Numerical simulation of solid data carrier grinding process

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Abstract. In this article we consider a general approach and method to assess the solid data carrier destruction in a shredder using grinding rotors with teeth. Numerical simulation of the grinding process was carried out in the LS-DYNA by discrete element method and finite element method (FEM-DEM). Evaluation and comparison with a real grinding process was based on a phenomenological approach.

1. Introduction
One of the most effective means of physical destruction of various data carrier (paper, memory cards, CDs, etc.) is crushing and grinding them into small fractions in specialized shredders. Traditionally, engineering uses analytical methods [1], [7], [8], [10], [12], calculation of crushing parameters, calculation of kinematics and strength. The complexity and engineering time, as well as the required number of prototypes and full-scale tests to develop engineering to the performance goals, depends on the requirements and targets of the design. In turn, the use of digital design and digital twins methods [14], [15], which use numerical methods for evaluating the prototype design at an early stage, will reduce the time spent on engineering, optimization and testing and, therefore, will reduce financial costs. The purpose of this work is to develop and test a numerical modeling method of a grinding process of a solid data carrier (CD-disk) using crushing roller with cutting teeth installed in the prototype of shredder. Another goal of this work is to demonstrate the possibilities of combined application of the finite element and discrete element method for evaluating the grinding process of solid data carriers. The implementation of the virtual tests described in the work was carried out on the basis of the platform CML-BenchTM (digital platform for the development of digital twins and an activity management system in the field of digital design, mathematical modeling and computer engineering, development of the engineering center CEC SPbPU) using commercial licenses LS-DYNA and computational resources of CNTI.

2. Finite element model description
The shredder considered in this work belongs to the cascade type of rotary crushers [16] and has three rows of cutting rollers. The simulation was carried out for the second level of the rollers, which should provide data carrier grinding to a 2 mm fraction. The developed finite element model of the shredder contains the following:

a) Geometric (CAD) (Fig. 1) and finite element (CAE) plastic shredder block models (Fig. 2);

The object of finite element modeling is a plastic grinding block, as well as a sample of a 14 mm×14 mm polycarbonate CD disk with thickness of 1.2 mm, located directly between the cutting teeth of the
grinding block rotors (Fig. 3). Within this study three modifications of this finite element model have been developed:
- with cutting rotors made of absolutely hard material and an average element size of 3 mm (Fig. 2, a),
- with three rows of cutting teeth made of strain sensitive material and an average finite element size of 1.5 mm (Fig. 2, b),
- one of the rotors is modeled entirely, the second rotor is made in the form of three rows of cutting teeth, an ejector is added under one of the cutting rollers (Fig. 2, c). An average size of finite element on rollers is 1.5 mm. A strain sensitive material is used.
Configuration №1 of the finite element model was used to estimate the size of the produced fractions of the shredded object because of the longer calculation time. The main purpose of the grinding modeling in configurations №2 and №3 was to estimate the stress-strain rate of the rotors and ejector. To study the ejector operation, which cleans the space between the rows of rotor teeth, a set of “glued” CD fragments was created, simulating a disk fragment stuck in the space between the rows of teeth. For this CD fragment the friction coefficients were changed (up to $\mu = 0.7$), taking into account the sticking effect of fragments to the rotors, and an artificial obstacle was created to keep these fragments at the ejector.

b) Information about all connectors;
Bolted connection are modeled using absolutely rigid constraints, bearings - using absolutely rigid cylindrical joints.
c) The complete materials data required for the assigned task used in the models is shown in Table 1:

| Material          | $E$, MPa | $\nu$ | $\rho$, kg/m$^3$ | $\sigma_{0.2}$, MPa | $\sigma_{b}$, MPa |
|-------------------|----------|-------|------------------|----------------------|-------------------|
| HVG Steel         | $1.9 \times 10^5$ | 0.3   | 7850             | 445                  | 790               |
| Steel 45          | $2.0 \times 10^5$ | 0.3   | 7826             | 245                  | 470               |
| D16 aluminium     | $7.2 \times 10^4$ | 0.34  | 2800             | 360                  | 460               |

d) Operation mode data.
The rotation speed of the grinding and cutting rollers is 25 rpm.

Figure 1. CAD model of the shredding block.
3. Numerical simulation of shredding process

The study of the grinding process is a numerical simulation of the process of crushing a sample of a solid data carrier - a CD-disk. To simulate the destruction of a CD-disk sample the discrete element method was chosen which works in conjunction with the finite element method in the LS-DYNA. The discrete element method is the most optimal and convenient in the grinding process simulation, which is confirmed by numerous studies and tracking the size of fragmented particles.

The discrete element method is widely used in various industries and science for numerical modeling of soils [2], [9] and other flowing medium, crushing of rocks [3], and business process modeling [4]. The material settings [11] describing the CD sample, as well as the particle size are shown in Fig. 4. These parameters were optimized on the basis of numerous design estimates using a phenomenological approach.

Figure 2. FE-models of the shredding block shown in 3 configurations.

Figure 3. CD-disk specimen, containing discrete elements.

Figure 4. Discrete elements settings in LS-DYNA input file.
At the beginning, the CD sample is directly above the cutting teeth of the rollers. The cutting rollers have an initial rotation speed of 25 rpm, which corresponds to the operating mode of the shredder prototype (II.d). Thus, under the gravitation the CD sample falls under the cutting teeth and is shredded by rotors.

![Graphical Interpretation of the problem formulation.](image)

**Figure 5.** Graphical Interpretation of the problem formulation.

![FE-model of the shredding block, configuration №3.](image)

**Figure 6.** FE-model of the shredding block, configuration №3.

To carry out numerical modeling of the grinding process, an explicit integration method (Explicitdynamics) was used, presented in the finite element software package LS-DYNA.

**4. Results**

Within this study we estimated not only the nature of destruction and the size of the breakaway fragments of the CD-disk sample, but also the stress-strain state of crushing rotors teeth and the ejector. Fig. 7 and Fig. 8 shows storyboards of the destruction process of a CD-disk sample in three configurations of the finite element model.
Figure 7. Shredding process of CD-disk specimen, configuration №1.

Figure 8. Shredding process of CD-disk specimen, configuration №2.

Fig. 9 and Fig. 10 shows the fields of equivalent stresses in the teeth of crushing rotors and parts of the ejector arising during grinding.
5. Discussion
Numerical modeling of grinding showed that the size of the data carrier fragments after processing is 1.7–1.9 mm, which corresponds to the characteristics of the second level of grinding rotors. The maximum values of the equivalent stresses in the grinding rollers teeth are 10.4 MPa and they appear at the moment of direct interaction of the tooth with CD-disk sample, which were not yet grinded. (Fig. 9). The resulting stresses do not exceed the yield point of the tooth material (II.c), therefore, they are in the elastic deformation zone.

The maximum equivalent stresses arising in the part of the ejector do not exceed 0.5 MPa, which in turn also indicates the absence of plastic deformations. The maximum nodal deformations observed in the ejector are $4 \times 10^{-4}$ mm, which excludes the possibility of rotor jamming due to the contact of the teeth with the ejector comb.

The results of the study demonstrate the effectiveness of the application of the developed method and in particular the use of finite element and discrete element modeling of the grinding process. This approach makes it possible to effectively assess material grinding by measuring its size, number of fragments, stress fields and internal deformations of the working parts of the product. The implementation of this method in future will allow to reduce the design and testing time of products. In
comparison with scientific studies [5], [6], [13], which describe the application of a similar approach in the numerical modeling of the process of crushing rocks, this work considers the process of grinding samples of solid data carrier. This fact is the uniqueness of this study and its practical value. In this work the material of which the CD was made was not validated, and the process of fragment expansion after grinding was not analyzed due to the lack of some of initial data. What we also have to analyze in this work will be a full-sized validation of the mathematical model of the material (parameters of particles and their interaction with each other) of the shredded object, the transition to a single universal finite element model of the grinder, as well as the full simulation of the grinding process from the beginning till the end.

6. Conclusion

The developed method demonstrates the possibility of practical application in describing grinding processes of objects. Furthermore, using a verification process in order to get more realistic and valid model can improve the quality of overall development process.

References

[1] Austin L G and Klimpel R R 1964 The theory of grinding Industrial & Engineering Chemistry (56(11)) pp 18-29
[2] Asaf Z, Rubinstein D and Shmulevich I 2007 Determination of discrete element model parameters for soil tillage Soil & Tillage Research (92)
[3] Barrios Gabriel K P and Tavares L M 2016 A preliminary model of high pressure roll grinding using discrete element method and multi-body dynamics coupling International Journal of Mineral Processing
[4] Bing Du, Cangcai Zhai, Guojiang Dong and Jiang Bi 2017 FEM-DEM coupling analysis for solid granule medium forming new technology Journal of Materials Processing Technology
[5] Cleary P W and Sinnott M D 2014 Simulation of particle flows and breakage in crushers using DEM: part 1 – compression crushers Miner. Eng.
[6] Du Bing, Zhao Cangcai, Dong Guojiang and Bi Jiang 1961 FEM-DEM coupling analysis for solid granule medium forming new technology Journal of Materials Processing Technology
[7] Bond F C 1961 Crushing and Grinding Calculations Trans. Am. Inst. Min. Eng (Allis-Chalmers, Milwaukee, Wisc)
[8] Bond F C 1952 The Third theory of comminution Trans. Am. Inst. Min. Eng.
[9] Jiang M J, Yu H.-S and Harris D 2005 Discrete element modeling of deep penetration in granular soils International Journal for Numerical and Analytical Methods in Geomechanics
[10] Kick F 1883 Dinglers Polytech
[11] LS-DYNA® 2017 Keyword User's Manual (Volume I R10.0) p 2065
[12] Rittinger R P 1857 von, “Reprocessing science” (Berlin)
[13] Yu Nagata, Yuki Tsunazawa, Kouji Tsukada, Yuichi Yaguchi, Yosuke Ebisu, Kohei Mitsuhashi and Chiharu Tokoro 2020 Effect of the roll stud diameter in the capacity of a high-pressure grinding roll using the discrete element method Minerals Engineering
[14] Borovkov A I and Ryabov Y A 2019 Determining, development and application of digital twins: Approaches of Competence center of NTI SpBSTU New manufacturing technologies Digital substation (№12 (in Russian))
[15] Borovkov A I, Ryabov Y A, Kukushkin K V, Maruseva V M and Kulemin V Y 2018 Digital twins and digital transformation of military industrial enterprises Defence technics (in Russian)
[16] Borhsev V Ya 2004 Material grinding equipment: crushers and mills TGU (in Russian) p 75