Characterization of Togolese Gneisses and Granites by Rock Drilling Test

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Abstract: This paper introduces the study of Togolese gneiss and granites' intrinsic properties such as mineralogical composition, density, porosity, homogeneity one the one hand, and their mechanical properties such as resistance to attrition, abrasion and puncturing depth on the other. After the correlation analysis, significant correlations between the mechanical properties of the rocks (Los Angeles and Micro-Deval) and the depth of perforation obtained by the rock drilling test were found, as well as the not significant correlations between the mineralogical composition and the physical properties of the rock were observed. Laboratories test often performed to obtain Los Angeles and Micro-Deval values are expensive and time consuming. For this, the depths (parallel and perpendicular to the foliation planes for the gneisses or two perpendicular planes for the granites) obtained during a rock drilling test will be used to estimate its coefficients (Los Angeles and Micro-Deval). This study, is based on a database of a sample size of 32 to determine the parameters of the multifactorial model of size 6 used for the validation tests.

Keywords: Mineralogical Composition, Density, Porosity, Homogeneity, Mechanical Properties, Rock Drilling Test, Models

1. Introduction

A longstanding a construction begins with the use of materials (sands, fine gravels, stones) coming from good quality natural rocks used as such or crushed. The aggregates are the prevalent materials composing the bed, base and surface course of roads, and are also used in fabricating concrete and mortar cement. The durability of the quality of these bases under the influence of the traffics depends on their mechanical and physical properties.

The principal specification for the use of the aggregates relates to their mechanical resistance: they must possess sufficient hardness to resist deterioration and fragmentation in consequence of load application. This is crucial because once in use these aggregates will be bound together, either by a hydraulic binder in the case of Portland cement concrete, either by a bitumen binder in the case of asphaltic concretes, or by forces of friction created by compaction in the case of road aggregates.

Currently in Togo, the aggregates most used in civil engineering come from the gneisses and the granites originating from careers used for industrial production and which function permanently, or from old careers exploited by the local population.

The current tests used to evaluate the quality and durability of these aggregates are expensive, complex and long in procedure, especially when installation of new production units is involved.

The intrinsic characteristics, such as the mineralogical composition, the porosity, the density and the homogeneity of the gneisses and the granites have been studied and their influence on the mechanical properties of the aggregates resulting from these rocks has been demonstrated [1, 2, 3, 4]. The drillability test was used, for example in the characterization of limestones [5] and the statistics prove the correlation between the properties of the rocks and their drillability [6]. Several

authors have proposed methods of predicting the rock drillibility based on cognitive systems of comparative or neural networks and wear factor using engineering properties of rocks analysis [7] and drilling rate (DR) using the rock mass drillability index (RDi) involved the intact rock mechanical properties structural properties of rock masses [8] but also many parameters including rock properties, machine parameters of the chosen rig and the working process [9].

In the attempt to reduce the rather high costs of traditional tests, we propose an approach based on drillability tests which would enable to determine the mechanical properties of the aggregates used in civil engineering in Togo.

2. Material and Methods

2.1. Characteristics of the Rocks

The aims are, first to determine a correlation between the rock drillability and the characteristics of the sampled gneisses and granites; and second, to construct models of rock drillability according to the mechanical and physical properties, particularly the rock's resistance to abrasion by Los Angeles, resistance to attrition by Micro-Deval, its porosity, homogeneity and density.

Table 1. Characteristics of the gneisses and the granites.

Echantillon	rock	Texture	LA	MD	Density	Homogeneity	Porosity,%	Quartz,%	Biotite,%
K1	ga	Foliation clear	18	6,0	4,44	3,24	0,41	12,5	2,4
St	gr	Equante	22	8,2	2,53	0,992	2,06	10,6	4,2
Km1	gg	Foliation clear	19	6,6	2,99	2,811	0,50	59,2	4,4
D1	gr	Equante	22	8,2	2,52	3,2	0,41	23,8	8,1
Ls2	gg	Foliation clear	26	10,5	3,3	2,009	0,79	46,7	0,2
Ls1	gg	Foliation clear	26	10,5	3,63	0,743	2,46	42,7	0,8
Gk1	gb	Foliation clear	26,7	10,9	2,87	0,563	4,45	11,1	10,1
L1	gb	Foliation clear	28	11,6	3,77	0,854	2,53	9,5	14,9
Kp1	gba	Foliation frustrates	29,8	12,6	2,25	1,16	1,67	7	4,9
R1	gba	Foliation frustrates	30	12,7	3,2	0,436	3,92	5,6	6,9
Gll1	gba	Foliation frustrates	38,7	17,6	3,44	0,654	3,63	5,4	10,6
Wn1	gba	Foliation frustrates	44,5	20,8	3,08	0,666	3,54	5,8	10
Ng4	gr	Equante	26	10,5	2,53	1,21	1,57	6,8	2,9
Li 5	gba	Foliation clear	31,5	13,6	3,6	0,922	2,28	6,5	15,2
Gli2	gba	Foliation	28,7	11,4	2,87	0,604	4,26	10,3	22,1
B1	gb	Foliation clear	26	10,0	3,08	1,316	2,63	15	18,4
Ag1,2	gba	Foliation	36	12,4	3,132	0,5	4,07	6,5	16,6
Ag4	gab	Foliation	41,5	17,8	3,01	0,983	1,09	3,2	11,1
Ag6	gab	Foliation	33,8	13,6	3,21	0,597	3,82	4,8	7,8
L3	gbag	Foliation clear	27,6	11,0	3,8	0,729	3,94	9,9	22,1
Gk2	gb	Foliation	26,7	10,4	2,87	0,563	4,63	11,1	10,1
Kp3	gb	Mylonitique	20,7	8,7	2,91	1,0295	1,21	38,9	15,2
R6	gb	Foliation clear	26	13,3	2,85	0,548	1,5	7,7	13,1
Gli3	gb	Foliée	30	9,2	3,025	0,494	4,38	17	28.5
R4	gb	Foliée	24,7	9,2	2,35	0,343	1,51	14,7	16,5
Gl2	gba	Foliation frustrates	38,7	16,2	3,44	0,654	6,5	5,4	10,6
Nd3	gr	équante	25.9	9.8	3.02	1.143	1.63	5.2	5.4
Nb1	gr	équante	26	8.2	2.79	0.287	5.153	5.1	0.0
Nd1	gr	équante	28	12.2	3.68	0.338	4.91	7.0	2.0
F2	ga	Foliation clear	23	7.9	2.81	3.2	0.324	11.2	0.0
Ng6	gr	équante	28	12.2	2.4	0.621	3.752	6.7	2.5
Ng10	gr	équante	28	12	2.68	0.523	4.118	7.0	4.5
St5	gr	équante	22	8.2	2.85	0.894	2.895	22.4	2.9

ga=gneiss with amphibole
gb=gneiss with biotite
gba=gneiss with biotite and amphibole
gab=gneiss with amphibole and biotite
gr=granite
gg=granulite with garnet
gbag=gneiss with amphibole, biotite and garnet
Bio=biotite
LA=coefficient Los Angeles
MD=coefficient Micro-Deval in the presence of water

For these purposes, we look at the gneisses of the structural unit of the Bénino-Togolese plain and the granites of the West African craton [10]. In total, have been analyzed thirty-two (32) samples taken (Figure 1) in the areas of Lomé, Kpalimé and Atakpamé, more precisely in the vicinities of Lilicopé (L1, L3, L5), Kpédji (Kp1 and Kp3), Gakocopé (Gk1 et Gk2), Badja (B1), Gléi (Gli2 and Gli3), Agbélouvé (Ag1, 2, Ag4 and Ag6), Glécopé (Gl2), Rodokpé (R 1, R 4, R 6) of Dapaong (St, St5, D1, Ng4, Ng6, Ng10, Nd1, Nb1) and Kara (Km1, Ls1, Ls, 2, K1, F2).

Figure 1. *The sample prepared for the test.*

The characteristics of the studied rocks are summarized in table 1.

The essential intrinsic characteristics characterizing the samples are: the density, the mineralogical composition, porosity, the homogeneity [10]. The mechanical characteristics of the aggregates [11] consist of the resistance to abrasion using the Los Angeles machine and the resistance to attrition using the Micro-Deval machine [12, 13].

2.2. The Rock Drillability Test

The main question is to find out whether there exist possible correlations between the rock drillability test and the intrinsic and mechanical characteristics of the aggregates. The rock drillability test consists in measuring the depth created by the drill in a rock during a fixed time (T), or in determining the time during which the drill leaves on the rock a print with a fixed depth.

The rock drilling test consisted in perforating the gneissic and granitic rocks using a drill of 6mm of diameter with the speed of 550 rpm under a load of 1daN. After the time of perforation fixed at 10 S, we measure the depth PF created by the drill in a sample of parallelepiped form.

To perform the perforation, a drill press CINCINNATI (Figure 2) to which was hung a dynamometer applying a drilling force of 1 daN was used. On each sample, five perforations were made parallel to the layers of foliation and five perpendicularly to the foliation layers. By foliation we understand the entirety of the parallel plans according to which the new minerals crystallize.

After the perforation, a slide caliper was used to measure the depth of perforation obtained after 10 s.

Figure 2. *The CINCINNATI drilling machine.*

2.3. Data Processing

Laboratory practices open a broad horizon of problems for which the use of statistical methods proves profitable and sometimes even indispensable. Among these methods, a paramount place is granted to the statistical study of the reciprocal connections between the variables. The mathematical tools used [14] in this field are primarily: correlation analysis and regression analysis.

The regression analysis enables to deduce an estimating equation which describes the functional nature of the relation between two variables, whereas the correlation analysis gives a measurement of the force of this relation.

In this study, the statistical analysis is used to determine the correlations between the rock drillability and other characteristics of the gneisses and granites, as well as the construction of models of rock drillability in correspondence with the mechanical properties of the rocks from which the gneisses and granites come.

3. Results and Discussion

3.1. The Drillability Test Results

The results of the tests made in accordance with the various directions in the foliation are presented on the figures 3 and 4. Figure 5 presents the variation of the characteristics of the rocks according to the average depth determined by the layers of foliation (both parallel and perpendicular).

The clouds of points on the figures bellow show that from the analyzed samples it is impossible to obtain significant correlations, and to delineate regressions whatever the perforation method. This is explained by the large variety of petrographic types of the sampled gneiss and granites.

Nevertheless, it is possible to make certain important observations in relation to the average depth of perforation the speed of 550 rpm.

(a) Relating to the mineralogical composition

The data of perforation of the samples show that the depth of perforation depends on volume fraction of quartz in the rock. Thus, the rocks which depth of perforation is lower than 2mm have a volume fraction of quartz ≥10%.

There is a reduction of perforation depth with the increase of quartz fractions.

(b) Relating to the homogeneity

The analysis of the samples in relation to the homogeneity shows that the samples of depth perforation lower than 3,5 mm have a high homogeneity.

(c) Relating to the aggregate's resistance to shock (coefficient LA) and wear (coefficient MD)

One notices a marked tendency of the increase in the resistance of the aggregates when the depth of drilling rock decreases.

For the rocks of various types, the groups of dots are very dispersed. On the other hand, the analysis of tables 3 and 4 on the correlation of the foliated rocks and granites, shows strong intragroup correlations between the intrinsic properties

(homogeneity and porosity), the mechanical properties (rock drillabilitty and LA, rock drillability MD, LA and MD) and between mineralogical and mechanical property (contain of quartz and LA, contain of quartz and MD, contain of quartz and rock drillability) for the average depth of perforation. This enables to determine: a) the homogeneity from the porosity, b) LA from the drilling property, c) MD starting from the rock drillability and d) the contain of quartz from the rock drillability.

3.2. Analyses Correlation and Mathematical Model

The analysis of correlation gives the measurement of the intensity of the dependence between two variables. This intensity is significant when the coefficient of correlation is close to the unit (r≥0.5).

The mathematical functions allowing the determination of these characteristics per rock drilling test are indicated on the diagrams of figure 4.

The depth of drilling rests on several factors and a multifactorial mathematical model based on the characteristics of the rock such as the Los Angeles coefficient, the Micro-Deval coefficient, the density, the homogeneity, the porosity and the contain of quartz and biotite, use monofactorial models. The study of the connection between several factors, entitled multifactorial regression, can be presented by the following equation:

$$Y_{1,2,...k} = f(x_1, x_2 ... x_k) \qquad (1)$$

$Y_{1,2},...\ Y_k$: studied characteristic,
$x_1, x_2,.... x_k$: parameters of the model.

The best result for the totality of samples is obtained for the model that takes into account the Los Angeles coefficient (linear) and the quartz contents (power). The influence of other parameters is expressed in logarithmic form.

$$Pm = \alpha(LA) + \beta + \gamma(Q^{-0.817}) + \lambda \log(MDE) + \kappa \log(H) + \delta \log(d) + \varepsilon \log(B) + \xi \log(P) \qquad (2)$$
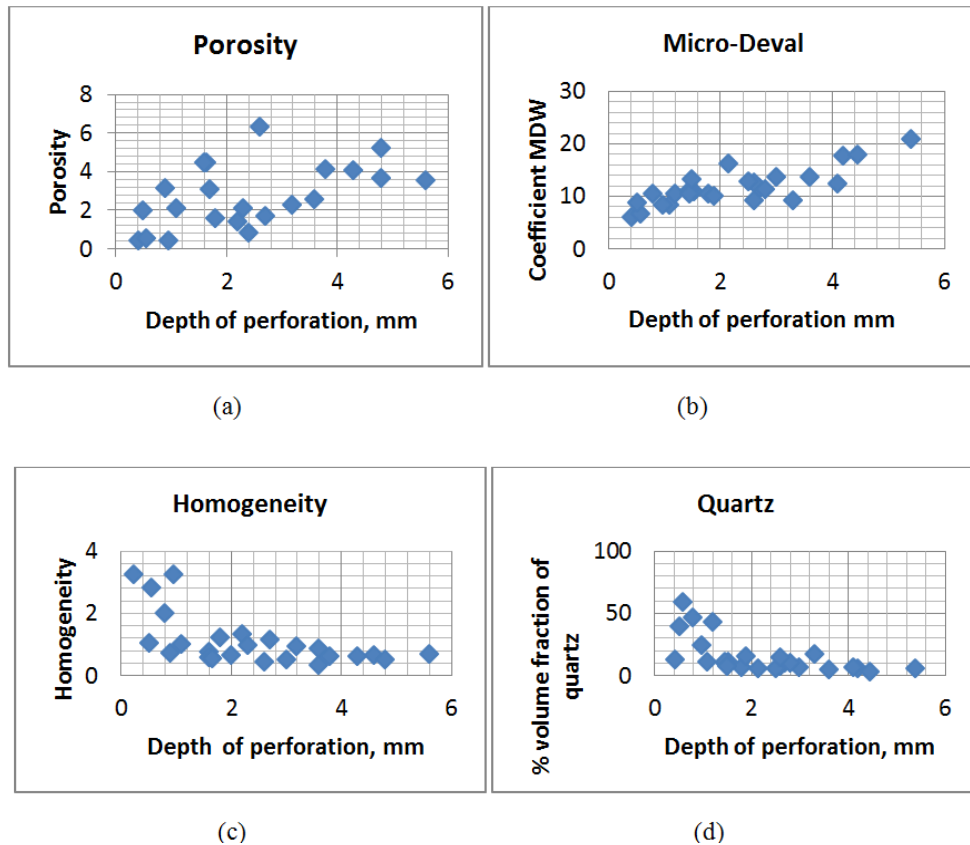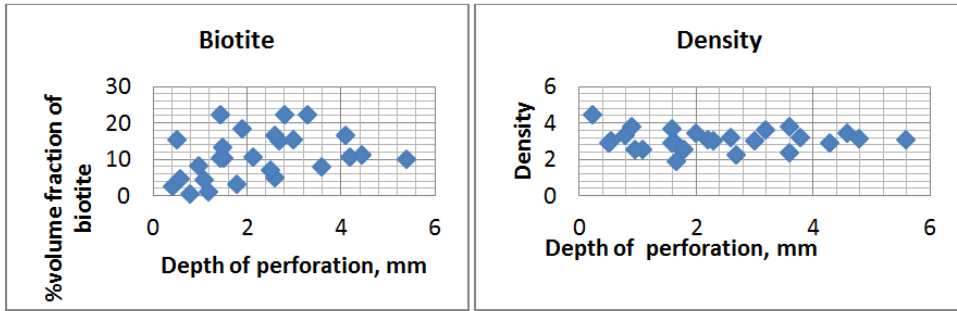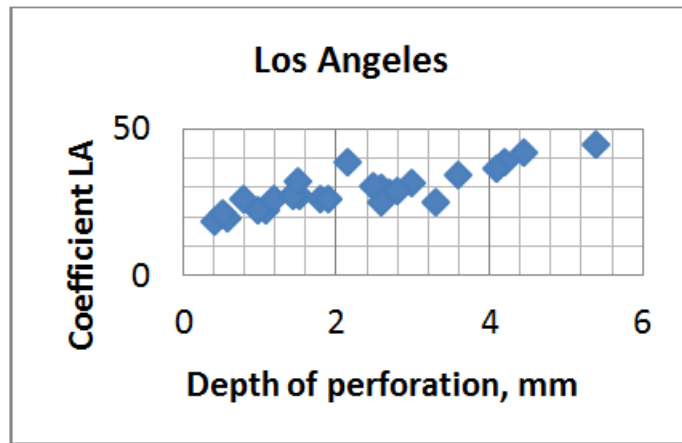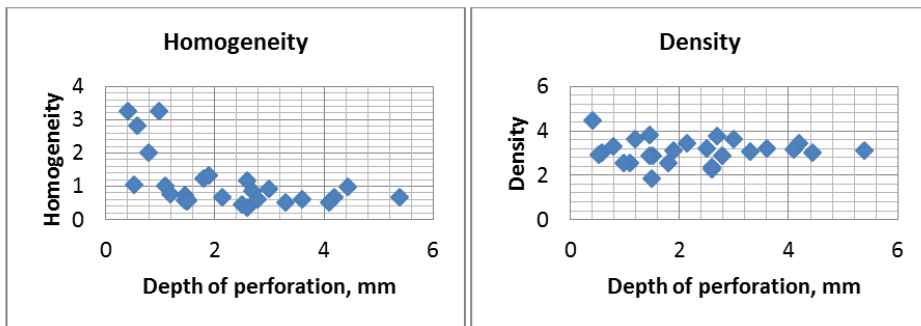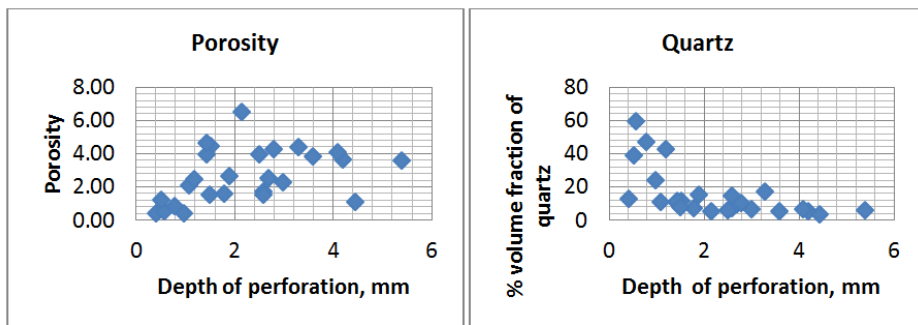
Pm: average depth of perforation (mm)
LA: coefficient Los Angeles
Q: content of quartz (% volume)
MDW: coefficient Micro Deval in the presence of water
H: homogeneity
D: density
B: contain of biotite (% volume)
P: porosity

(a)

(b)

(c)

(d)

(e)

(f)

(g)

Figure 3. *Variation of the characteristics of the rocks according to the rock drillability Pf in the plan of foliation, speed 550 rpm.*
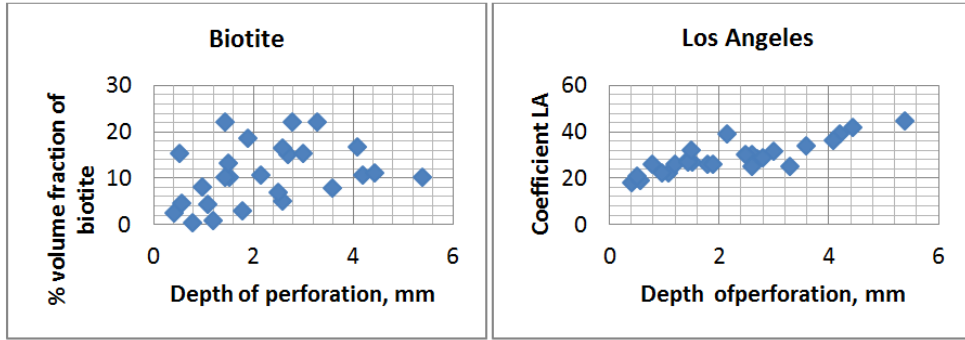

(a)

(b)

(b)

(d)

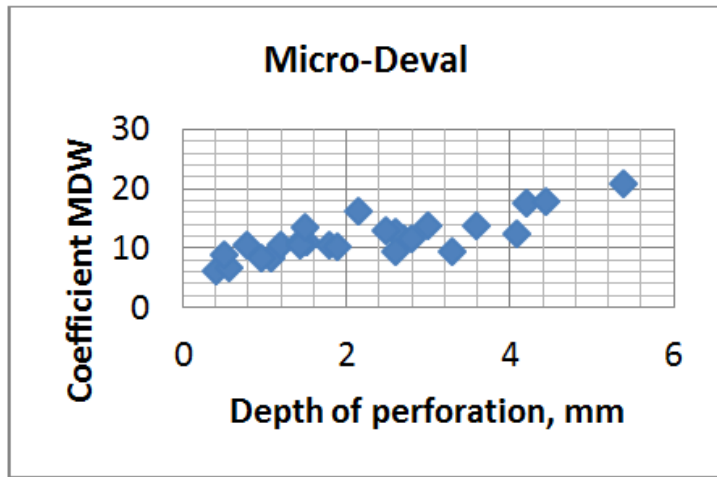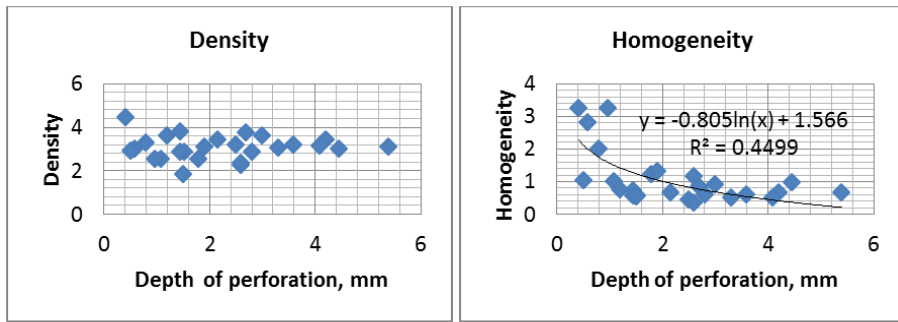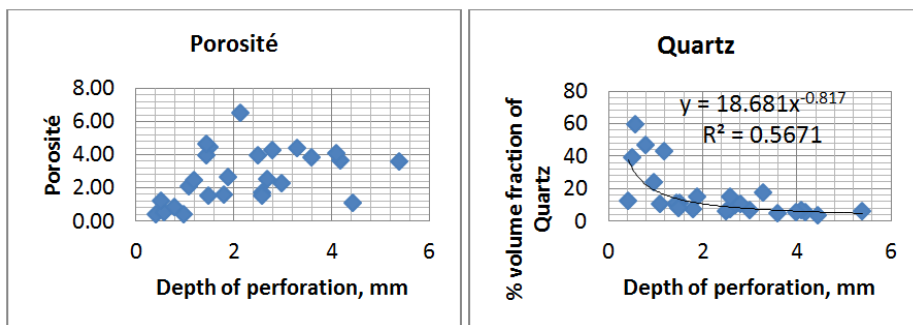(e)   (f)

(g)

Figure 4. *Variation of the characteristics of the rocks according to the rock drillabilityPpf perpendicular to the plan of foliation, speed 550 rpm.*

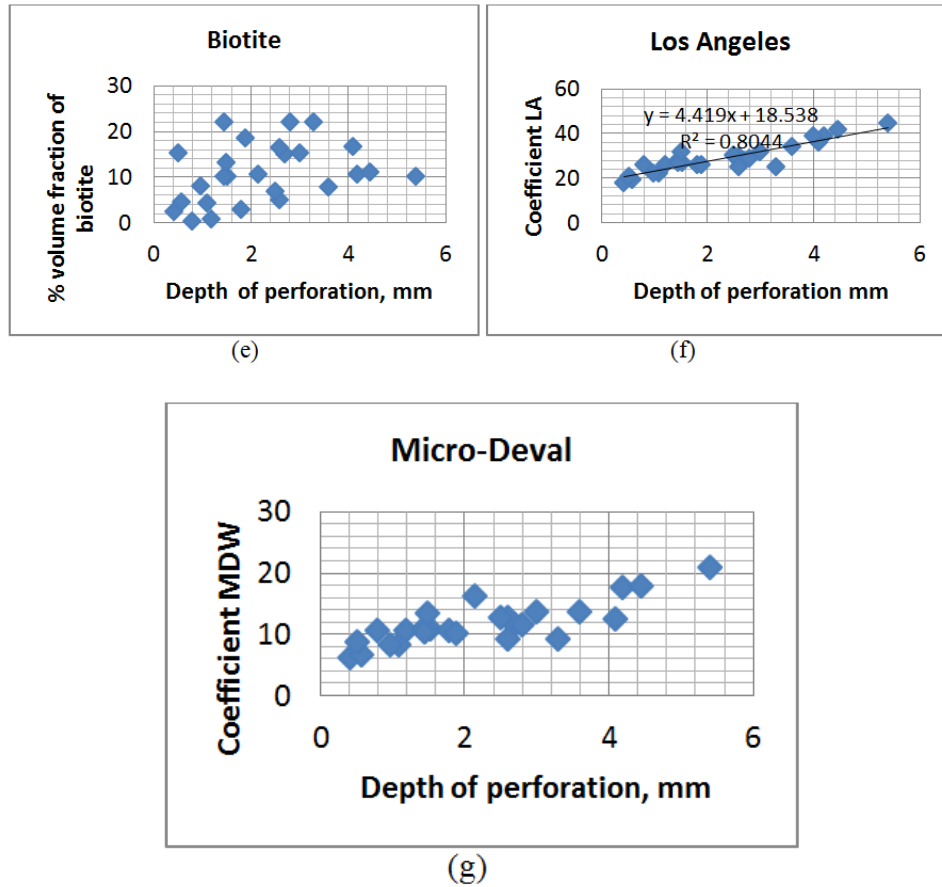(a)   (b)

(c)   (d)

(e)

(f)

(g)

Figure 5. *Variation of the characteristics of the rocks according to average rock drillability Pm, speed 550 rpm.*

Table 2. *Coefficient of correlation of the foliated characteristics of the gneisses and granites at the speed 550 rpm.*

	Pf	**Ppf**	**Pm**	**LA**	**MDW**	**Density**	**Homogeneity**	**Porosity**	**Quartz**	**Biotite**
Pf	1.0000	0.6552	0.9082	0.7741	0.7167	0.0775	-0.5949	0.6591	-0.5404	0.3393
Pm	0.9082	0.9046	1.0000	0.8868	0.8298	0.0578	-0.5823	0.4808	-0.6094	0.3202
LA	0.7741	0.8454	0.8868	1.0000	0.9740	-0.0092	-0.5461	0.4354	-0.5525	0.1408
MDW	0.7167	.07927	0.8298	0.9740	1.0000	0.0002	-0.5086	0.3683	-0.5011	0.0644
Density	0.0775	0.0394	0.0578	-0.0072	0.0002	1.0000	0.1198	0.1405	0.0475	0.0232
Homogeneity	-0.5949	-0.4538	-0.5823	-0.5461	-0.5086	0.1198	1.0000	-0.6199	0.4844	-0.4559
Porosity	0.6591	0.2617	0.4808	0.4354	0.3683	0.1405	-0.6179	1.0000	-0.3962	0.5041
Quartz	-0.5404	-0.5618	-0.5525	-0.5525	-0.5011	0.0475	0.4844	-0.3962	1.0000	-0.2734
Biotite	0.3393	0.2568	0.1408	0.1408	0.0644	0.0232	-0.4559	0.5041	-0.2734	1.0000

Table 3. *Coefficients of probability of the foliated gneisses and granites at the speed 550 rpm.*

	Pf	**Ppf**	**Pm**	**LA**	**MDW**	**Density**	**Homogeneity**	**Porosity**	**Quartz**	**Biotite**
Pf	1.0000	0.0002	0.0000	0.0000	0.0000	0.7009	0.0011	0.0002	0.0036	0.0833
Ppf	0.0002	1.0000	0.0000	0.0000	0.0000	0.8453	0.0194	0.1873	0.0023	0.1959
Pm	0.0000	0.0000	1.0000	0.0000	0.0000	0.7747	0.0014	0.0111	0.0007	0.1034
LA	0.0000	0.0000	0.0000	1.0000	0.0000	0.9715	0.0032	0.0232	0.0028	0.4835
MDW	0.0000	0.0000	0.0000	0.0000	1.0000	0.9991	0.0067	0.0587	0.0078	0.7498
Density	0.7009	0.8453	0.7049	0.9715	0.9991	1.0000	0.5518	0.4847	0.8141	0.9086
Homogeneity	0.0011	0.0174	0.0014	0.0032	0.0067	0.5518	1.0000	0.0006	0.0104	0.0169
Porosity	0.0002	0.1873	0.0111	0.0232	0.0587	0.4847	0.0006	1.0000	0.0408	0.0073
Quartz	0.0036	0.0023	0.0007	0.0028	0.0078	0.7141	0.0104	0.0408	1.0000	0.1676
Biotite	0.0833	0.1959	0.1034	0.4835	0.6498	0.9086	0.0169	0.0017	0.1676	1.0000

Ppf depth of perforation in the perpendicular plan of foliation
Pf=dept of perforation to the plan of foliation
Pm= depth of average perforation
LA=coefficient Los Angeles
MD=coefficient Micro-Deval in the presence of water

The matrix representation of the model is given by equation 3.

$$
\begin{bmatrix} Pm_1 \\ Pm_2 \\ \vdots \\ Pm_{n-1} \\ Pm_n \end{bmatrix} = \begin{bmatrix} LA_1 & 1 & Q_1^{-0.817} & \log MDE_1 & \log H_1 & \log d_1 & \log B_1 & \log P_1 \\ LA_2 & 1 & Q_2^{-0.817} & \log MDE_2 & \log H_2 & \log d_2 & \log B_2 & \log P_2 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ LA_{n-1} & 1 & Q_{n-1}^{-0.817} & \log MDE_{n-1} & \log H_{n-1} & \log d_{n-1} & \log B_{n-1} & \log P_{n-1} \\ LA_n & 1 & Q_n^{-0.817} & \log MDE_n & \log H_n & \log d_n & \log B_n & \log P_n \end{bmatrix} \times \begin{bmatrix} \alpha \\ \beta \\ \gamma \\ \lambda \\ \kappa \\ \varepsilon \\ \xi \end{bmatrix} \quad (3)
$$

This system is equivalent to the following:

$$E_1 = M_1 \times C_1 \quad (4)$$

E1: - matrix of the Pm coefficient

M1: intermediary matrix. This matrix is formed by the values of the mineralogical composition, the structure, the homogeneity and the density, corresponding to the samples for which one wishes to identify Pm

C1: coefficients of the model

The coefficients of the model are determined using the following equation:

$$C_1 = M^{-1} \times E_1 \quad (5)$$

The system of equation (Eq. 3) being overdetermined, the criterion of minimization selected is that of least squares. The resolution of this system of equations is developed in the Matlab program [14] with the functions: pinv and lsqr on figure 6.

Values of the coefficients obtained:

$\alpha=0.2322$; $\beta=-0.84628$; $\gamma=0.89016$; $\lambda=-1.5602$; $\kappa=-0.4385$; $\delta=-0.095$; $\varepsilon=0.1827$; $\zeta=-0.263$

Once these coefficients are calculated, one can determine the Pm coefficient using the following matrix product:

$$LA_1 = M_1 \times C_1 \quad (6)$$

Figure 6 represents the simultaneous layout of the values of average perforation depth measured and identified according to the model.

The gaps noticed in relation to the measured data are linked to the diversity of the types of studied rocks. When one applies this same model to the rocks of evident foliation texture or equate, one obtains more reliable results (figure 7) with the values of the obtained coefficients:

$\alpha=0.241$; $\beta=-1.6628$; $\gamma=3.2627$; $\lambda=-1.5236$; $\kappa=0.11$; $\delta=-0.034$; $\varepsilon=0.1366$; $\zeta=-0.0472$.
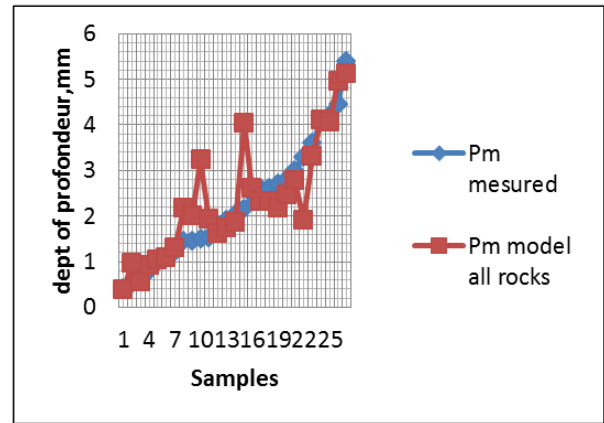

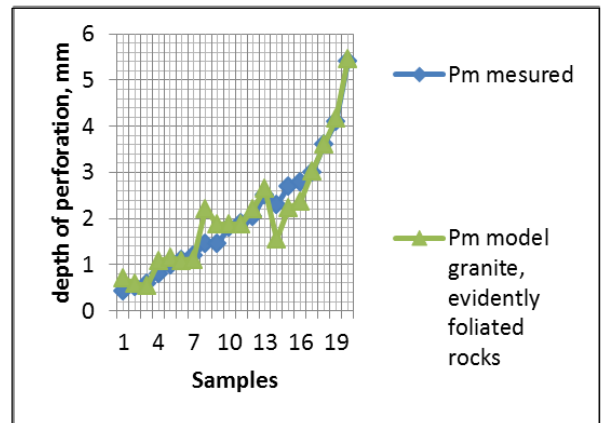*Figure 6.* Average depths of perforation Pm measured and identified according to the model.

Figure 7. Average depths of perforation measured and identified according to the model Pm for the evidently foliated gneisses and granites.

The simulation of the model applied to the six (06) granite and gneiss samples with foliated structure gave the results presented in Table 4.

Table 4. Simulation results.

Samples	Depth of perforation Pm according to model, mm	Depth of perforation Pm real, mm	Gap between real and model,%
Nb1	0.70	0.68	2.94
Nd1	0.71	0.70	1.43
F2	1.38	1.40	-1.43
Ng6	1.80	1.80	0.00
Ng10	1.94	1.90	2.11
St5	2.00	2.10	-4.76

4. Conclusion

The Togolese gneisses and granite were characterised by two types of properties: intrinsic with the porosity, the homogeneity, the mineralogical composition, the density, and mechanical with the Los Angeles coefficient, the Micro-Deval coefficient, and the rock drillability.

For the intrinsic properties, it is necessary to note the significant correlation between the homogeneity and the porosity of the rocks with evident foliated texture. For the mechanical properties, there is a significant correlation between the drilling property and the Los Angeles and Micro-Deval coefficients and finally between the Los Angeles coefficient and the Micro-Deval coefficient.

The significant correlations were observed between the rock drillability, the Los Angeles coefficient and the Micro-Deval coefficient and the contain of quartz.

The analysis of the regressions was permitted to construct mathematical models for estimation the intrinsic and mechanical properties the gneisses with evident foliated texture and granites by the rock drilling test.

The multifactorial analysis confirms the interdependence between the rock dryllability and the properties of the rocks.

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