Characterization of Malaysia Sand for Possible Use as Proppant

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Abstract

This paper presents results on literature and experimental works on Malaysia local sand for possible use as proppant specifically local sand resourced from Terengganu area. This project includes the study on the characteristics of proppants and research on the laboratory experiments in testing the characteristics of Terengganu sand as proppant. The sand sample from the desired area are tested by its; particle size distribution, density, roundness and sphericity, turbidity, mineralogy, crush resistance, permeability, and conductivity. The sand characteristics should meet the specifications set by American Petroleum Institute (API RP 56) or International Standard Organization (ISO 13503-5) for commercial proppant. The results obtained from the analyses are compared to the existing sand based proppant in the market. The size distribution, turbidity and bulk density of Terengganu sand agree with the commercial proppant. Even though Terengganu sand do not completely surpass the typical sand based proppant at certain characteristics (roundness, sphericity, crush resistance), they show promising results and meet some of the API and ISO requirements. Recommendations are also proposed in this paper for future improvement in increasing the quality of project results.

Index Terms: hydraulic fracturing, Malaysia sand, proppant, well stimulation.

1. INTRODUCTION

Hydraulic fracturing is a well stimulation method specially performed on reservoirs with low permeability to ease the flow of hydrocarbon into wellbore. Specially engineered fracturing fluid is pumped into the pay zone or desired fracturing area at rate and pressure high enough to extend and wedge the fracture hydraulically (Veatch, 1989). Propping agent, proppant such as grain of sand is added to the fracturing fluid to keep the fracture open. Presently, there is still no local proppant manufacturer and supplier in Malaysia. Proppant is produced commercially from overseas, especially in the United States and Canada. These circumstances lead to unsecured supply of proppant and instability of well stimulation cost.

In Malaysia, the abundant amount of natural silica sand is devoted to the country's glass-making and construction industry (Kwan, 2006). Until today, there is still no local proppant producer and supplier, which leave the Malaysian oilfield developers with no other choice but to import proppant from foreign suppliers which contributes to the high cost of well stimulation. Therefore, an alternative of producing proppant locally could help reducing this problem. The abundant source of silica sand in Malaysia shows a potential for Malaysia to produce its own proppant. By introducing the application of Malaysian silica sand as proppant, it is also hoped that Malaysia economy would boost up with the progression of the sand industries and the reduced cost of well stimulation. Up till today, no prior studies have been done on the local silica sand for the use as proppant. This project will give an approach of the properties of local sand for the possible use as proppant.

By introducing our abundant natural resource for application in the oil and gas industry, this can contribute to improvement in Malaysia economy especially if our proppant is qualified to be exported to the global market. Currently, silica sand based proppant is the most commonly used proppant in the U.S due to its ready availability and low cost (Veatch *et al.*, 1989). This proppant is employed for closure stress below 5000 psia due to its propensity to disintegrate at higher closure stress (Youngman et al., 2002). But its low cost and abundance existence, adjustment and enhancement have been made to increase it strength such as resin and epoxy coating.

2. METHODOLOGY

The experiments conducted are totally influenced by the availability of the facilities provided by the university. Adjustments and modifications have been done from the Recommended Practice (API RP 56) according to equipments availability.

Sieve Distribution and Grain Size

First, sample is dried to a constant weight at a temperature of 110 +/- 5ºC (230 +/- 9ºF). Suitable sieve sizes are selected to obtain the required information as specified and are nested in order of decreasing size of opening where the pan is placed below the bottom sieve. The sample is placed on top sieve and lid is placed over top sieve. The sieves are then agitated by a sieve shaker for 10 minutes. The weight of material retained is determined on each sieve. The percentages of passing and total of percentages retained are calculated and sieve distribution graph is plotted.

Bulk Density

An empty 100ml (100cc) measuring cylinder is placed on the weighing machine and the reading on the machine is set to zero. Next, the measuring cylinder is filled with the sand sample until the reading is 100ml. The reading is taken and bulk density is calculated from equation

$$\text{Bulk Density, } \rho = \frac{\text{weight of dry sand (g)}}{\text{Volume of dry sand (cc)}}$$

Roundness and Sphericity test

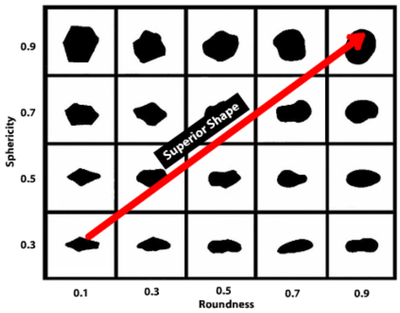


Figure 1. Krumbein Roundness and Sphericity Chart

SEM machine is used to observe sand particle in magnification of 20x and 40x. The results are then compared with the Krumbein Roundness Sphericity Chart to determine the degree of roundness and sphericity.

Turbidity Test

5g of sample is placed in the sample cell. The cell is filled with distilled water to the line (about 15 ml), taking care to handle the sample by the top. The cell is then capped and shaken vigorously to suspend the particles present for 30 s +- 5 s. The sample cell is placed in the turbidimeter and the turbidity readings are taken.

X-Ray Fluorescence Test

XRF is used to determine the mineralogy of a material. XRF is non-destructive, multi-elemental, fast and economical if compare to other competitive techniques. The samples that are to be analyzed has to be compacted n pallet before the analysis can be conducted.

X-Ray Diffraction Test

XRD is used to detect traces of minerals in a material. X-ray powder diffraction is a rapid analytical technique primarily used to phase identification of a crystalline material. For this project, it is used to confirm the XRF results.

Crush Resistance Test

The sieved sand (-20/+40 US Mesh) is filled into the crush cell to a concentration of 1.95g/cm^2. A uniform loading rate is applied to the cell to reach the desired stress level (500 psi, 1000 psi, 1500 psi, 2000 psi, 2500 psi and 3000 psi) and the stress is held for 2 minutes before released. Material is then sieved again after the crush test is carried out. The amount of the crushed material is calculated as percent weight of proppant smaller than specified range.

Conductivity Test

For this test, benchtop permeability system is being used to calculate the conductivity of sand pack where

$$kW_f = 5.41X10^{-4}\,\mu\,Q/(\Delta P) \quad \text{(SI units)}$$

$$kW_f = 26.78\,\mu\,Q/(\Delta P) \quad \text{(US customary units)}$$

W_f is the proppant pack width which is 2.54 cm according to the mould that is used to hold the sand in the core holder.

The results for this experiment are represented in computer data acquisition system software which is purchased together with the equipments. The software computes the value of permeability according to Darcy's Law equation. This test is conducted with 30 000 ppm brine solution as the test liquid.

3. RESULTS & DISCUSSION

Sand samples from Kampung Meraga and Kampung Batu Tampin, Kemaman have been obtained. Besides the local sand sample, commercial proppant has also been obtained. From now on, these indications will be used for these three samples;

Commercial proppant : Sample 1
Kampung Meraga : Sample 2
Kampung Batu Tampin : Sample 3

Sieve Analysis

More than 70% of the sand particles is in the range of 0.3 – 0.6 mm. But most importantly, the results show that the sand is in the range of desired particle size of 0.41 – 0.72 mm. The sand is not tightly distributed, which means they are not greatly uniform which could due to the sampling method.

Table 1. Particle Size Distribution

Sieve Size (mm)	Percentage retained (%)		Total Passing (%)	
	Sample 2	Sample 3	Sample 2	Sample 3
1.180	1.26	2.94	1.26	2.94
0.600	20.04	29.27	21.30	32.21
0.425	50.40	52.66	71.69	84.87
0.300	21.19	12.85	92.89	97.72
0.212	6.41	2.06	99.30	99.77
0.150	0.62	0.17	99.92	99.95
0.063	0.06	0.08	99.98	100.03
Pan	0.02	0.02	100.00	100.05

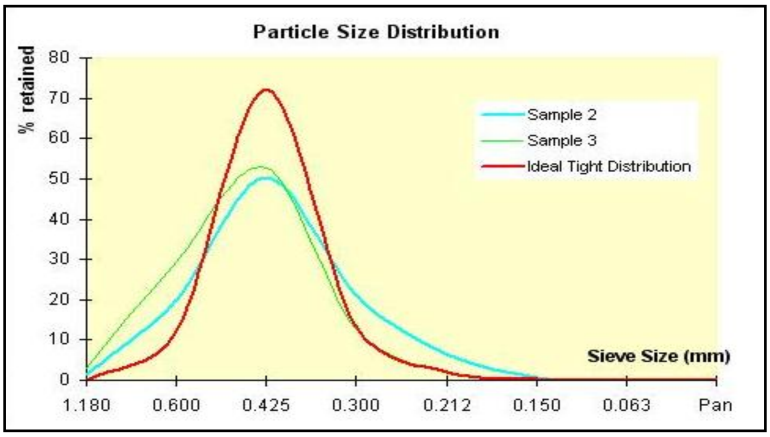


Figure 2. Particle Size Distribution

Bulk Density

The bulk density of all three samples has been measured without the closure stress. The bulk density will increase substantially if the proppant is under the reservoir condition.

Table 2. Bulk Density for Sand Sample

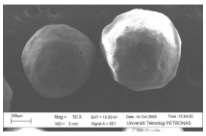
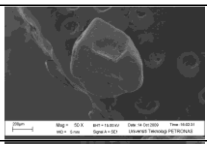
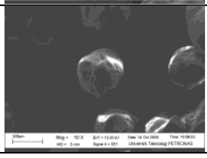
Sample	Density (g/cc)
Sample 1	1.60
Sample 2	1.49
Sample 3	1.46
Ottawa	1.54
Brady	1.57

Result shows that the local sand possesses lower density value. Proppant is typically purchased by mass. However the benefit of a proppant is based on its volume. For typical hydraulic fracturing, the density of the proppant will significantly impact the achieved fracture width (CarboCeramics, 2008). Fracture width will be narrower with denser proppant.

Roundness and Sphericity Test

Roundness and sphericity influence on porosity of the proppant pack once it is being injected into the formation. Typical sand proppant should possess the value of 0.7 for both roundness and sphericity. As shown in Table 3, Sample 1 meets the requirement for desired roundness and has ideal value for sphericity. The local sand samples however do not meet the desired value. The roundness and sphericity of our local sand do not transgress greatly comparing to the required value. Some adjustment could be looked upon in mending this drawback

Table 3. Roundness and Sphericity of Sand Samples

Sample	Mag: 40x	Roundness	Sphericity
Sample 1		0.7	0.9
Sample 2		0.5	0.7
Sample 3		0.5	0.7

Turbidity Test

Ottawa and Brady sand has the maximum turbidity value of 250 FTU. All three samples meet the requirement that is set by the industry for turbidity.

Table 4. Turbidity of Sand Samples

Sample	Turbidity (FTU)
Sample 1	226
Sample 2	232
Sample 3	241

X-Ray Fluorescence Test

The surveying report from The Department of Mineral and Geosience Malaysia (JMG) has provided us with the initial study on the chemical composition possessed by the sand samples of Kampung Meraga and Kampung Batu Tampin. From the XRF analysis, the results obtained have been tabulated as below;

Table 5. Sand Samples Composition (XRF Analysis)

Content (Weight %)	Sample 1	Sample 2	Sample 3
SiO_2	**46.07**	**88.94**	**88.18**
Al_2O_3	49.46	5.30	5.73
K_2O	0.0948	1.47	1.14
Cr_2O_3	0.0127	Nil	Nil
Fe_2O_3	1.053	0.8379	1.034
ZrO_2	0.06639	0.0043	Nil
CaO	0.181	1.43	1.50
MgO	Nil	0.905	1.18
TiO_2	2.237	0.144	0.204
MnO	Nil	0.009	0.010
Rb_2O	Nil	0.0040	Nil
P_2O_5	0.776	0.958	1.01
V_2O_5	0.0317	Nil	Nil
Ga_2O_3	0.0091	Nil	Nil
SrO	nil	0.0061	0.0066

Sample 2 and 3 show high content of silica which indicates good purity of silica sand. Sample however shows high percentage of Al_2O_3. Al_2O_3 is an additive that has been added to increase its strength. More information on this additive is discussed in the results of the next mineralogy analysis, XRD.

Table 5. Sand Sample Composition (JMG Report)

Composition	Mean (%)	
	Sample 2	Sample 3
SiO_2	99.16	98.51
Fe_2O_3	0.037	0.044
TiO_2	0.54	1.27
Al_2O_3	0.029	0.030
L.O.I	0.22	0.16

X-Ray Diffraction Test

Sample 1 shows traces of mullite, an important constituent in porcelain. Mullite, $Al_6Si_2O_{13}$ is used widely as a protective coating due to its high strength (6 – 7 Mohs Scale Hardness) and its insolubility in acid, including HF (Bowen *at al.*, 1924). The presence of mullite in Sample 1 indicates that Sample 1 had been treated before it is sold in the market

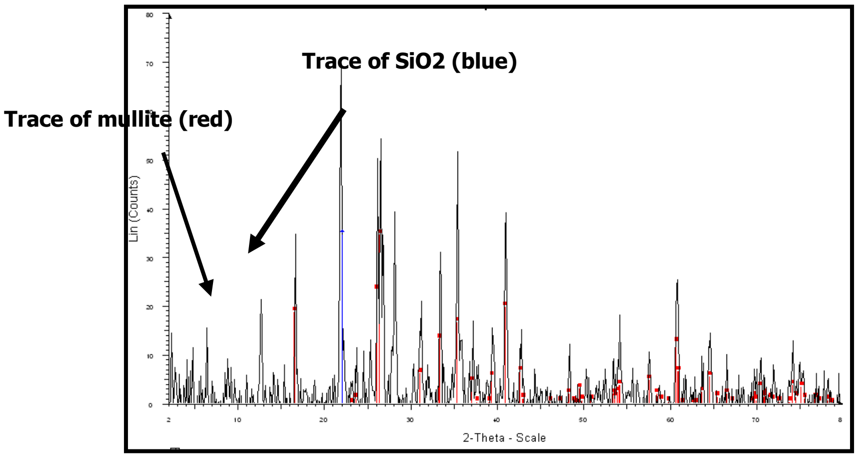


Figure 3. XRD Analysis of Sample 1

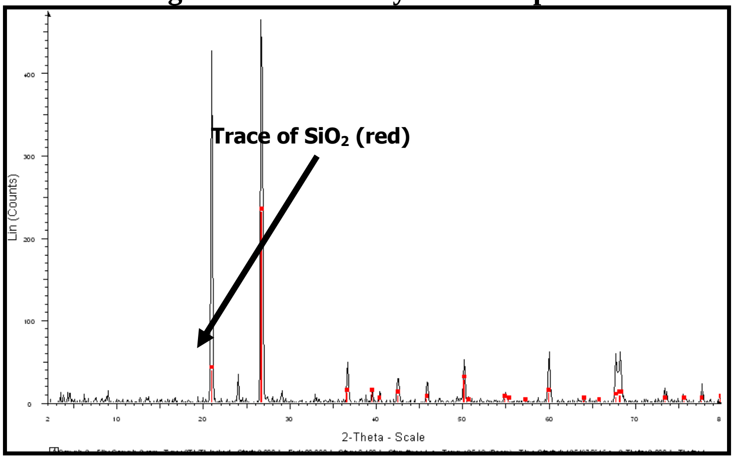


Figure 4.XRD Analysis of Sample 2

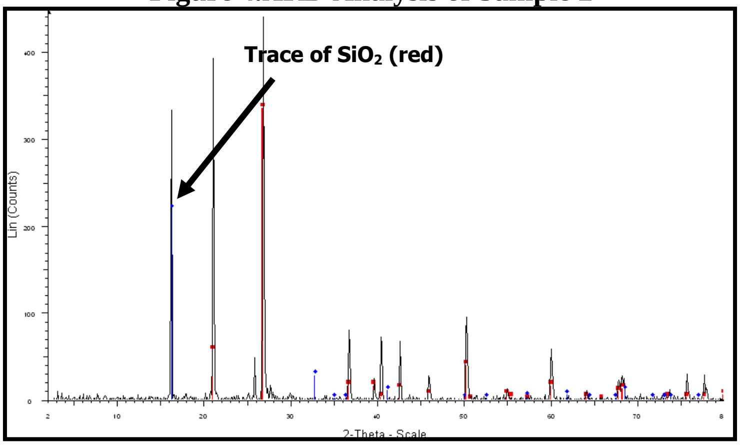


Figure 5. XRD Analysis of Sample 3

Crush Resistance Test

Table 6. Crush Results for Sand Samples

psi	% of Fine		
Pressure	Sample 1	Sample 2	Sample 3
500	0	3.25	1.913478
1000	0	9.916667	9.833333
1500	-	16.81781	15.47421
2000	5.041322	20.45827	19.83333
2500	8.264463	23.71901	23.83333
3000	11.83333	-	-

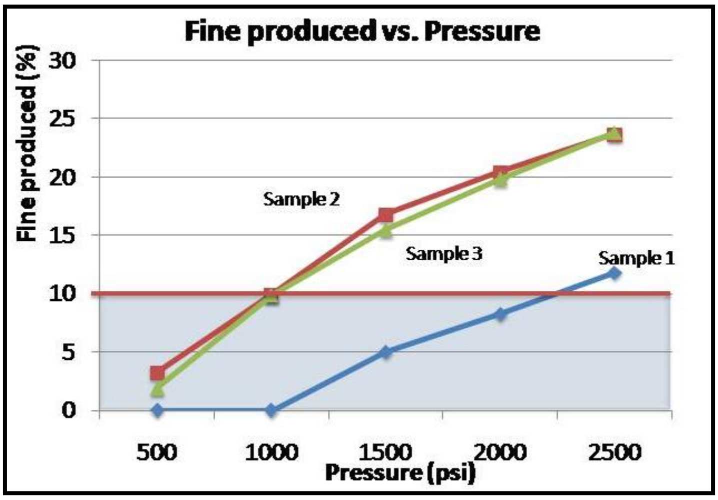


Figure 6. Crush Resistance Comparative Graph

API standard only allows 10% by weight of fine production after pressure is exerted on it. Sample 1 shows really high crush resistance comparing to Sample 2 and 3 where it does not produce 10% of fine by weight until 2250 psi confined pressure. As mentioned previously, particle shape influences the crush resistance of the sand. Angular grains tend to crush easier comparing to rounder ones. Sample 1 has also been treated with mullite, a chemical which contributes to its high strength.

Conductivity Test

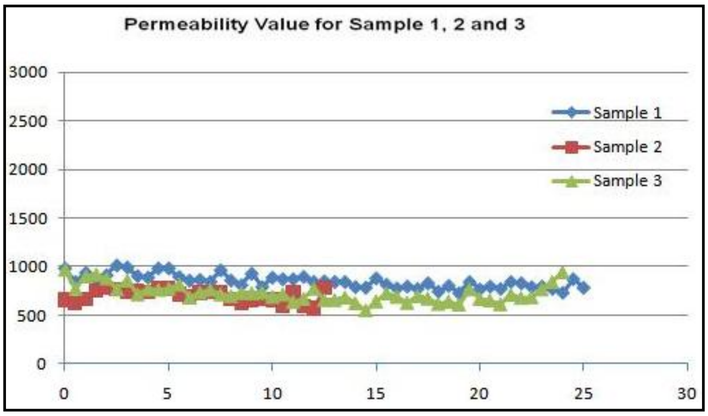


Figure7. Permeability of Sand Samples

Averaged values of permeability for all three samples are obtained once a constant line is produces from the experiment. Sample 1 possesses the highest value of permeability, followed by Sample 2 and Sample 3. The particle shape of Sample 1 which is high in roundness and sphericity contributes to its high permeability, comparing to Sample 2 and 3.

From the value of permeability obtained, conductivity can be determined from the equation,

$$kW_f = 5.41X10^{-4}\,\mu\,Q/(\Delta P) \quad \text{(SI units)}$$

$$kW_f = 26.78\,\mu\,Q/(\Delta P) \quad \text{(US customary units)}$$

Where k ispermeability in millidarcies, mD

μ is1.05 cp

Q is1.50 cc/sec
L is5.08 cm
A is 5.06 cm^2
ΔP is a variation from 0.1 psi to 0.5 psi

We have learnt that the proppant pack width, W_f is equal to the diameter of the mould, **2.54 cm** or **0.0833 ft**. The results for the conductivity of all three samples are presented in Table 4.13.

Table 7. Conductivity Value for Sample 1, Sample 2, and Sample 3

Sample	Permeability	Conductivity	
		mD.cm	mD.ft
Sample 1	836	2123.44	69.64
Sample 2	698	1772.92	58.14
Sample 3	672	1706.88	55.98

Sample 1 gives the highest value of conductivity comparing to Sample 2 and Sample 3. Be reminded that the equipment utilized for this particular conductivity test is not the standard equipment for proppant testing. For this reason, the dependency on the accuracy of the results is still questionable. However, the outcome of this experiment should give good initial indication on the qualitative assessment on the samples.

4. CONCLUSION & FUTURE DIRECTIONS

The present studies can be deduced as below;

- Sample 2 and Sample 3 show good potential for possible use as proppant with certain limitations.
- From the early reports by JMG, both Sample 2 and 3 possess high purity of SiO2 which is >98% (Johari and Eki, 2001). Sample 2 has the mean value of 99.16% and Sample 3 has the mean value of 98.51%
- The sphericity and roundness for both local sand sample have the same range of 0.5 – 0.7 RS on the Krumbein Chart.
- The density and the turbidity of both local sand sample meet agree with the density and the turbidity of the commercially available proppant.
- Both Sample 2 and Sample 3 start to produce more than 10% fine under the pressure of 1000 psi and above. The two samples could be used as proppant for reservoir with the pressure less than 1000 psi. For pressure above 1000 psi, the fines produced would fill the porous medium in between the sand particle hence the permeability will be reduced.
- The conductivity of local sand is 16 – 20% lower than the commercial proppant. Even though the test is not conducted according to the recommended practice API RP 56, this shows good comparison in between commercial proppant (Sample 1) to possible local proppant (Sample 2, Sample 3).

Based on the results, it is possible for Malaysia to produce our own local proppant with some essential adjustments;

1) To coat the sand with resin for improved characteristics

Coating sand with resin could improve the roundness and sphericity of sand particle. Resin could provide better resistance for the sand on high closure stress. Furthermore, resin-coated sand can reduce the proppant flow back problem that can cause the fracture to close and reduce the permeability.

2) To coat sand with mullite

As discovered on Sample 1 which is treated with mullite, our local sand's strength can be improved with the presence of mullite. Besides improving the strength, coated-sand will also be protected from acidic environment as mullite is insoluble in acid, HF included where silica dioxide would dissolve in HF (Bowen *et al*., 1924).

3) To collaborate with proppant testing company

Until today, there are few proppant testing companies which are active in the industries such as PropTester (United States of America), PANterra (The Netherlands), and FracTech Laboratories (England). If the university could have collaboration with a proppant testing company, tests can be done with standard procedures where the results would be more representative and reliable.

REFERENCES

[1] Aw, P.C.: "Geological Survey Report: Silica Sand Deposits at Batu Tampin and Kampung Meraga, Kemaman, Terengganu ": Jabatan Mineral dan Geosains Malaysia (1978).

[2] Bench Top Permeability System, BPS-805 Operator's Manual, Geosciences and Petroleum Department, Universiti Teknology PETRONAS (September 2009).

[3] Bowen, N. L., Greig, J. W. and Zeiss, E. G.: "Mullite, a new silicate of alumina" (1924).

[4] Determination of Particle Size Distribution Laboratory Manual, Civil Engineering Department, Universiti Teknologi Petronas (July 2009).

[5] "Industrial Mineral Production Statistics and Directory of Producers in Malaysia 2007," ed. Minerals and Geoscience Department Malaysia (2007).

[6] Introduction to X-Ray Diffraction, Bruker AXS (2001)

[7] Kaufman, P. et al.: " SPE 110697: Introduction New API / ISO Procedures for Proppant Testing", Society of Petroleum Engineers, presented in *2007 SPE Annual Technical Conference and Exhibition* (Anaheim, California, USA, 2007).

[8] Kwan, P.T.:"The Mineral Industry of Malaysia 2006,"Geological Survey, US Department of Interior (accessed 24 February 2009). Available : http://minerals.er.usgs.gov/minerals/pubs/country

[9] Mullite, AzoMaterials, (accessed on 27 October 2009). Available : http://www.azom.com/Details.asp?ArticleID=925

[10] Veatch, R.W Jr. et al.: "An Overview of Hydraulic Fracturing," in *Recent Advances in Hydraulic Fracturing*: SPE (1989).

[11] Youngman, R., Okel, P., Akbar, S.: "Proppant Composition for Gas and Oil Well Fracturing," Fairmount Minerals, Ltd (2002).