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TEXTURAL PROPERTIES OF ROCK FOR PENETRATION RATE PREDICTION

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TEXTURAL PROPERTIES OF ROCK FOR PENETRATION RATE PREDICTION

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Abstract: The relationship between textural properties of selected Nigeria rocks and penetration rate of top-hole hammer drill was investigated. These rock samples were tested in the laboratory for mineral composition, silica content and porosity. Also, average grain size and packing density were determined from photomicrograph of the samples using empirical equations proposed by researchers. Penetration rate for each rock samples obtained in the field were correlated with the textural properties to establish their relationships. The results show that all textural character and penetration rate have high coefficient of correlation for all the samples. The highest penetration rate was experience on biotite hornblende-granite having mean packing density of 92.58% and the silica content vary for 82.60 - 82.72%. This has revealed that penetration rate of rock drill bit in quarries is related to textural rock properties and this will be necessary to have overview of time of drilling as well as rock response to mechanical loading.

Keywords: Textural properties, rocks, packing density, penetration rate, top-hole-hammer drill and quarry

1. Introduction

Investigations of nature, characteristics as well as properties of rock are essential for determination of response of rock mass to mechanical fragmentation in quarries and mines. Also, rock engineers are eager to know or make projection before and during exploitation of particular rock type. Bilgin et al.,[1] opined that the ability of excavation machines to operate and cut effectively in hard rock is limited by system stiffness and the ability to of the cutting tool to withstand high forces. The variation in the resistance experience on different rock types depend on the textural character and mineralogical composition of the rocks. However, considering design of mechanical equipment for drilling operation, excavation, hauling and crushing rely to a large extent on quality and quantity of textural characteristics data available. This will help mine manager in selection of appropriate machinery for their different levels of operation and guarantee optimum performance of the equipment.

William et al.,[2] define rock texture as the degree of crystallinity, grain size or granularity and fabric or geometrical relationship between the constituent of a rock. Erosy and Waller [3] explained that textural characteristics refer to the geometrical features of rock particles such as grain size, grain shape, grain orientation, relative areas of the grain and matrix (packing density) and compositional features such as mineral content, cement type, degree of cementation or crystallization and bond structure and concluded that textural character are major factor in determining the mechanical behaviour of rocks which can be used as a predictive factor for assessing the drillability, mechanical and wear performance of rocks. In addition Ulusay et al.,[4] described all these properties as petrographic characteristics affecting the behaviour of rock and can be readily measured in the laboratory and determined during routine thin-section studies. Also, Tug rul and Zarif [5] confirmed that the physical and mechanical behaviour are a function of mineralogical and textural character of the rock.

It had been examined that grain boundary or contact relationship are complex [6]. In the study of [7] the variation in penetration rate correlate with changes in the nature of rock and the variation in rotary toque having clear impact from changes in rock hardness. Some group of researchers expressed that mineral composition and fabric have a key effect on damage mechanism of rock and identified that two mechanisms throughout the loading
process are compaction and micro-cracking [8]. Therefore, precise determination of penetration rate will assist projecting time that would be consumed in drill at certain depth of rock. This can also be explained as the rate at which the bit enters or advanced in to the rock. Beste et al. [9] observed that rock is normally considered rather hard and offers resistance to bit penetration. The penetration mechanisms of drilling may vary in character depending on rock type. Kahraman et al. [10] correlated penetration rate with rock properties and they discovered Schmidt hammer value has strong correlation with penetration. Penetration rate has been known as the most effective parameter in determining the boundary between different rock types [11]. This work is to study evaluate textural characteristics as well establish their relationship with penetration rate.

2. Materials and Method

2.1 Rock samples

Feldspar granite, Biotite hornblende granite and Coarse biotite granite were used for the various test required for this work.

2.2 Determination of mineral composition

The thin section prepared from the rock samples were viewed under a polarizing microscope and the mineral composition of the rocks were estimated as presented in Tables 1-3. The results show that the percentage of quartz, biotite and plagioclase are 42, 30.6, and 13.1% for feldspar granite; 51.11, 17.78, and 6.66% for biotite hornblende granite and 57.14, 26.98, and 3.17% for coarse biotite granite. Table 4 presents the average grain of the samples. The results show that the percentage of quartz, biotite and plagioclase are 42, 30.6, and 13.1% for feldspar granite; 51.11, 17.78, and 6.66% for biotite hornblende granite and 57.14, 26.98, and 3.17% for coarse biotite granite.

2.3 Determination of average grain size

The average grain size was measured manually from the photomicrograph of the thin section. In addition, all the grains in the reference area were measured and the average of grain size was calculated for all the samples.

2.4 X-ray fluorescence test for determination of silica content

The palletized samples were inserted into the sample holder were prepared in accordance with [12], so that the beams of x-ray light can fall on flat surface of the palletized sample. The RIX 3100 X-Ray Spectrometer equipped with a monitor process each sample inserted and analyse the percentage of each elements present in the sample. The result is presented in Table 5.

2.5 Determination of porosity

Porosity was determined using saturation and caliper technique as suggested by [13]. The representative sample of the rock was machined to conform to cubiod. The bulk volume $V_b$ was calculated from caliper reading for each dimension. The sample was saturated by water immersion for a period of 5 days. The sample was removed surface dried, and the saturated surface dry mass was determined. The sample was dried to a constant mass at a temperature of $105^\circ$C, cooled in a desiccator and its mass determined to give grain mass $M_s$. The pore volume and porosity were obtained using equations 1 and 2 as shown in Table 6.

\[
V_p = \frac{(M_s - M_w)}{\rho_w}
\]

where $\rho_w$ = density of the saturated fluid (water)

\[
\text{Porosity} (\phi) = \frac{V_p}{V_b}
\]

2.6 Determination of packing density

The packing density for the samples were determined using equation 3 proposed by [14] and the results are presented in Table 7.

\[
PD = \frac{\text{Length Grains along traverse}}{\text{Length of Traverse}}
\]

3. Results and Discussion

3.1 Textural properties

The mineral composition of feldspar granite, biotite hornblende granite and coarse biotite granite are shown in Tables 1-3. The results show that the percentage of quartz, biotite and plagioclase are 42, 30.6, and 13.1% for feldspar granite; 51.11, 17.78, and 6.66% for biotite hornblende granite and 57.14, 26.98, and 3.17% for coarse biotite granite. Table 4 presents the average grain of the samples. The results show that the average grain size vary from 0.94-0.99, 0.65-0.68 and 0.65-0.68mm for feldspar granite, biotite hornblende granite and coarse biotite granite respectively.

Table 5 presents the silica content of the samples. The result shows that the silica content vary from 57.16-57.21, 82.5-82.72 and 76.04-76.12% for feldspar granite, biotite hornblende granite and coarse biotite granite respectively. Table 6 shows the porosity of the samples. The results revealed that porosity vary from 1.03-1.07, 0.87-0.93 and 0.72-0.74% for feldspar granite, biotite hornblende granite and coarse biotite granite respectively. Table 7 shows the packing density of the samples. The results show that the packing density vary from 92.18-94.53, 91.60-94.40 and 92.82-94.24% for feldspar granite, biotite hornblende granite and coarse biotite granite respectively.
### Table 1: Mineral composition of *Feldspar-Granite*

<table>
<thead>
<tr>
<th>Rock Code</th>
<th>Minerals</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>IK01</td>
<td>Biotite</td>
<td>30.60</td>
<td>30.56</td>
<td>30.64</td>
<td>30.64</td>
<td>30.62</td>
</tr>
<tr>
<td></td>
<td>Quartz</td>
<td>42.00</td>
<td>42.10</td>
<td>41.90</td>
<td>42.12</td>
<td>41.95</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>13.10</td>
<td>13.06</td>
<td>13.12</td>
<td>13.14</td>
<td>13.30</td>
</tr>
<tr>
<td></td>
<td>Opaque</td>
<td>3.80</td>
<td>3.80</td>
<td>3.80</td>
<td>3.80</td>
<td>3.80</td>
</tr>
<tr>
<td></td>
<td>Orthoclase</td>
<td>10.70</td>
<td>10.48</td>
<td>10.54</td>
<td>10.30</td>
<td>10.33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

### Table 2: Mineral composition of *Biotite Hornblende-Granite*

<table>
<thead>
<tr>
<th>Rock Code</th>
<th>Minerals</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB02</td>
<td>Microcline</td>
<td>6.67</td>
<td>6.67</td>
<td>6.67</td>
<td>6.67</td>
<td>6.67</td>
</tr>
<tr>
<td></td>
<td>Hornblende</td>
<td>8.89</td>
<td>8.89</td>
<td>8.89</td>
<td>8.89</td>
<td>8.89</td>
</tr>
<tr>
<td></td>
<td>Biotite</td>
<td>17.78</td>
<td>17.80</td>
<td>17.75</td>
<td>17.81</td>
<td>17.82</td>
</tr>
<tr>
<td></td>
<td>Quartz</td>
<td>51.11</td>
<td>51.09</td>
<td>51.18</td>
<td>51.14</td>
<td>51.07</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>6.66</td>
<td>6.66</td>
<td>6.64</td>
<td>6.66</td>
<td>6.66</td>
</tr>
<tr>
<td></td>
<td>Orthoclase</td>
<td>2.22</td>
<td>8.89</td>
<td>8.87</td>
<td>8.83</td>
<td>8.89</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

### Table 3: Mineral composition of *Coarse Biotite-Granite*

<table>
<thead>
<tr>
<th>Rock Code</th>
<th>Minerals</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE03</td>
<td>Hornblende</td>
<td>12.70</td>
<td>12.70</td>
<td>12.70</td>
<td>12.70</td>
<td>12.70</td>
</tr>
<tr>
<td></td>
<td>Biotite</td>
<td>26.98</td>
<td>27.00</td>
<td>27.01</td>
<td>27.01</td>
<td>26.96</td>
</tr>
<tr>
<td></td>
<td>Quartz</td>
<td>57.14</td>
<td>57.10</td>
<td>57.12</td>
<td>57.09</td>
<td>57.16</td>
</tr>
<tr>
<td></td>
<td>Plagioclase</td>
<td>3.17</td>
<td>3.20</td>
<td>3.17</td>
<td>3.20</td>
<td>3.18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

### Table 4: Average grain size of selected rocks in Nigeria

<table>
<thead>
<tr>
<th>Rock Name and Code</th>
<th>Average grain size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td>Location 2</td>
</tr>
<tr>
<td><em>Feldspar-Granite</em> (IK01)</td>
<td>0.94</td>
</tr>
<tr>
<td><em>Biotite Hornblende-Granite</em> (IB02)</td>
<td>0.67</td>
</tr>
<tr>
<td><em>Coarse Biotite-Granite</em> (DE03)</td>
<td>0.68</td>
</tr>
</tbody>
</table>

### Table 5: Silica content of selected rocks in Nigeria

<table>
<thead>
<tr>
<th>Rock Name and Code</th>
<th>Silica (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td>Location 2</td>
</tr>
<tr>
<td><em>Feldspar-Granite</em> (IK01)</td>
<td>57.17</td>
</tr>
<tr>
<td><em>Biotite Hornblende-Granite</em> (IB02)</td>
<td>82.64</td>
</tr>
<tr>
<td><em>Coarse Biotite-Granite</em> (DE03)</td>
<td>76.09</td>
</tr>
</tbody>
</table>

### Table 6: Porosity of selected rocks in Nigeria

<table>
<thead>
<tr>
<th>Rock Name and Code</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1</td>
<td>Location 2</td>
</tr>
<tr>
<td><em>Feldspar-Granite</em> (IK01)</td>
<td>1.05</td>
</tr>
<tr>
<td><em>Biotite Hornblende-Granite</em> (IB02)</td>
<td>0.91</td>
</tr>
<tr>
<td><em>Coarse Biotite-Granite</em> (DE03)</td>
<td>0.73</td>
</tr>
</tbody>
</table>
Table 7: Packing density of selected rocks in Nigeria

<table>
<thead>
<tr>
<th>Rock Name and Code</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feldspar-Granite (IK01)</td>
<td>92.96</td>
<td>93.75</td>
<td>92.96</td>
<td>94.53</td>
<td>92.18</td>
</tr>
<tr>
<td>Biotite Hornblende-Granite (IB02)</td>
<td>91.95</td>
<td>91.95</td>
<td>93.00</td>
<td>94.40</td>
<td>91.60</td>
</tr>
<tr>
<td>Coarse Biotite-Granite (DE03)</td>
<td>92.88</td>
<td>93.52</td>
<td>92.82</td>
<td>94.24</td>
<td>92.82</td>
</tr>
</tbody>
</table>

Table 8: Penetration rate of selected rocks in Nigeria

<table>
<thead>
<tr>
<th>Rock Name and Code</th>
<th>Location 1</th>
<th>Location 2</th>
<th>Location 3</th>
<th>Location 4</th>
<th>Location 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feldspar-Granite (IK01)</td>
<td>0.25</td>
<td>0.26</td>
<td>0.25</td>
<td>0.26</td>
<td>0.25</td>
</tr>
<tr>
<td>Biotite Hornblende-Granite (IB02)</td>
<td>0.30</td>
<td>0.30</td>
<td>0.31</td>
<td>0.31</td>
<td>0.30</td>
</tr>
<tr>
<td>Coarse Biotite-Granite (DE03)</td>
<td>0.30</td>
<td>0.29</td>
<td>0.30</td>
<td>0.29</td>
<td>0.30</td>
</tr>
</tbody>
</table>

3.2 Penetration rate of the selected samples
Penetration rate for all the samples vary from 0.25m/min for feldspar granite to 0.31m/min for Biotite hornblende-granite as presented in Table 8.

3.3 The relationship between penetration rate and textural properties
3.3.1 Penetration Rate and Quartz Percentage
The model coefficients for penetration rate and quartz content are presented in Table 9. It was observed that linear relationship exist between penetration rate and percentage of quartz for the selected rocks. The relationship is expressed in equation 4. The plot of penetration rate and regression standardized predicted value for quartz content shows that the model is valid having multiple coefficient of $R^2 = 0.689$ as shown in Fig. 1. Also, the summary of the models presented in Table 10 confirms the validity of the model equation having multiple correlation coefficient of $R^2 = 0.830$.

$$PR = -211.163 + 0.657QZ1 + 0.937QZ2 + 2.380$$

where,
- $PR =$ penetration rate,
- $QZ1$, $QZ2$, $QZ3$ are quartz content for feldspar granite, biotite hornblende granite and coarse biotite granite respectively.

Table 9: Coefficients of the model for penetration rate using quartz contents of the selected rocks

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td>Zero-order</td>
<td>Partial</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>-211.163</td>
<td>150.245</td>
<td>-1.405</td>
<td>.394</td>
<td></td>
</tr>
<tr>
<td>QZ1</td>
<td>.657</td>
<td>.462</td>
<td>2.405</td>
<td>1.423</td>
<td>.390</td>
</tr>
<tr>
<td>QZ2</td>
<td>.937</td>
<td>.790</td>
<td>1.566</td>
<td>1.186</td>
<td>.446</td>
</tr>
<tr>
<td>QZ3</td>
<td>2.380</td>
<td>1.651</td>
<td>2.633</td>
<td>1.442</td>
<td>.386</td>
</tr>
</tbody>
</table>

a Dependent Variable: PR

Table 10: Model summary for the variables of the selected rocks

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R Square Change</td>
<td>F Change</td>
<td>df1</td>
<td>df2</td>
<td>Sig. F Change</td>
</tr>
<tr>
<td>1</td>
<td>.830(a)</td>
<td>.689</td>
<td>-.244</td>
<td>.02887</td>
<td>.689</td>
</tr>
<tr>
<td>2</td>
<td>.842(a)</td>
<td>.709</td>
<td>-.165</td>
<td>.02794</td>
<td>.709</td>
</tr>
<tr>
<td>3</td>
<td>.825(a)</td>
<td>.681</td>
<td>-.277</td>
<td>.02925</td>
<td>.681</td>
</tr>
<tr>
<td>4</td>
<td>.899(a)</td>
<td>.809</td>
<td>.234</td>
<td>.02265</td>
<td>.809</td>
</tr>
<tr>
<td>5</td>
<td>.893(a)</td>
<td>.798</td>
<td>.191</td>
<td>.02329</td>
<td>.798</td>
</tr>
</tbody>
</table>

a Predictors: (Constant), QZ3, QZ2, QZ1; AVG3, AVG2, AVG1; Si3, Si2, Si1; n3, n2, n1 and PD3, PD2, PD1
b Dependent Variable: PR
3.3.2. Penetration Rate and Average Grain Size

The model coefficients for penetration rate and average grain size are presented in Table 11. The model equation for prediction of penetration rate using average grain size of the selected rocks is expressed in equation 5. The plot of penetration rate and regression standardized predicted value for average grain size shows that the model is valid having multiple coefficient of ($R^2 = 0.709$) as shown in Figure 2. Also, the summary of the models presented in Table 10 confirms the validity of the model equation having multiple correlation coefficient of $R^2 = 0.842$, this shows that 84.2% of the variation in penetration rate could be attributed to average grain size of the selected rocks.

$$PR = 3.52 - 1.004AVG1 - 1.129AVG2 - 1.554AVG3 \quad (5)$$

where,

$PR =$ penetration rate,

$AVG1$, $AVG2$ and $AVG3$ are average grain size for feldspar granite, biotite hornblende granite and coarse biotite granite respectively.

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG1</td>
<td>B: 3.052, Std. Error: 3.250</td>
<td>Beta: -0.893, Std. Error: 1.562</td>
<td>-0.643, t: -0.319</td>
<td>-0.347</td>
<td></td>
</tr>
<tr>
<td>AVG2</td>
<td>B: -1.129, Std. Error: 0.818</td>
<td>Beta: -0.780, Std. Error: 0.818</td>
<td>-1.380, t: -0.767</td>
<td>-0.745</td>
<td></td>
</tr>
<tr>
<td>AVG3</td>
<td>B: -1.554, Std. Error: 2.566</td>
<td>Beta: -0.849, Std. Error: 2.566</td>
<td>-0.606, t: -0.327</td>
<td>-0.327</td>
<td></td>
</tr>
</tbody>
</table>

---

3.3.3 Penetration Rate and Silica Content

The model coefficients for penetration rate and silica content are presented in Table 12. The model equation for prediction of penetration rate using average grain size of the selected rocks is expressed in equation 6. The plot of penetration rate and regression standardized predicted value for average grain size shows that the model is valid having multiple coefficient of ($R^2 = 0.681$) as shown in Figure 3. Also, the summary of the models presented in Table 10 confirms the validity of the model equation having multiple correlation coefficient of $R^2 = 0.825$, this shows that 82.5% of the variation in penetration rate could be attributed silica content of the selected rocks.

$$PR = 136.831 - 1.119Si1 - 0.118Si2 - 0.825Si3 \quad (6)$$

where,

$PR =$ penetration rate,

$Si1$, $Si2$ and $Si3$ are silica content for feldspar granite, biotite hornblende granite and coarse biotite granite respectively.
Table 12: Coefficients of the model for penetration rate silica contents of selected rocks

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td>Zero-</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>136.831</td>
<td>135.873</td>
<td>1.007</td>
<td>.498</td>
<td></td>
</tr>
<tr>
<td>Si1</td>
<td>-1.119</td>
<td>1.411</td>
<td>-.865</td>
<td>-.794</td>
<td>.573</td>
</tr>
<tr>
<td>Si2</td>
<td>-.118</td>
<td>.183</td>
<td>-.401</td>
<td>-.644</td>
<td>.636</td>
</tr>
<tr>
<td>Si3</td>
<td>-.825</td>
<td>.873</td>
<td>-1.018</td>
<td>-.945</td>
<td>.518</td>
</tr>
</tbody>
</table>

a Dependent Variable: PR

3.3.4. Penetration Rate and Porosity
The model coefficients for penetration rate and porosity are presented in Table 13. The model equation for prediction of penetration rate using average grain size of the selected rocks is expressed in equation 7. The plot of penetration rate and regression standardized predicted value for porosity shows that the model is valid having multiple coefficient of \( R^2 = 0.809 \) as shown in Fig. 4. Also, the summary of the models presented in Table 10 confirms the validity of the model equation having multiple correlation coefficient of \( R^2 = 0.899 \), this shows that 89.9% of the variation in penetration rate could be attributed porosity of the selected rocks.

\[
PR = 16.620 - 8.159n1 + 1.004n2 - 11.876n3 \quad (7)
\]

where,

- \( PR \) = penetration rate,
- \( n1, n2 \) and \( n3 \) are porosity for feldspar granite, biotite hornblende granite and coarse biotite granite respectively.

Table 13: Table coefficients of the model for penetration rate using porosity of the selected rocks

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td>Zero-</td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>16.620</td>
<td>11.091</td>
<td>1.498</td>
<td>.375</td>
<td></td>
</tr>
<tr>
<td>n1</td>
<td>-8.159</td>
<td>5.878</td>
<td>-4.851</td>
<td>-1.388</td>
<td>.397</td>
</tr>
<tr>
<td>n2</td>
<td>1.004</td>
<td>1.212</td>
<td>1.097</td>
<td>.829</td>
<td>.559</td>
</tr>
<tr>
<td>n3</td>
<td>-11.876</td>
<td>8.169</td>
<td>-4.588</td>
<td>-1.454</td>
<td>.384</td>
</tr>
</tbody>
</table>

a Dependent Variable: PR

3.3.5. Penetration Rate and Packing Density
The model coefficients for penetration rate and packing density are presented in Table 14. The model equation for prediction of penetration rate using average grain size of the selected rocks is expressed in equation 8. The plot of penetration rate and regression standardized predicted value for packing density shows that the model is valid having multiple coefficient of \( R^2 = 0.798 \) as shown in Fig. 5. Also, the summary of the models presented in Table 10 confirms the validity of the model equation having multiple correlation coefficient of \( R^2 = 0.893 \), this shows that 89.9% of the variation in
penetration rate could be attributed packing density of the selected rocks.  
\[ PR = 0.733 + 0.013PD1 - 0.030 PD2 + 0.012PD3 \]  
where,  
PR = penetration rate,  
PD1, PD2 and PD3 are packing density for feldspar granite, biotite hornblende granite and coarse biotite granite respectively.

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>Correlations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (Constant)</td>
<td>.733</td>
<td>2.127</td>
<td>.345</td>
<td>.789</td>
<td></td>
</tr>
<tr>
<td>PD1</td>
<td>.013</td>
<td>.039</td>
<td>.457</td>
<td>.334</td>
<td>.795</td>
</tr>
<tr>
<td>PD2</td>
<td>-.030</td>
<td>.016</td>
<td>-1.316</td>
<td>-1.878</td>
<td>.311</td>
</tr>
<tr>
<td>PD3</td>
<td>.012</td>
<td>.054</td>
<td>.278</td>
<td>.213</td>
<td>.866</td>
</tr>
</tbody>
</table>

Table 14: Coefficients of the model for penetration rate using packing density

a Dependent Variable: PR

Fig. 5: Plot of penetration rate against regression standardized predicted value for packing density

4 Conclusion
Investigating the relationship between penetration rate and textural properties of rocks are essential to understand the behaviour of rock under mechanical loading. The penetration rate is an important variable to be able to project time to drill in mines or quarry. Among the textural properties selected for this study viz., quartz proportion, silica content, average grain size, porosity and packing density. All these properties were found to have strong relationship with penetration rate. It could be concluded that rock drill penetration are different because of variation in the textural characteristics of these rocks.

References

