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Predicting the Rate of Penetration in Percussive Drilling by Finite Elements Simulation

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ABSTRACT

Percussive drilling is widely used drilling method, especially in hard rock formations, due to its efficiency in terms of rate of penetration (ROP). On the other hand, despite the considerable research effort devoted thus far, the fracture mechanisms in bit-rock interaction are not fully understood. In this method, an impact induced compressive stress wave forces hard metal inserts (bit buttons) in the drill bit to penetrate into the rock. The penetration results in material removal through direct fragmentation of the rock beneath the buttons and, more importantly, by the coalescence of the side cracks (lateral chips) induced by individual buttons. The debris and fragments are flushed away from the borehole during the action. The drill bit is also rotated between the impacts in order to improve the process (impacting the same spots many times would halt the penetration eventually). In the development and optimization of drill bits, sound understanding of these fracture mechanisms is crucial. In the present work, a finite elements based numerical code is employed in an attempt to predict the rate of penetration during percussive drilling with a typical multiple-button bit. In this method, the rock is described as a viscoplastic damaging material and the bit-rock interaction is modelled by contact mechanics approach while solving the system equations with explicit time marching. The stress states leading to material damage are indicated by a rate-dependent three-surface yield surface consisting of the Drucker-Prager criterion, Rankine criterion as a tensile cut-off, and a parabolic cap surface as a compression cut-off. Thus, porous rocks can also be modelled. Due to the high asymmetry of the rock behavior in tension and compression, separate scalar damage variables are defined to account for failure in tension and compression. Thereby, the material removal is indicated by critical values of these damage variables. A criterion to predict the ROP based on single impact is first developed. Then, multiple impacts while rotating the bit between the impacts (indexing) are simulated in order to demonstrate the validity of the single impact ROP prediction scheme.