using the Comsol Multiphysics package. The phase field method embodied in this package was used to follow the boundary between air and a granular fluid. The input parameters of the problem are $\omega = \pi/2\ s^{-1}$, $\rho = 2642\ kg/m^3$, and $\mu = 2\times10^{-5}$ Pa s.

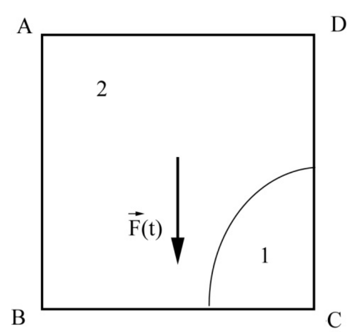

FIGURE 1. Computational scheme. *1*—granular material, *2*—air

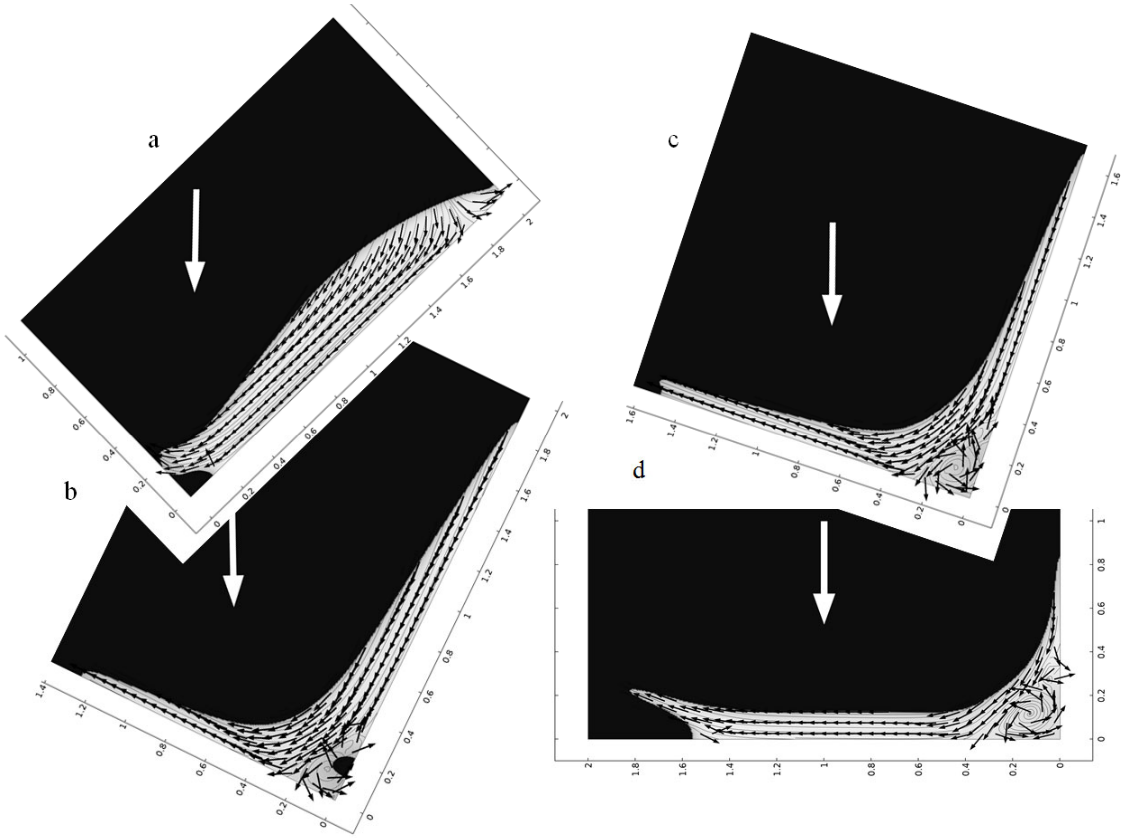

FIGURE 2. Granular fluid flow at various instants of time: 0.5 (a), 0.7 (b), 0.8 (c), and 1 s (d)

RESULTS AND DISCUSSION

Three stages can be distinguished in a moving granular fluid when the bucket is overturned. A granular material moves along the *BC* wall during the first stage, thus forming a jet (Fig. 2b), which hits bottom *AB*, as a result, a vortex occurs at the junction point *B* (Figs. 2b and 2c). These two structures (jet and vortex) provide the fundamentals to consider the flow behavior and wear specifics. Figure 3 demonstrates the curve of pressure arising at the moment of hitting. As seen, it is four times higher than a static pressure caused by this volume of a granular material. A granular fluid is spread along the bucket bottom *AB* (Fig. 2 b) with a lowered pressure during the last—third—stage. Therefore, peak stresses and vortex movement along *ABC* are the reasons for aggressive friction of a material against the bucket walls, thus resulting in their fast wear. The results of industrial experiments [3] pointed out that after 6 months of operation an armouring mesh is completely worn out in the zone of bucket pouring out, and further operation causes damage of wear plates. The most typical damage of these plates includes chipping and surface separation. These kinds of damage are possibly due to vortex flow of a material (Figs. 2b–2d) and high pressure of rock at the bucket bottom–back wall edge.

CONCLUSION

To sum up, this study revealed the behavior of a viscous material in a rectangular zone in the turning mode. When the granular material is overthrown, there was a jet and vortex detected, which have a significant influence on abrasion. The obtained curve of pressure along the bottom and back wall of the bucket is inhomogeneous. The maximum of this curve is at the junction point.

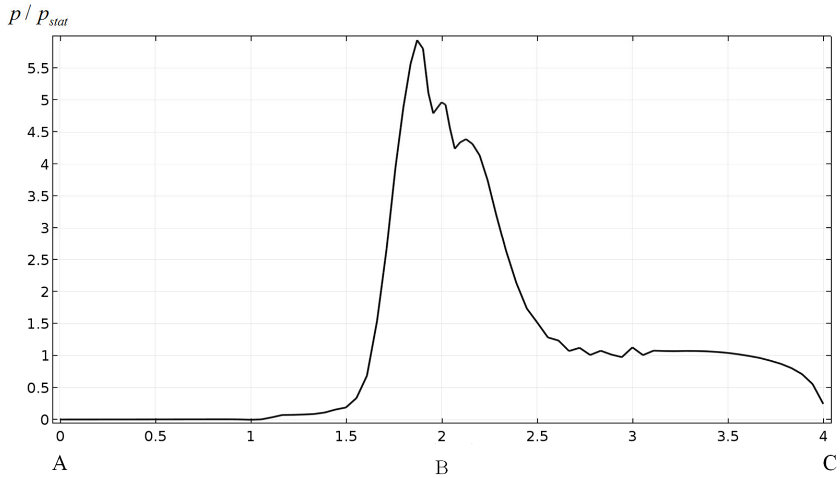

FIGURE 3. Granular fluid flow at various moments of time 0.5 (a), 0.7 (b), 0.8 (c), and 1 s (d)

ACKNOWLEDGMENTS

The work is performed at the financial support of the Russian Science Foundation (project No. 15-19-00065).

REFERENCES

1. C. Qiu, Y. Wang, L. Guo, and J. Liu, Adv. Mater. Res. **580**, 20–23 (2012).
2. B. Grnez, Gorn. Promyshl. 3, 34–39 (2008).
3. S. V. Raykov, Zagotov. Proizv. Mashinostr. 12, 10–13 (2014).
4. S. V. Konovalov, V. E. Kormyshev, V. E. Gromov, Y. F. Ivanov, E. V. Kapralov, and A. P. Semin, J. Surf. Investig. **10**, 1119–1124 (2016).
5. K. L. Dahm, E. Torskaya, I. Goryacheva, and P. A. Dearnley, Proc. Inst. Mech. E. Part J: Eng. Tribology **221**, 345–3353 (2007).
6. V. D. Sarychev, S. A. Nevskii, and V. E. Gromov, Mater. Phys. Mech. **22**, 119–128 (2015).
7. A. F. Revuzhenko, J. Mining Sci. **50**, 819–830 (2014).
8. L. A. Vaisberg, I. V. Demidov, and K. S. Ivanov, Obogasch. Rud. 4, 21–31 (2015).
9. F. Marinelli, A. P. Van den Eijnden, Y. Sieffert, R. Chambon, and F. Collin, Finite Elem. Analys. Design. **119**, 45–62 (2016).
10. A. V. Schvab, A. A. Martsenko, and M. S. Martsenko, Vestn. Tomsk State Univer. 4, 126–132 (2013).
11. F. Bignonnet, L. Dormieux, and D. Kondo, Int. J. Plasticity **79**, 259–274 (2016).
12. M. G. Tarantino, L. Weber, and A. Mortensen, Acta Mater. **117**, 345–355 (2016).