

SIMULATION OF ROCK CUTTING WITH EVALUATION OF TOOL WEAR

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1. Introduction

High tool wear can be one of the main problems in rock cutting works [3]. Changes of tool geometry due to wear lead to difficulties in the tool penetration reducing thus cutting performance. Practical observations show that Different wear mechanisms can occur in rock cutting. Abrasive wear is one of the most important mechanisms in cutting of hard rocks especially in the presence of quartzite. Scraping of the rock surface leads to high temperatures, which softens the tool tip, resulting in increasing wear of adhesive character. Different wear mechanisms can act in parallel.

The main motivation of the research work presented in this paper is development of the numerical model increasing possibilities to predict abrasive and adhesive wear of rock cutting tools under different process conditions.

2. Numerical model of rock cutting with wear evaluation

In the approach adopted the wear is evaluated based on the simulation of rock cutting process. Evaluation of wear requires determination of forces of cutting as well as temperature distribution. This means necessity to analyse rock cutting as a thermo-mechanical process.

A numerical model of the tool-rock system allowing us to simulate a process of rock cutting has been developed within the framework of the discrete element method (DEM) [2]. In this model the tool is considered rigid and a rock material is represented as a collection of rigid spherical (in 3D) or cylindrical (in 2D) particles interacting among themselves with contact forces. The cohesive elastic perfectly brittle model is assumed for the contact interaction.

The translational and rotational motion of rigid spherical or cylindrical elements (particles) is governed by the standard equations of rigid body dynamics. For the i -th element we have

$$(1) \quad m_i \ddot{\mathbf{u}}_i = \mathbf{F}_i, \quad I_i \dot{\boldsymbol{\omega}}_i = \mathbf{M}_i,$$

where \mathbf{u} is the element centroid displacement in a fixed (inertial) coordinate frame \mathbf{X} , $\boldsymbol{\omega}$ – the angular velocity, m – the element mass, I – the moment of inertia, \mathbf{F} – the resultant force, and \mathbf{M} – the resultant moment about the central axes.

Thermal phenomena during rock cutting (heat absorption and conduction) are described by the heat balance equation, which for a single particle can be written in the following form:

$$(2) \quad m_i c \dot{T}_i = Q_i,$$

where: m_i – particle mass, c – specific heat, T_i – particle temperature, Q_i – heat flux.

Thermo-mechanical coupled problem defined by Eqs. (1) and (2) is solved using the staggered solution scheme. The two problems are coupled by heat generation process – heat generated by friction is evaluated in the solution of mechanical problem and passed to the solution of thermal problem.

The tool-rock interaction is modelled assuming Coulomb friction model extended on frictional heat generation and wear accumulation on the tool surface. Wear is considered using the classical formula of Archard [1]:

$$(3) \quad \dot{w} = k \frac{p_n v_T}{H},$$

where \dot{w} is the wear rate, p_n – the contact pressure, v_T – the slip velocity, H – the hardness of worn surface and k is a dimensionless wear parameter. The influence of temperature on wear is accounted for by taking the hardness as a function of temperature $H = H(T)$. The tool shape can be modified according to the accumulated wear obtained by integration of Eq. (3).

Values of wear constants k for different combinations of materials can be determined in laboratory tests. Wear is a relatively slow process and it can be observed after many work cycles. In the numerical algorithm developed wear is accelerated using scaled wear constants.

3. Numerical results

Simulation of rock cutting with one pick of a roadheader has been analysed using a model shown in Fig. 1a. Material sample is represented by an assembly of randomly compacted 92000 discs of radii 1–1.5 mm. Model parameters for sandstone have been determined for the discrete element model [2]. Thermomechanical analysis with wear evaluation has been carried out. Results of the analysis are shown in Figs. 1b-c. Failure of rock during cutting is shown in Fig. 1b. Temperature distribution in the tool and rock is shown in Fig. 1c, the highest temperature is observed in the contact zones, where the frictional heat is generated. The same area has maximum wear amounts as it is shown in Fig. 1d.

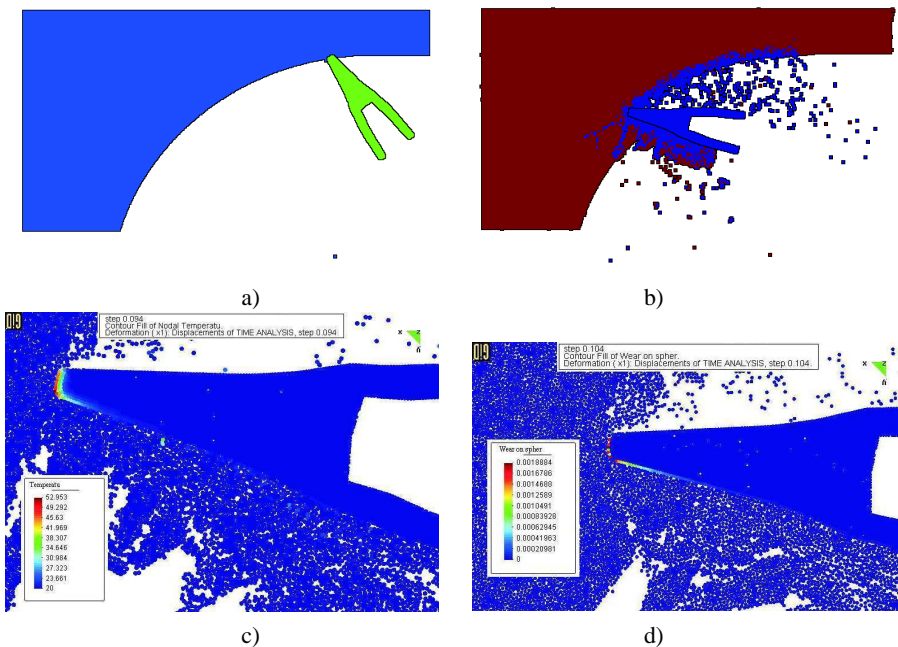


Figure 1. Simulation of rock cutting by a pick of a road header: a) numerical model, b) failure mode, c) map of temperature, d) accumulated wear on the tool surface

References

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