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INVESTIGATION OF THE RELATION BETWEEN CORING PARAMETERS AND FORMATION REPRESENTATION

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ABSTRACT

Coring is an essential operation for subsurface formation evaluation. It is a key to recover cores from formation and have them unaltered for best formation representation. Numerous reasons could influence core integrity that could produce data through core characterization that could misrepresent the formation. The aim of this paper is to investigate the influence of the (input vs. output) coring parameters and coring bit type on the coring performance and the cored formation property representation in high strength rocks. Such aim was investigated through coring operations applying Weight On Bit (WOB), rotary speed (revolution per minute- rpm), etc. In this research, high strength granite blocks were cored using a fully instrumented large-scale laboratory drilling simulator. Two main types of coring bits were utilized in the coring operations including a thick-wall coring bit and a thin-wall coring bit. The range of the applied WOB varied between a low weight (1kN) and a high weight (15kN) with increment increase of (2.5 kN). The applied rpm ranged between 60rpm and 300 rpm with increment increase of 60 rpm. Granite formation was characterized for rock property determination. The indirect Tensile (IT) Strength Test was conducted for the granite Material Characterization (MC). The analyzed and reported results of the overall coring performance, parameters (parameters vs. type of coring bit), and the IT for granite MC showed an influence of the un-optimized applied coring parameters and the random selection of the coring bit could remarkably impact the coring performance outcome and misrepresent rock property of the cored formation. Results recommend optimal selection of coring bit and applied coring parameters are essential for best coring performance

Keywords: *coring performance*, *WOB,* materials characterization, indirect tensile strength, *formation representation.*

NOMENCLATURE

σ_{IT}	Indirect Tensile Strength
σ_{UCS}	Unconfined Compressive Strength
DAQ-SYS	Data Acquisition System
DTL	Drilling Technology Laboratory
EKD	Early Kick Detection
GLF	Geomechanics Loading Frame
IT	Indirect Tensile
LDS	Large-scale Drilling Simulator
MC	Material Characterization
MUN	Memorial University of Newfoundland
ROP	Rate of Penetration
rpm	revolution per minutes
pVARD	PASSIVE Vibration Assisted Rotary Drilling
TkWCB	Thick Wall Coring Bit
TnWCB	Thin Wall Coring Bit
TOB	Torque On Bit
UCS	Unconfined Compressive Strength
WOB	Weight On Bit

1. INTRODUCTION

Coring operations are essential in many fields, including oil and gas, geothermal, and mining operations. Among the main objectives of coring is formation evaluation, formation characterization, rock property determination, and operation cost reduction. For mining companies for instance, coring is a key and an innovative methodology for initiating pilot holes for narrow vain mining (uneconomic mines to be developed through conventional methods) to guide large diameter drill bits or cutter heads for economic mineral recovery. Such methodology has been recently adopted by mining companies worldwide. [1]

Research has been also focused on investigating techniques and approaches to improve coring performance either in petroleum coring recovery operation or other sectors [2-6], eliminating causes of core jamming [7], and through numerous ways including inventing Down Hole assemblies that enhances downhole parameters [6,7], optimizing applied parameters [2,6, 7], evaluating utilized equipment [7-9], etc.

One key factor for evaluating coring performance from the rock mechanics prospective is evaluating the rock properties before coring for optimal parameters applications [2,7,8].

This research uses granite as coring formation. Granite strength, which is considered one important mechanical property that influences the coring performance was investigated through the Indirect Tensile (IT) strength tests, previously by our research group at Drilling Technology Laboratory (DTL) of Memorial University of Newfoundland (MUN), Canada [10-13] and as a part of this research as per the relevant ASTM D3967-16 - standards [14].

IT strength is widely used in research [15,16] as a method for strength estimation that manly follows the splitting or tensile fracture, from which the shear fracture generated by Unconfined Compressive Strength (UCS) can be estimated through correlations [17,19].

The aim of this research investigates the coring performance outcomes based on the core bit type selected and applied versus generated parameters, and the cored formation representation.

MATERIALS AND METHODS

All materials for this research are categorized into two main groups including (i) isotropic and high strength granite blocks, retrieved granite cores, and prepared disc samples, ii) Geomechanics Loading Frame (GLF) its Data Acquisition System (DAQ-Sys), and iii) Fully instrumented Laboratory Drilling and coring Simulator (LDS) and coring bits.

2.1 Granite blocks

This research used granite blocks (Figure 1) to study the influence of the coring bit types and the variation of the applied coring parameters on the overall coring performance. Although, granite has been characterized to be high strength and an isotropic formation through intensive tests conducted at the Drilling Technology Laboratory (DTL) at Memorial University of Newfoundland (MUN), Canada [10-13], one more important step is carried out in this research, which is to correlate coring performance and coring bit types with the property of the cored formation and to investigate the possibility of such correlations to be used for formation representation.

For the IT strength test, cores were obtained from the coring operation using the two main types of coring bits associated with the core granite block shown in Figure 2. The dimension of the granite block was (~ 45 cm long, ~ 45 cm wide, and ~ 20 cm thick).

FIGURE 1: CORED GRANITE BLOCK WITH TWO CORE BIT TYPES USED FOR CORING EXPERIMENTS

FIGURE 2: HEOMECHANICS FRAME USED FOR MATERIAL CHARACTERIZATION THROUGH IT TESTS

Disc samples, as per the ASTM D3967-16 standard [14] were prepared and tested using a Geomechanics Loading Frame (GLF). A full description of the GLF including its DAQ-Sys is described by Shah el al 2020 [20], where the setup of the compression section used in this research of the GLF is shown in Figure 3.

2.2 Large-scale laboratory Drilling Simulator

A Fully instrumented Large-scale laboratory Drilling Simulator (LDS) (Figure 3) was utilized for the coring experiments. LDS used for the coring experiments is capable to operate in under two main modes including hydraulic more or pneumatic mode to provide the required trust or Weight On Bit (WOB). LDS WOB is designed to reach 100 kN. LDS has the opting for manual operation. The manual operation is used for bit position adjustment, pre-drilling initiation, and research team personal training purposes. The LDS also has the option for be automatic operation. This is run through a DAQ-SYS, which utilizes LabVIEW software. For the coring and drilling experiments used for research purposes, the automatic operation mode is usually used.

The LDS is safe, advanced, and a fully instrumented equipment used for drilling and coring experiments at DTL-MUN. For safety, LDS has three safe interlocks all around the LDS for rapid emergency responses. It is also controlled to stop operation after reaching a pre-set 1100 (N-m) of Torque On Bit (TOB). LDS is also supported by a safe operation color including red for not safe to operate and that the LDS is not in an operation mode, yellow for cautions and attentions need to be considered, and green for the readiness of safe operation. The two main color codes experiences most in our operations are red and green, where the yellow only blinks as a sign of transiting between modes such as transiting between manual and automatic modes. For the advancement, LDS has the capability to provide rotary speed as revelation per minutes (rpm) from 1 rpm to 100 rpm in any increment between. LDS can also rotate anti clockwise for research purposes. LDS is fully instrumented for high accuracy real-time data recording. LDS records the actual applied WOB at the operation regardless the inserted parameters. The recorded WOB is measured by a load cell installed at the top portion of the LDS. Such installation positions allows the load cell to consider suspended weight added by different portions of the Bottom Hole Assembly (BHA) such as longer versus shorter drill string, different sizes of drill bits, etc. LDS is also equipped with laser sensors to measure vibrations, and upstream versus downstream pressure for Early Kick Detection (EKD) experiments.

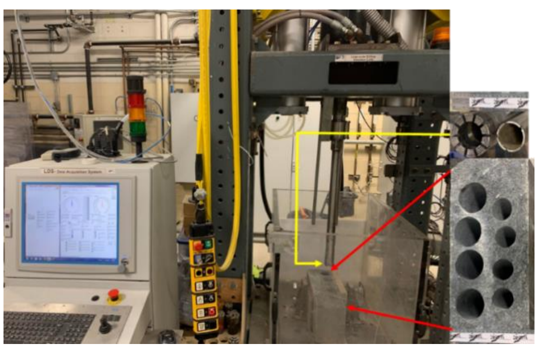

FIGURE 3: LDS USED FOR CORING

2. RESULTS AND DISCUSSION

This section provides discussion on results covering the granite properties characterization and granite coring.

Results of granite strength estimation obtained from the IT tests confirmed the high strength of granite. As per the ASTM D3967-16 standard [14], equation (1) was used for granite IT strength estimation. The averaged IT strength was determined and displayed with individual and averaged values of granite density in Figure 4.

$$\sigma_{IT} = 2*P/\pi*D*T \qquad (1)$$

Where:

$\sigma_{IT:}$ Strength of Indirect Tensile Test (MPa), P: Maximum load at failure (Newton), D: Sample diameter (mm), and T: Sample thickness (mm).

Equation (1) provided averaged IT strength equal to 16.08 (MPa). As a rule of thumb for correlating the IT strength with the Unconfined Compressive Strength (UCS), Equation 2 was adopted in estimating granite σUCS as 160.80 (MPa), which categorizes granite as a high strength formation.

$$\sigma_{UCS} = \sigma_{IT} * 10 \qquad (2)$$

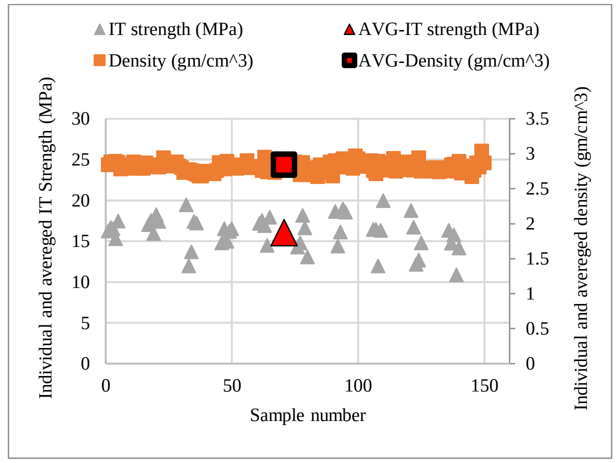

FIGURE 4: INDIVIDUAL AND AVERAGED IT STRENGTH AND DENSITY

Results of granite coring performance using the two coring bit types including the Thick Wall Coring Bit (TkWCB) and the Thin Wall Coring Bit (TnWCB) are summarized in Table 1 and 2. The coring experiments using both coring bits were conducted at the same rotary speed equals 298.5 rpm. Four sets of WOB were applied from low to high and the corresponding recorded TOB and the calculated ROP and TnWCB are also reported in Table 1 top for TkWCB and bottom for TnWCB.

TABLE 1: SUMMARY OF APPLIED, MEASURED, AND CALCULATED CORING PARAMETERS FOR ALL CORE TYPES

Coring bit type	Test Number	WOB (kN)-TkWCB	TOB (N-m)-TkWCB	ROP (m/hr)-TkWCB
Thick Wall Coring Bit (TkWCB)	B6	1.34	79.47	1.27
	B7	6.22	139.60	3.10
rpm = 298.5	B8	11.11	206.34	5.33
	B9	16.14	290.31	6.87
Coring bit type	Test Number	WOB (kN)-TnWCB	TOB (N-m)-TnWCB	ROP (m/hr)-TnWCB
Thin Wall Coring Bit (TnWCB)	C6	0.9415	72.2725	3.90
	C7	5.9465	134.7828	4.53
rpm = 298.5	C8	10.9993	10.9993	3.88
	C9	15.8633	203.5810	3.87

Results reported in Table 1 show that as the WOB increases inducing increase in ROP and TOB at the same rpm and flow rate (FR). However, the corresponding rate of increase and the consistency of the increase in the ROP and TOB differs based on the core bit type used. Table 2 reports the generated models from bit position data with time, from which ROP was calculated. These models are generated from the bit position data with time shown in Figures 5 for TnWCB and TkWCB.

TABLE 2: SUMMARY OF GENERATED MODELS USED FOR ROP CALCULATIONS

Coring bit type	Test Number	Model: Position (cm) = a * Time (Sec) + b	R
Thick Wall Coring Bit (TkWCB) rpm = 298.5	B6	y = 0.0353x + 0.0358	0.9998
	B7	y = 0.0862x - 0.0254	1
	B8	y = 0.1481x - 0.0406	0.9999
	B9	y = 0.1908x - 0.1704	0.9995
Coring bit type	Test Number	Model: Position (cm) = a * Time (Sec) + b	R
Thin Wall Coring Bit (TnWCB) rpm = 298.5	C6	y = 0.1083x - 0.0468	0.9996
	C7	y = 0.1258x + 0.3743	0.999
	C8	y = 0.1078x - 0.1086	0.9995
	C9	y = 0.1076x - 0.085	0.9991

The TkWCB performance results showed larger increase increments in ROP than that of the TnWCB. Moreover, the total margin between the lowest ROP and the highest ROP is wider in the TkWCB than that in the TnWCB as shown in Figure 5. In contrast, although the TkWCB shoed higher ROP, the corresponding torque was more stable than that of the TnWCB as shown in Figures 6 and 7. One reason of this could be linked to equivalent distribution of WOB as load per bit thickness. This will be carried out for further investigation and will be reported in future publications.

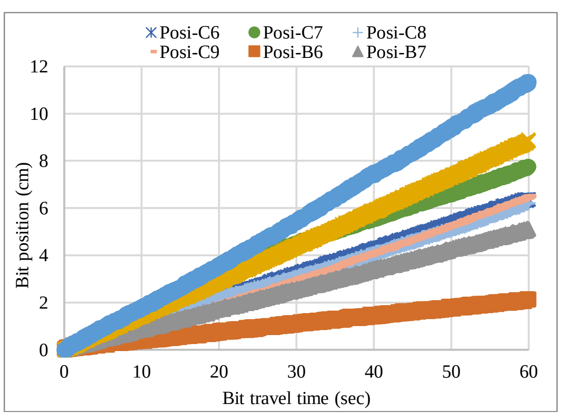

FIGURE 5: BIT POSITION WITH TIME FOR TNWCB AND TKWCB

Taking into consideration the core wall thickness for evaluating the core performance, the TkWCB showed superior performance than the TnWCB. The coring performance of both core bits used in this research cannot be compared apple to apple due to many reasons, which include differences in wall thickness, differences in the contact area, cutters' shapes and orientations, etc., however, their performance can be analyzed based on their individual performance with respect to the reached ROP and the produced TOB for each bit at various applied parameters.

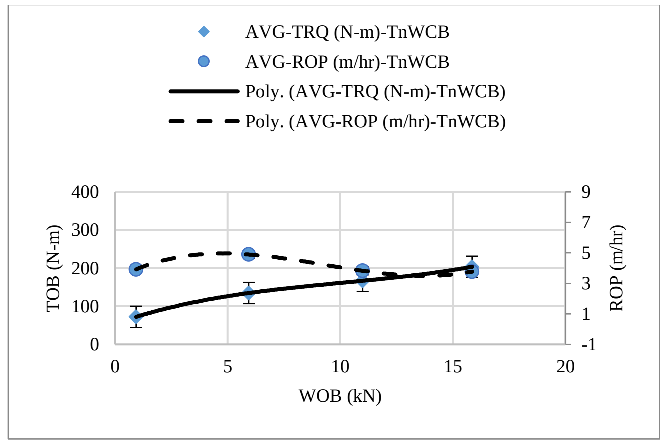

FIGURE 6: AVERAGED TOB AND ROP VERSUS WOB FOR TNWCB

Figure 6 shows averaged results of TOB and ROP versus applied WOB for the TnWCB. Although the ROP corresponsive to the lowest WOB was high (3.9 m/hr) compared to that of TkWCB (1.27 m/hr) at the same WOB, TOB of both core bits was not of a large difference considering the larger bit wall and higher contact area in the case of the TkWCB.

As the coring progresses as a result of the increase of the applied WOB, it was noticed that the rate of increase in ROP using the TnWCB was low (Figure 6) compared to that produced by the TkWCB (Figure 7). Furthermore, the TnWCB produced lower ROP or the same as the initial while the TOB was increasing (Figure 7).

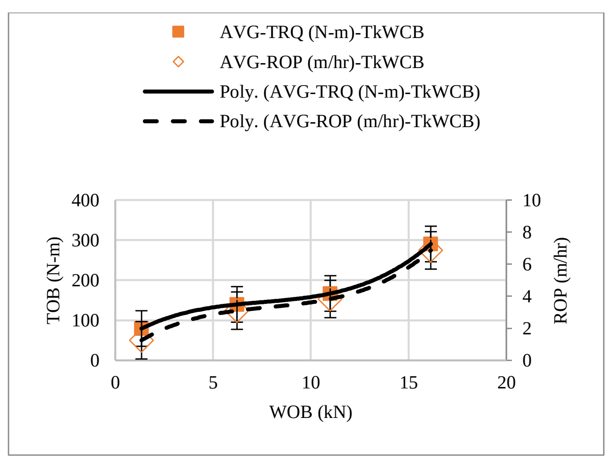

FIGURE 7: AVERAGED TOB AND ROP VERSUS WOB FOR TKWCB

On the other hand, TkWCB produced a progressive ROP in consistent and rapid rate. ROP was also noticed to be positively corresponsive to the TOB with followed similar pattern as a sign of good coring performance of the TkWCB.

For formation representation, the coring bit that produces good performance as per ROP and a positively corresponding TOB under the condition of the cored isotropic formation that has consistent property distribution, coring results can indicate type of formation being cored. The stability of obtained results could tell the isotropy of the cored formation. However, the unstable results or fluctuated results could be linked to two main reasons including (i) un adequately applied coring parameters such as WOB, rpm, flowrate, etc., or (ii) encountering anisotropic or heterogeneous formation during coring.

As per the laboratory results shown in Figure 6, when the cored formation was known as granite, which is tested to as an isotropic formation, the inconsistency in results produced by the TnWCB did not support the formation representation and therefor, the reason could be the 2nd reason explained above which is an inadequate parameter application. Conversely, the coring performance represented in ROP and the corresponding TOB produced by the TkWCB was more representative of the cored formation as shown in Figure 7.

3. CONCLUSION

High strength and isotropic granite formation was cored at DTL-MUN using thin and thick wall coring bits. The coring conditions and the applied coring parameters were similar when coring by both bits.

Granite was also tested for its strength determination through an indirect tensile strength test.

For cored formation representation, results showed that the thick wall coring bit is more supportive for such representation than the used thin wall coring bit.

As the coring was conducted in an isotropic formation (granite), the stability results of TkWCB confirmed that the applied parameters were in an efficient window, and that the thick wall of the bit could be adequate to carry the applied load, not like that of the TnWCB.

This finding is targeted for a follow up in future work and results to be published in future publications.

4. FUTURE WORK

This research is planned to continue for more investigation on the relation between the applied coring parameters and the cored formation representation suing different materials and core bit types. The planned work relevant to this research also includes evaluation of core performance under different conditions of core bit type, applied parameters, formation cored, and components of Bottom Hole Assembly (BHA).

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