EFFECTS OF PETROGRAPHICAL ROCK PROPERTIES TO THE STRENGTH AND BEHAVIOR OF ROCK

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Abstract: *This paper presents the study of the relationship between petrographical rock properties to strength and behavior of the rock. The study was conducted on sandstone core sample of Pahang, Malaysia. The petrographical rock properties such as mineralogy, grain size, sorting and cementation were studied by thin section and X-Ray diffractometry (XRD) analysis. The strength and behavior of rock such as compressive strength (Co), tensile strength (To), shear strength (So), friction angle (ϕ), Young's modulus (E), Poisson's ratio (υ) and rock behavior were studied by using Servo Control Hydraulic Testing Machine (SCHTM). The results show that for finer grain size, poorer sorted sand, higher amount of quartz, feldspar, other stable minerals and higher degree of cementation, there will be higher Co, To, So, ϕ, E, υ and these rocks behave more elastically.*

1 INTRODUCTION

One of the most fastest and simplest way to evaluate rock strength is using well log. Well log alone, however, is not satisfactory for predicting the strength and behavior of rock. Therefore, in order to predict accurately the engineering problems associated with wellbore stability, reservoir rock compaction and sand production, the better understanding of how the petrographical rock properties affect the strength and behavior of rock is required.

Most of the previous studies have concentrated on strength variations measured on single rock type and have documented the influence of porosity on strength. Some of them focused on the effects of mineralogy and clay content on strength. However, the effects of clay contents on rock strength give the mixed results. When clay interbeds with sandstone, it will reduce the strength of the rock. Inversely, when clay acts as cementing material, it will increase the strength of the rock. This paper focuses on the effects of mineralogy, grain size, sorting and clays acts as cementing materials on strength and behavior of the rock.

2 EXPERIMENTAL WORK

2.1 Sample preparation

Core samples were selected from different locations of Pahang, Malaysia and then cored to 6 inches diameter with various depth. Then these samples were prepared for petrographic (thin section and XRD) and mechanical properties analysis.

2.2 Petrographic properties tests

To study mineralogy, grain size, sorting and cementation, thin sections were made of. The thin section preparation procedure involved vacuum impregnation with a blue resin to aid recognition of the pore space. The determination of rock composition involving counting of 300 points in each thin sections. Grain size and sorting were analyzed by using calibrated scale in the ocular of the microscope.

The XRD studies were carried out by using the D500-SIEMENS system and set up at 40mA, 40Kv, use Cu, Kα radiation with Ni filter. The X-ray diffractometry for whole rock run from $3^\circ2\theta$ to $50^\circ2\theta$, scanning speed $1^\circ2\theta$/min.

2.3 Mechanical properties tests:

The mechanical rock properties such as compressive strength, tensile strength, Young modulus, Poisson's ratio, shear strength and friction angle were studied using SCHTM under uniaxial, triaxial and tensile strength tests. For uniaxial and triaxial tests, sample was prepared to cylindrical shape with dimensions of 2" in diameter and 5" in length (L/D=2.5). For tensile strength test, sample was prepared to cylindrical shape of 2" in diameter and 1" in length (L/D=0.5).

Uniaxial tests:

In this test, the specimen was put centrally within the SCHTM, the axial and radial strain gauge were attached to the surface (opposite each other) of the specimen. Then load was

applied at a constant rate of $0.7MN/m^2/sec$ (ASTM standard) until the specimen fail. The process of the specimen deformation can be seen computer monitor. The uniaxial compressive strength (Co), Young modulus (E) and Poisson's ratio were calculated using the following equation:

$$C_u = \frac{F}{A} \tag{1}$$

$$E = \frac{\sigma_i}{\varepsilon_i} \tag{2}$$

$$\upsilon = \frac{\sigma_i}{\varepsilon_i} \tag{3}$$

Tensile strength test (Brazilian test)

In this test, the specimen was placed horizontally between platens of the SCHTM. The load was applied at a constant rate $0.05 \ MN/m^2/sec$ (ASTM standard) until the specimen fail, the load was then removed. Tensile strength was calculated using equation 4.

$$T = 0.636 \ \frac{F_c}{DL} \tag{4}$$

Triaxial test

In this test, the specimen was put inside the Triaxial Hoek Cell, and was placed centrally within the platens of the SCHTM. The confining pressure was applied from hydraulic pressure intensifier. Initially, small confining pressure ($1.5MN/m^2$) was applied in the Triaxial Hoek Cell to constraint the specimen and the end cap allowing mounting of the cell to the bottom platen of the SCHTM. The confining pressure was increased to 50 Bar, then specimen was load at a constant rate of $0.7MN/m^2/sec$ (ASTM standard) until the specimen fail. The same procedure was repeated with 100 and 150 bar confining pressure to obtained Mohr envelope in order to get shear strength and friction angle value.

3 RESULTS AND DISCUSSIONS

Results of the thin section analysis are presented in Table 1, detailed photographs of these thin sections are presented in Figure 1 to Figure 5. Generally, these sandstone composed mainly of

quartz (Q, varying from 49.9% to 60.1%), Feldspar (F, varying from 7.0% to 16.8%), mica (M, varying from 0.5% to 7.3%), some rock fragments such as granite (Gr), volcanic (Vo), quartzite (Qz), chert (Ch) and schist (Sh). The accessory minerals such as tourmaline (T), epidote (E) and zircon (Z) present with small amount from trace to 0.6%. The cementing material consists mainly of clays (C, varying from 13.5% to 24.5%), some carbonate (Ca) and quartz (q). Grain size was varying from very fine to fine grain sandstone (VF-F), fine to medium grain sandstone (F-M) and medium to coarse grain sandstone (M-C). Sorting was varying from poorly sorted sand (P) to moderately sorted sand (M) and well sorted sand (W).

The results of XRD analysis are shown in Table 2. This result is in agreement with thin section analysis although the amount of quartz is a little higher, it is acceptable for semi-quantitative analysis in XRD due to its large uncertainties.

The results of mechanical rock properties tests were shown in Table 3. The behavior of rock can be seen from plot of axial stress and axial strain (Figure 6 to Figure 8).

3.1 Effects of grain size to the mechanical rock properties

Previous works showed that effect of grain size to the mechanical rock properties give a mixed results. Cade et al (1992) stated that for finer grain size, there will be less strength and hence more compaction. Using cathodoluminescent, they observed that finer grain sandstone displays grain contact which indicates a greater volume of dissolved grain. In contrast, the studies of Vuturuki et al (1974) and Plumb et al (1992) showed that strength generally decreases as grain size increases. It is explained by the probability that larger grains can contain long favorably-oriented Griffith flaws. Grains with the longest favorably-oriented flaws are the weakest in compression.

The results from these experiments are in agreement with Vuturuki et al (1974) and Plumb et al (1992). With others properties such as sorting, mineralogy and cementation degree are almost the same. We can see that for finer grain size sample, there will be higher C_o, E, So, ϕ and T_o and lower υ. From figure 6, we also see that the yield point (the transition from elastic to plastic behavior) and slope of the curve from the finer grain sandstone is higher than the coarser one. These show that sample with finer grain was deformed more elastically.

3.2 Effects of sorting to the mechanical rock properties

From the experimental results, we can see that, sample with poorly sorted sand will have higher C_o, E, So, ϕ and T_o and lower υ. It is because, in poorer sorted sand, there will be a larger number of grain contacts per unit volume supporting the stress than in better sorted sand. However, effect of sorting to mechanical rock properties is less compare to the effect of grain size. From the Figure 7, we can also see that this effect is not the major one, the slope of the stress - strain curve of these two samples are almost similar, only the yield point from poorly sorted sample is higher then the well sorted sample.

3.3 Effects of mineralogy and cementation to the mechanical rock properties

From the Table 3, we can see that for sample with higher amount of quartz, lower amount of mica and higher degree of cementation there will be higher C_0, E, So, ϕ and T_0 and lower υ. This is due to:

- Strong quartz and other stable minerals such as K-feldspar and plagioclase play a significant role in supporting the external applied load.
- The present of mica and other grains which can be deformed plastically causes the loads unhomogeneously distributed through the relatively low strength minerals.
- Cementation will support the external load by increased number of grain contact per surface area.

From figure 8, we also see that the yield point and slope of the curve from sample with higher amount of quartz, lower amount of mica and higher degree of cementation are higher compared to the others. While, the yield point and slope of sample with lower amount of quartz, higher amount of mica and lower degree of cementation are the lowest one . These show that sample with higher amount of quartz, lower amount of mica and higher degree of cementation was deformed more elastically. These samples are difficult to compact even under the high stress.

3.4 Conclusion

The study has shown that strength and behavior of the rock are affected by petrographical rock properties. This will help engineer to evaluate more accurately the mechanical rock properties from well logs.

The rocks with finer grain size, poorer sorted, higher amount of quartz, feldspar and other stable minerals, lower amount of mica and plastic deformation minerals and higher degree of cementation will have higher compressive strength, tensile strength, shear strength, friction angle, Young modulus, lower Poisson ratio and is more stable. These rocks will be deformed more elastically and difficult to compact even under the high stress.

Nomenclature

A   = area of cross section, m^2
Co = compressive strength,   MPa
D   = diameter, mm
E   = Young mudulus, GPa
F   = force, KN
L   = length, mm
So = shear strength, MPa

τ = tensile strength, Mpa

σ = stress, Mpa

ε = strain

υ = Poisson's ratio

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Table 1: Results of thin section an[...]

Sample Group	Grain size	Sorting	Mineralogy														
			Rock grains			Rock fragments					Cements			Accessory minerals		
			Q	F	M	Gr	Vo	Qz	Ch	Sh	C	Ca	q	T	E	Z
A	F-M	W	58.8	10.8	1.0	Ir	2.2	2.8	2.4	Tr	20.0	0.6	1.3	0.1	Tr	Tr
B	F-M	M	55.5	9.0	2.8	1.7	2.5	4.0	3.7	Tr	18.0	0.2	2.3	0.3	Tr	Tr
C	F-M	W	59.1	7.0	0.5	0.5	0.5	3.3	3.0	Tr	24.5	0.1	1.0	0.5	Tr	Tr
D	F-M	P	60.1	7.3	0.6	0.3	0.5	3.1	3.1	Tr	23.1	Tr	1.3	0.6	Tr	Tr
E	VF-F	W	58.0	9.9	2.5	1.0	1.5	4.1	1.3	0.8	18.0	0.2	2.7	Tr	Tr	Tr
F	M-C	M	49.9	16.8	7.3	Tr	3.0	4.0	3.4	1.0	13.5	Tr	1.0	0.1	Tr	Tr
G	M-C	P	54.0	14.7	4.5	0.2	3.0	3.6	3.2	0.8	15.1	Tr	0.7	0.1	0.1	Tr
H	M-C	P	57.7	9.0	2.7	1.1	1.7	4.3	1.5	1.0	17.8	0.1	3.1	Tr	Tr	Tr

Tr: trace

Table 2: Results of XRD
analysis

Sample Group	Quartz	Feldspar	Mica/Illite	Clays
A	67.8	8.0	1.0	23.2
B	63.9	6.5	3.5	26.1
C	71.1	5.0	1.0	22.9
D	70.0	4.7	1.2	24.1
E	70.4	5.1	2.8	21.7
F	60.2	11.0	8.5	20.3
G	60.4	9.3	6.6	23.7
H	69.2	5.6	3.0	22.2

Table 3: Results of mechanical properties tests

Sample Group	Co (MPa)	E (GPa)	?	So MPa	?	To (MPa)
A	56.7	14.63	0.17	18.1	44.5	1.81
B	51.2	11.08	0.19	15.5	44.0	1.82
D	67.5	15.02	0.16	18.0	46.0	1.84
F	21.0	7.60	0.32	12.8	39.7	1.03
H	44.5	9.87	0.24	13.1	41.5	1.52
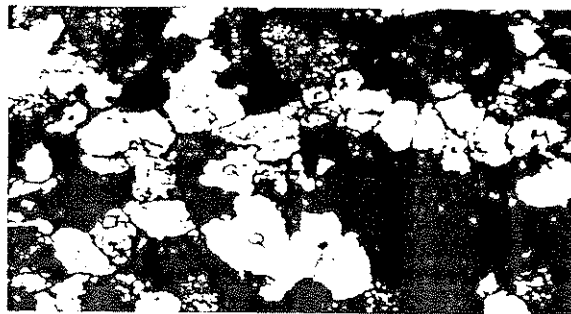
Fig 1: Sample group A: Fine to medium grained sandstone subarkose, well sorting. The composition consists of quartz (Q), feldspar (F), chert (Ch) and high degree of cementation.
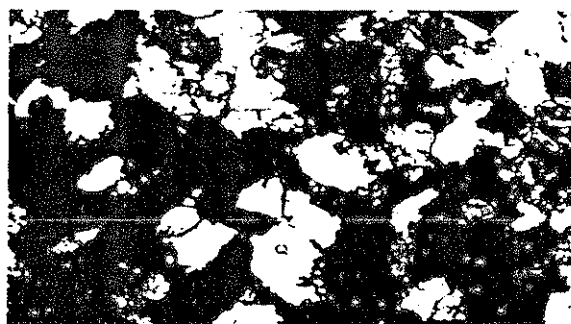
Magnification: 70x

Fig 2: Sample group B: Fine to medium grained sandstone subarkose, moderately sorting. The composition consists mainly of quartz (Q), feldspar (F), mica (M), chert (Ch), tourmaline (T) and intermediate degree of cementation.
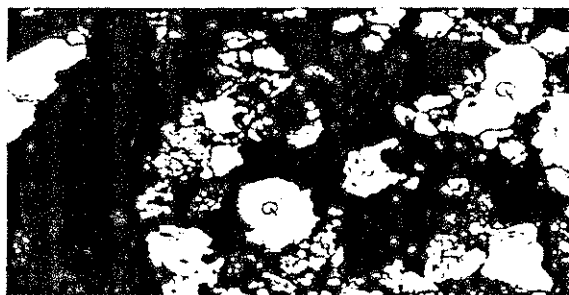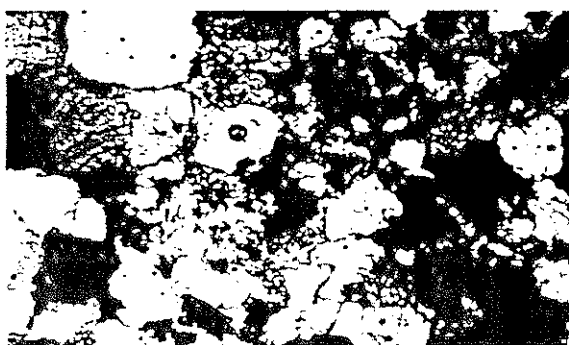
Magnification: 70x

Fig 3: Sample group D: Fine to medium grained sandstone subarkose, poorly sorting. The composition consists mainly of quartz (Q), feldspar (F), microquartzite (Mq), tourmaline (T) and high degree of cementation .

Magnification: 70x

Fig 4: Sample group F: Medium to coarse grained sandstone Lithic Arkose, moderately sorting. The composition consists mainly of fractured quartz (Q), weathered feldspar (F), mica (M), and low degree of cementation .
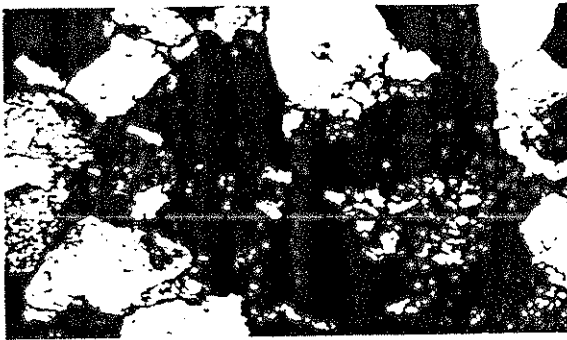
Magnification: 70x

Fig 5: Sample group H: Medium to coarse grained sandstone Lithic Arkose, poorly sorting. The composition consists mainly of quartz (Q), feldspar (F), chert (Ch), volcanic fragment (V), moderately degree of cementation .
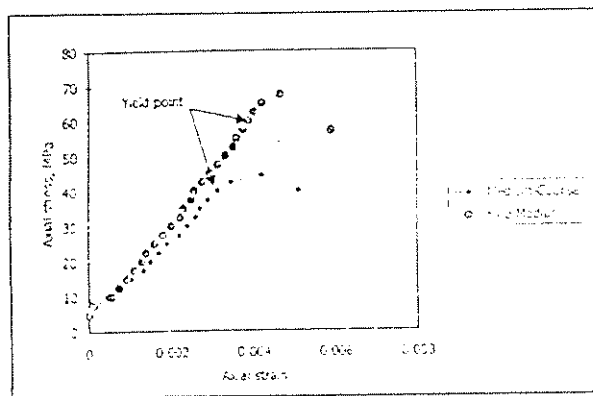
Magnification: 70x

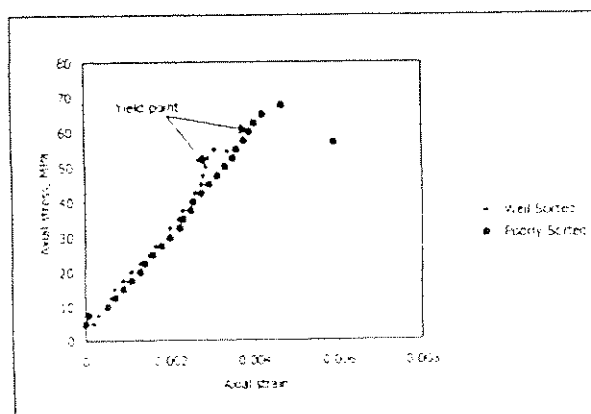Fig 6: Effects of grain size to the stress-strain behavior.

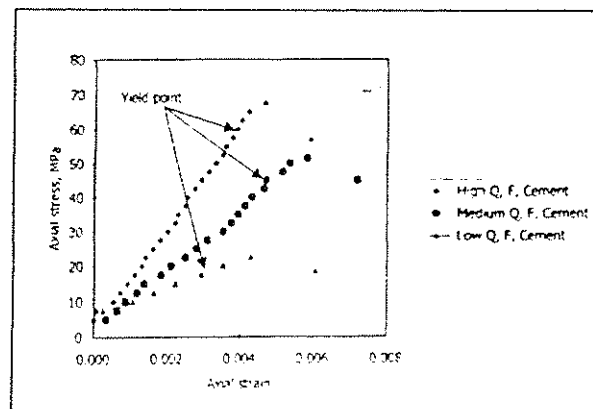Fig 7: Effects of sorting to the stress-strain behavior.

Fig 8: Effects of mineralogy and cementation to the stress-strain behavior.