Development of an experimental device to simulate the drilling process of impregnated segments

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ABSTRACT

Impregnated diamond drilling bits are mainly dedicated to hard and very abrasive rocks. A research project, carried out in collaboration between the Mining Department (FPMs), Belgium and Security DBS (a Halliburton company, having a manufacturing plant located in Brussels, Belgium), intends to increase the performances of these specific drilling bits.
To reach the project objectives, we need to better understand the influence of technical parameters (segment composition, rock properties and drilling variables) on the cutting process.
A testing bench (based on a computer-driven facing lathe) has been developed to simulate drilling, by use of a fixed impregnated segment of 13 mm diameter cutting on rotating cylindrical rock samples of 200 mm diameter. Rate of penetration (from 10 to 100 µm/round), rotation speed (max 900 rpm) and length of tests are adjustable in order to obtain different drilling simulations and wear rates. A 3-component piezoelectric dynamometer measures the forces on the cutting tool. Preliminary tests in Granite and Porphyry present typical behaviours.

1 INTRODUCTION

Current application of impregnated diamond drill bits is limited primarily to operations in hard and abrasive rocks where conventional like PDC and roller cones bits achieve poor performance, show excessive wear and have short bit life.

As the name describes, the cutting face of these bits is composed of impregnated diamond segments that, because of their composition, create a self-sharpening effect in abrasive rock. Inside the diamond segments, diamond particles are evenly distributed and surrounded by a metal binder.
During drilling, the metal bond of the impregnated segments is gradually worn away, continually exposing fresh and sharp diamond particles. Under correct conditions, dependant upon the rock abrasiveness, this self-sharpening process allows the bit to maintain a constant aggressive cutting structure during drilling.

Practically, several parameters will intervene in the complex mechanisms between the rock and the impregnated segments, influencing the rate of penetration (ROP), both short- and long-term evolution, and bit life. These parameters may be categorised as follows:

- Technological Parameters: impregnated segment composition (bond composition, hardness, diamond size, quality and concentration)
- Technical Parameters: drilling parameters (thrust forces, rotational speed)
- Rock Properties: (composition, grain size, mechanical properties, abrasiveness).

Studying and understanding the interactions and relationships between these various parameters is fundamental to improving performance of impregnated drill bits, not only in terms of reducing drilling costs by delivering higher ROP and/or longer bit life, but also in identifying new potential applications for these bits.

2 GENERAL DEFINITIONS

Previous studies have made it possible to define relationships between the technical parameters when drilling with impregnated bits. Miller and Ball [(2)] performed an experimental study by coring in a Bushveld norite, and presented a model relating the bit pressure (weight on bit/active surface) with the diamonds wear mode and a drilling performance indicator.

To quantify the performance, they used the specific energy, defined as the work done per unit volume of rock excavated [(4)]. Each rock is characterised by the minimum energy needed to remove a given unit volume of rock, the "intrinsic specific energy". The difference between this minimum value and the energy measured during a drilling operation is representative of the technical efficiency of the drilling operation.

In the Miller and Ball model, the specific energy shows a minimum value of about 600 MPa to be synonymous with the most efficient drilling mode, corresponding to a critical bit pressure. At this pressure, all diamonds exposed indent the rock and the major wear mode is micro-fracturing. The calculated pressure applied per diamond is depending on rock properties and is in the range of the rock compressive strength (around 400 MPa).

At lower bit pressures, the specific energy increases (1.500 MPa), indicating a loss of efficiency. In this case, most diamonds exhibit wear flats. The specific energy also increases at upper bit pressures, and causes crushing of the diamonds as well as very fast wear.

Miller and Ball monitored drilling efficiency by calculating the specific energy, based on machine power consumption, corrected by machine energy losses and independent of generated torque.

In this study, drilling efficiency is determined by correlating the specific energy with forces actually applied on drilling bits. In this context, the specific energy is calculated as follows (4).

On a rotary drill, the specific energy is the sum of two terms: the first is related to the thrust, the second to rotation.

$$E = E_r + E_p \qquad (1)$$

Where:

$$E_r = \frac{2.\pi.T}{V} \qquad (2)$$

and $$E_p = \frac{F.\delta}{V} \qquad (3)$$

With E = Total specific energy [MPa]
E_r = Rotation specific energy [MPa]
E_p = Thrust specific energy [MPa]
T = Torque [N.mm]
F = Thrust Force [N]
δ = Depth of cut [mm]
V = Volume of drilled rock [mm^3]

These are the relationships used in this experimental study. The forces applied on the impregnated diamond segments during drilling provide critical information about the complex phenomena occurring at the rock/segment interface.

3 EXPERIMENTAL SET-UP

A conventional facing lathe was modified to study the rock cutting process of an impregnated diamond segment (cutter) in the laboratory.

Figure 1: the global experimental device

Using this device, a rock core is fixed on the lathe by its two ends, and rotation is transmitted through the chuck. Usually, cores measure 200mm diameter and 400mm long, but other dimensions can be used. In this simulation system, the rock rotates with respect to the impregnated diamond cutter. The range of rotation speed applicable on this device is from 0 to a maximum of 900 rpm.

The impregnated segments are cylindrical, with the following dimensions: 13mm diameter by 5mm thick. These cutters are composed of synthetic diamonds dispersed in a hardmetal-based bond. The typical size of the synthetic diamonds is between 100µm and 1 mm, and they account for up to 30% of the volume of the segments. When mounted on the device to simulate drilling, one face of the segment comes into contact with the rock, with the total segment face in contact with the rock.

The impregnated diamond cutter is fixed on a plate that can advance with axial or radial motion relative to the rock sample. The speed of advance of the plate is independent of the rotary speed of the rock core.

The forces applied on the cutter are measured by a 3-component piezoelectric sensor. Forces from –5000N to 5000N are measurable. Three charge amplifiers convert the sensor charge signals into an output voltage proportional to the forces sustained.

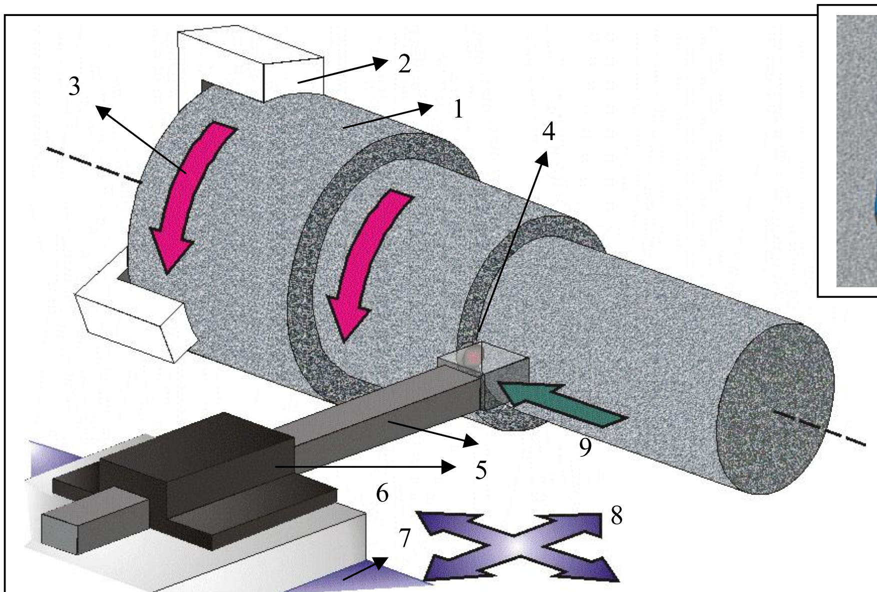
Finally, water is flushed for cuttings cleaning and segment cooling during the tests. The fluid charged with cuttings is then collected during the tests.

4 TEST PROCEDURE

During the cutting process, the cutter moves in the axial direction towards the chuck of the lathe at the selected speed. As the rotation speed and the rate of advance of the segment are constant during a test, the penetration per revolution (or depth of cut) also will be constant and is considered an imposed experimental parameter. The range of usable penetration per revolution is wide (from 10 to 100 µm/round), but practically, the experimental limit is imposed by the 3-component sensor. The maximum rate of penetration is related directly to the rock properties and the cutter characteristics.

On the usual rock core of 400mm length, two passes of 250mm length can be drilled from the outer diameter. Therefore, a total volume of 3823.2 cm^3 can be drilled on each sample, allowing significant wear of the segment for further observations.

The tests are computer-driven, with rate of advance controlled by monitoring the cutter position using an LVDT transducer for the radial displacement, and a potentiometer for the axial displacement.



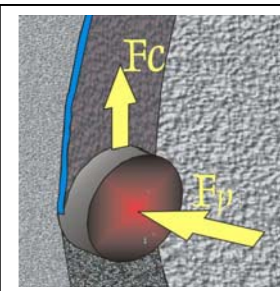


Figure 3 : Zoom on the cutting zone

Figure 2 : Experimental scheme :
1 : Rock sample - 2 : Lathe chuck -3 : rotation movement - 4 : Impregnated segment
5 : Fixation system - 6 : Piezoelectric sensor - 7 : Mobile plate - 8 : Plate Movements directions
9 : Drilling direction

Preliminary tests have been conducted to define a standard test procedure in order to study the influence of segment composition, rock property and applied technical parameters on the cutting process, the tool performance and lifetime.

The first tests were performed with a standard impregnated composition in two different rock lithologies: Lessines Porphyry (Belgium) and Tarn Granite (France).

The Lessines Porphyry is a quartziferous dacite containing mainly feldspar and plagioclases (45%), quartz (10%) micro-crystalline cement made of feldspar, plagioclases and quartz (50% of the cement). The Tarn Granite is composed mostly of quartz under mono-crystalline and micro-fractured structure (40%), feldspar (50%), biotite and muscovite.

Some mechanical properties of these rocks are presented in the table below:

	Lessines Porphyry	Tarn Granite
UCS (MPa)	132	118 ± 23
UTS (MPa)	9.8	9.8 ± 1.7
Rp (Mpa)	7973 +- 1531	7736.11 ± 1447.88
Abrasiveness (FPMs)	156.32	304.06 ± 93.03
Shore Hardness	55.6 +- 9.5	69 ± 12

Table 1 : Mechanical properties of Lessines Porphyry and Tarn Granite

UCS: uniaxial compressive strength
UTS: uniaxial tensile strength
RP: punching strength (measured according to the Schreiner method)
Abrasiveness (FPMs): test developed at the Faculty of Engineering Mons (FPMs) to measure the abrasiveness of rocks by wearing a puncher with a flat end on the surface of the tested rock.
Shore hardness: rebound test as recommended by the ISRM

This mechanical characterisation, performed in the rock mechanics laboratory of the FPMs, shows that both rocks present similar values of compressive, punching and tensile strengths, which ranks both as hard rocks. The major difference is the abrasiveness, although both are considered to be abrasive rocks.

Two impregnated segments of the same composition were tested, under identical conditions. The following table presents the technical parameters imposed during these tests.

Preliminary tests technical parameters	
Rate of advance:	11.1 mm/min
Rotation speed:	560 rpm
Linear speed of the segment:	5750 mm/s
Rate of penetration per revolution:	20 µm
Length of the test:	20mm
Volume of rock drilled:	163.8 cm³

Table 2: Technical parameters of preliminary tests

Typical measured forces are represented on the following graphs. The evolution of the total specific energy versus the measured cutting and thrust forces are also plotted.

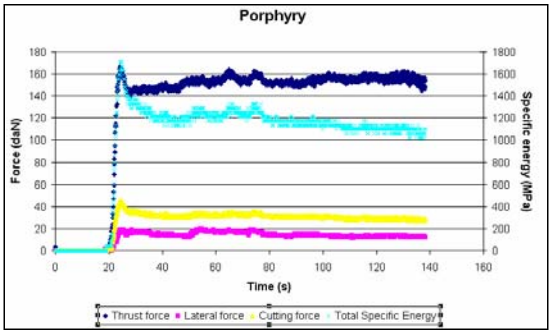


Figure 4: Drilling tests in Porphyry

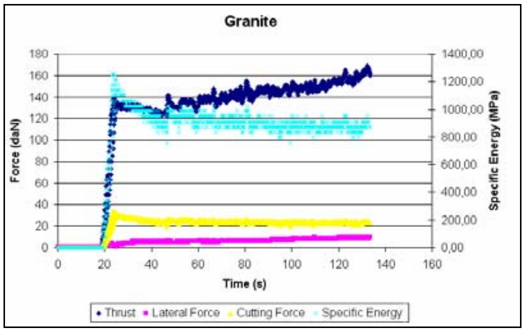


Figure 5: Drilling tests in Granite

Results of both tests exhibit the same range of magnitude. Specific energy of 1.100 MPa is reached in Porphyry, and 900 MPa in Granite. Because cutting surfaces are not pre-worn, the curves show a peak at the start of the tests for both rocks and the various parameters applied. However, the two rocks show different curve patterns, with porphyry rapidly reaching a steady state response, while granite thrust force increases slowly.

5 CONCLUSION

Improving performance of impregnated drilling bits requires a better understanding of fundamental mechanisms occurring at the interface between the rock and the cutter. The experimental device presented in this paper allows the study of the relationships between technical parameters, impregnated segments compositions, and rock properties, by simulating various drilling conditions.

The specific energy is calculated in order to quantify the cutting efficiency. As opposed to previous studies, the current experimental device allows calculation of the specific energy directly from the applied forces on the cutter, as during actual drilling operations.

A series of diamond impregnated composition segments will be tested and characterised, using various combinations of technical parameters (rate of penetration, thrust force) and rocks (UCS, cohesion, composition, abrasiveness). For each segment composition and rock type, the optimal cutting conditions will be defined.

The relationship between experimental conditions, measured forces evolution behaviour, and cutter wear characteristics will be investigated through microscopic analysis, and cutting models developed. In addition, current study observations and models will be used to develop and test new impregnated compositions, define optimal drilling parameters per composition-rock, and identify new potential applications for impregnated diamond drill bits.

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