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Experimental study on drilling of soft rocks

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Drilling is commonly occurring material deformation process in vast range of industries including manufacturing, mining, petroleum, infrastructure, biomedical etc. Due to its three-dimentional nature and multi-axial deformation of material, drilling is a very complex process involving severe plastic deformation of material, high strain and strain rates, volume change, tempretarure gradient etc. In addition to this, drilling in rocks becomes further more complicated due to additional complexity added by brittle fracture. Therefore, it becomes important to have a complete understanding of the process and the effect of drilling paramerets on the material response in order to make it more energy efficient and improve the productivity in industrial applications.

An attempt to understand the drilling in metals has been made by using a simplistic approach of decoupling the process into simpler process where, the penetration of the drill into the material and the rotatory motion has been correlated to indentation and cutting, respectively [1, 3, 8]. Similar framework has been adopted for rocks by many researchers where drill bits consist of many polycrystalline diamond compact cutters mounted on a tingesten carbide matrix [2, 5, 7]. In order to understand the interaction of these bits with rock, simplified models have been proposed for the cutters mounted on these bits [6]. This research work intends to understand the drilling mechanism experimentally by comparing drilling response (thrust force and torque) with the findings of intentation and cutting studies. Also, the force response (thrust and torque) were compared with the results obtained from the model.

Drilling experiments were performed on samples prepared using gypsum, which is an ideal model material for soft rocks [4, 9]. Sample porosity was controlled by controlling the water content during casting of the samples (46 mm x 46 mm x 20 mm). Twist drills with helix angle of 30^0 and 60^0 were used. The diameter of the drill (6 mm) was kept significantly smaller (~ 8 times) than the width of the sample. The tip angle was kept constant (120^0) for both the drills. The penetration rate was varied from 1 – 100 mm/min at constant rotation speed of 100 rpm. The penetration rate in combination with the rotation speed can be seen as depth of cut per revolution of the drill. The thrust force and torque were normalized with respect to the drill radius to compare the signatures with indentation [10, 11] and cutting [12] experiment results, respectively.

On comparing normalized thrust and torque signatures with indentation and cutting results, a remarkable similarity was observed. Figure 1 and 2 show normalized thrust and normalized torque, respectively, as a function of depth of cut per revolution (penetration rate/ rotation speed). Similar to indentation results, Fig.1a shows that the thrust force has a strong dependence on material porosity but remained independent of drill geometry (Fig. 1b). This indicated that the drill geometry (which is responsible for cutting the material) does not influence the indentation part (vertical penetration). In contrast to this, the normalized torque showed dependence on both, drill geometry and porosity (Fig. 2) which was evident from studies performed gypsum cutting [12]. Also, the torque signatures were remarkably similar to cutting forces and cyclic peaks were observed which indicated cyclic removal of the chips during cutting. The drilling results were compared with the theoretical model as well [6]. However, results corresponding to the 30^0 helix angle drill did not align with the model predintions. Suitable modifications in the model was suggested. Based on some preliminary experiments performed by imaging the drilling process, it was believed that there exists an optimum helix angle for which the model presdintions hold good.

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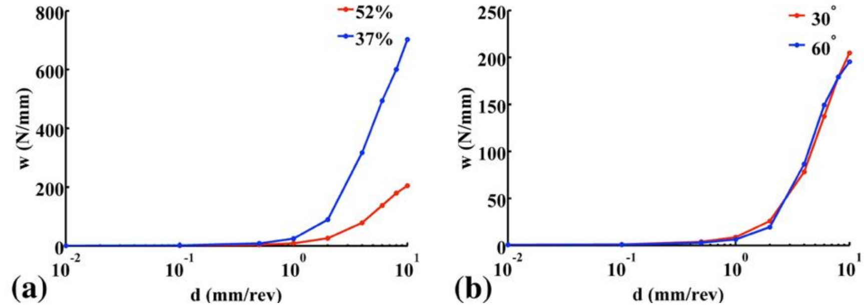

Figure 1: Normalized thrust vs depth of cut per revolution for (a) samples with 37% and 52% porosity and 30^0 helix drill, (b) samples with 52% porosity and 30^0 and 60^0 helix drill

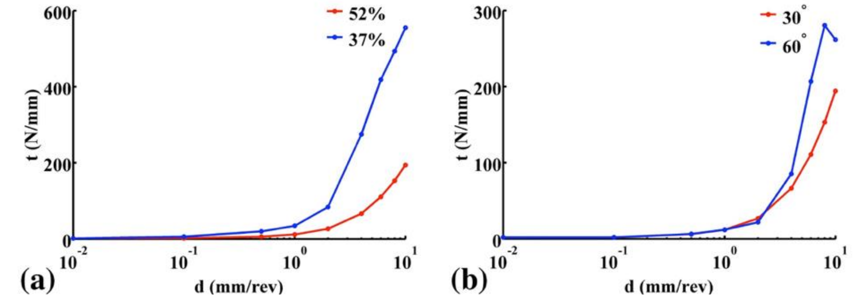

Figure 2: Normalized torque vs depth of cut per revolution for (a) samples with 37% and 52% porosity and 30^0 helix drill, (b) samples with 52% porosity and 30^0 and 60^0 helix drill

This study shows experimentally that drilling, which is a complex 3 dimentional process, can be studied by decoupling it into simpler 2 dimentional processes: cutting and indentation. The similarity between the experimental findings of cutting, indentation and drilling suggest that the findings of cutting and indentation studies can be clubbed together and can be used to understand drilling better.

Contributor statement

The first author was involved in planning and conducting the experiments, analysis and brainstorming the outcome of the analysed results.

The second author was involved in planning the experiments and brainstorming the outcome of the analysed results.

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