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Comparative Characterization Study of Malaysian Sand as Proppant

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***Abstract*—**This paper presents a review on published literature and experimental works on local sands for possible use as proppant, specifically those from Terengganu coastal area. This includes examination on characteristics of sand samples and selection of experiments for proppant testing. Sand samples from identified areas were tested according to particle size distribution, density, roundness and sphericity, turbidity and mineralogy. Results from sand samples were compared against proppant specifications set by API RP 56 and selected commercial proppants. The present study found that the size distribution, sphericity, turbidity and bulk density of Terengganu sands are at par with some of commercial proppants. Nevertheless, Terengganu sand samples do not completely surpass the required roundness for use as proppant.

***Keywords*—**Hydraulic fracturing, Malaysia sand, proppant, well stimulation.

I. INTRODUCTION

HYDRAULIC fracturing is a well stimulation method specially performed on reservoirs with low permeability to ease the flow of hydrocarbon into the wellbore. Specially engineered fracturing fluid is pumped into the pay zone or desired fracturing area at a rate and pressure high enough to extend and wedge the fracture hydraulically [1]. It has been estimated that up to 90 percent of the wells currently operating today have been fractured, and in the future, 60 to 80 percent of new wells may have to undergo fracturing in order to remain viable [2]. Propping agent, proppant such as grain of sand is added to the fracturing fluid to keep the fracture open.In Malaysia, the abundant source of natural silica sand is devoted to the country’s glass-making and construction industry [3]. Malaysian oilfield developers have been dependent on foreign suppliers which unnecessarily contribute to the high cost of well stimulation. Up till today, there is still no local proppant manufacturer in Malaysia and it appears that no prior studies have been conducted on the Malaysian sand for the use as proppant. Currently, sand based proppant is the most commonly used proppant in the U.S mainly due to its ready availability and low cost [1]. This proppant is employed for closure stress below 5000 psia due to its propensity to disintegrate at higher closure stress [4]. Strength comparisons for proppants used by the industry are shown in Fig. 1.

Resin coatings have been applied to sand to improve proppant strength. Resin-coated sand is stronger than conventional sand and may be used at closure stresses not higher than 8000psi, depending on the type of resin-coated sand [5]. Various resin coatings have also been used to reduce fines migration by encapsulating the grain and cementing the grains in place. Resins are also expected to add a degree of geochemical stability to the material [6].

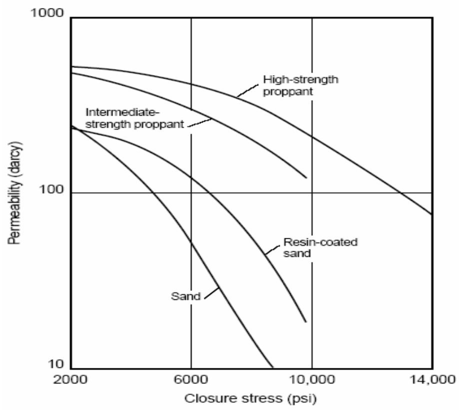

Fig. 1 Strength comparison of various types of proppants [5]

Resin helps spread stress over a large area of the sand grain and reduces the point loading. When grains crush, the resin coating helps encapsulate the crushed portions of the grains and prevents them from migrating and plugging the flow channel. Adding resin coating to proppant will greatly reduce proppant scaling [7]. Resin coating provides a hydrophobic layer that prevents water from dissolving the proppant surface and forming [8].These studies examine the properties of Malaysian sands such as grain size distribution, proppant strength, quantities of fines and impurities, roundness and sphericity and proppant density. The purpose of this study was to compare the characteristics between Malaysian sand with the existing commercial proppants in the market. The following experiments were performed on sand samples in accordance with API RP 56 [9] and ISO 1350-3 [10].

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II. EXPERIMENTAL SETUP

A. Sand Sampling

Field investigation was carried out from identified sites in Terengganu coastal area. Sand samples were collected from 0.6 meter to 1.0 meter depth from the surface as required by Geological Survey Department of Malaysia. The sand layer ranges from 0.3 meter to 3.5 meters in thickness. The average thickness was about 1.4 meters. The silica sand layer was usually the second layer below the overburden which varies from 10 to 30 cm thick and it consisted of grey to very light grey sand, which might vary in thickness from a few tenths of centimeters to about 3.5 meters [11]-[14]. Sample of Ceramic Proppant were collected from industry and properties of other commercial sand proppant such as Ottawa [15] and Jordan [16], [17] were referred to literature review for comparison purpose. From now on, these indications will be used for these eight samples;

Kampung Meraga, (Malaysia) : Sample 1
Kampung Batu Tampin, (Malaysia) : Sample 2
Kampung Rantau Abang B (Malaysia) : Sample 3
Kampung Kuala Abang (Malaysia) : Sample 4
Bukit Senyamok, Dungun (Malaysia) : Sample 5
Ceramic Proppant (China) : Sample 6
Ottawa White 30/70 (United State) : Ottawa
White Silica Sand (Saudi Arabia) : Jordan

B. Sieve Distribution and Grain Size

Samples were first dried at a temperature of 110 ± 5ºC (230 ± 9ºF). Suitable sieve sizes (16 to 100 mesh) were used to obtain the required information as specified and nested in order of decreasing size of opening where the pan was placed below the bottom sieve. The sample was placed on the top sieve and lid is placed over top sieve. The sieves were then agitated by a sieve shaker for 10 minutes. The weight of material retained was determined on each sieve. The percentages of passing and total of percentages retained were calculated and sieve distribution graph was plotted.

C. Bulk Density

An empty 100ml measuring cylinder was placed on the electronic balance and recorded. Next, the measuring cylinder was filled with the sand sample until the reading was 100ml. The reading was taken and bulk density was calculated from equation:

$$Bulk \quad Density = \frac{volume \;\; of \;\; dry \;\; sand(g)}{volume \;\; of \;\; dry \;\; sand(cc)}$$

D. Roundness and Sphericity test

SEM machine and microscope were used to examine sand particle in magnification of 20x and 40x. The results were then compared with the Krumbein Roundness Sphericity Chart (Fig. 2). The sphericity and roundness were recorded and an average roundness and sphericity were obtained. An average value of 0.6 or higher meets API RP 56 [9] specifications.

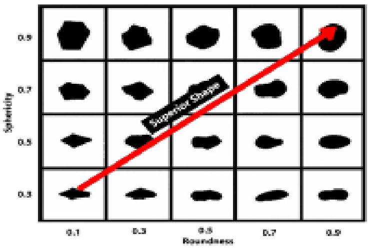


Fig. 2 Krumbein Roundness and Sphericity Chart [9]

E. Turbidity Test

5g of sample was placed in the sample cell. The cell was filled about 15ml of distilled. Then, the cell was capped and shaken vigorously to suspend the particles present for 30 s ± 5 s. The sample cell was placed in the turbidimeter for measurement.

F. Mineralogy Test

Baseline mineralogy tests were also conducted n proppant samples, including XRF and XRD. Mineralogical tests determined that sands were clean silica sand with trace ammount of iron, aluminium, titanium and potassium. Ceramic proppant contained high amount of aluminum with varying amount of silicon, titanium and magnesium.

III. RESULTS AND DISCUSSION

A. Sieve Analysis

Table I shows mean diameter and percentage in size for sand samples as compared with commercial proppants. The mean diameters of Malaysian sand samples were in the range of 0.17 – 0.28 mm. The sand samples were tightly distributed, which means they are greatly uniform. Proppants with larger grain sizes provide a more permeable pack; however, their use must be evaluated in relation to the formation that is propped and the increased difficulties encountered in proppant transport and placement.

TABLE I
MEAN DIAMETER AND PERCENTAGE IN SIZE FOR SAND SAMPLE

Sample	Mean Diameter	**In size (%)**
Sample 1	0.25	90.55
Sample 2	0.28	91.02
Sample 3	0.18	90.05
Sample 4	0.17	92.85
Sample 5	0.27	92.92
China	0.28	99.96
Ottawa	0.33	88.58
Jordan	0.24	92.20

Fig. 3 shows that all of the Malaysian sand samples, China and Jordan proppant meet API standards that require 90% of the sample be retained within a designated size range except Ottawa. Large proppants (e.g. 16/20 or 12/18 products) are poor candidates for dirty formations or subject to significant fines migration. The fines tend to invade the proppant pack, causing partial plugging and rapid reduction in permeability. In these cases, smaller proppant which resist the invasion of fines are more suitable. Although they offer less initial conductivity, the average conductivity over the life of the well will be higher and will more than offset the initial high provided by larger proppants. Malaysian sands belong to smaller proppant since the diameter range from 40/70 product.

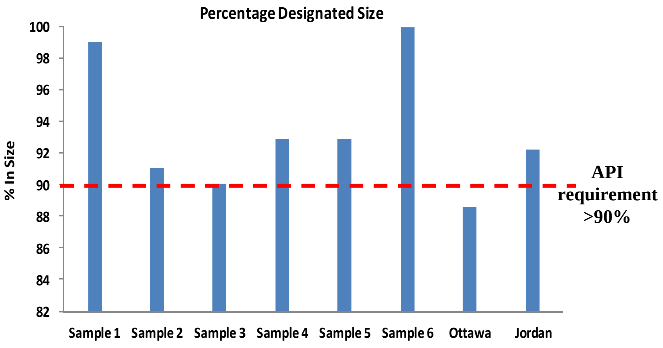


Fig. 3 Percentage designated in size comparative graph

Table II shows that Sample 2 and Sample 5 were failed to meet API standard than more than 0.1% larger than first sieve. Ottawa failed to meet API standards resulted in more than 1.0% of the sample can fall through the last sieve.

Fig. 4 shows grain size distribution of all Malaysian sand samples against commercial proppant and the average grain distribution for all samples were in the range of 0.150 -0.425 mm. If the grain size distribution contains a high percentage of the smaller grains, the proppant-pack permeability and conductivity will be reduced [5].

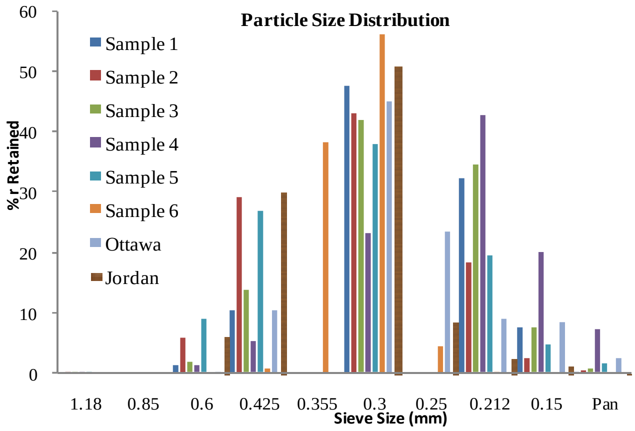


Fig. 4 Particle Size distribution Comparative Graph

TABLE II
PARTICLE SIZE DISTRIBUTION

Sieve Size (mm)	Percentage retained (%)							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Ottawa	Jordan
1.180	0.02	0.21	0.04	0.14	0.13	-	-	-
0.850	-	-	-	-		-	0.00	0.00
0.600	1.47	5.92	1.86	1.14	9.05	0.00	0.36	6.1
0.425	10.5	29.4	13.6	5.15	26.9	0.73	10.6	30.1
0.355	-	-	-	-	-	38.4	-	-
0.300	47.7	43.1	41.9	23.3	38.1	56.3	45.2	51.1
0.250	-	-	-	-	-	4.37	23.6	8.7
0.212	32.4	18.5	34.5	42.9	19.7	0.15	9.14	2.3
0.150	7.78	2.35	7.40	19.97	4.67	-	8.52	1.4
Pan	0.18	0.49	0.65	7.36	1.54	0.00	2.50	0.3

B. Bulk Density

The bulk densities of all Malaysian sand samples were measured without the closure stress. The bulk density will increase substantially if the proppant is under the reservoir condition. Result in Table III shows that all Malaysian sand and commercial proppants possessed lower densities value than China. Proppant density has an influence on proppant transport and placement. Proppant is typically purchased by mass.

TABLE III
BULK DENSITY FOR SAND SAMPLE

Sample	Density (g/cc)
Sample 1	1.49
Sample 2	1.46
Sample 3	1.56
Sample 4	1.64
Sample 5	1.75
Sample 6 (China)	1.81
Ottawa	1.53
Jordan	1.51

High density proppants are more difficult to suspend in the fracturing fluid and to transport in the fracture [5]. Fracture width will be narrower with denser proppant. Thus, higher-density proppants require more mass of material to create the same fracture with lower density proppants. For typical hydraulic fracturing, the density of the proppant will significantly impact the achieved fracture width [18]. Fracture width will be narrower with denser proppant.

C. Roundness and Sphericity

Fig. 5 shows that fracturing sand should have an average sphericity of 0.6 or greater and an average roundness of 0.6 or greater according to API PR 56. Sample 1 meets the requirement for desired roundness and has ideal value for sphericity. Local sand and Ottawa sand met the sphericity specification, but failed to meet the roundness specification of API minimum of 0.6 with values of about 0.52. However, the minimum roundness for B500 (Non-API) consideration is 0.5 which shows that all samples meet the Non API standards [19].

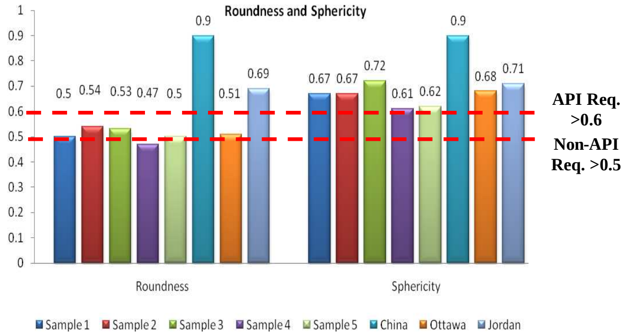
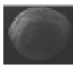
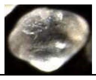


Fig. 5 Roundness and Sphericity Comparative Graph

Table IV shows values of the roundness and sphericity of sand samples as compared with commercial proppants. Roundness is a measure of the relative sharpness of particle corners and sphericity is a measure of how close the particle approaches the shape of a sphere. When the grains are round and about the same size, stresses on the propant are more distributed resulting in higher loads before grain failure occurs.

TABLE IV
ROUNDNESS AND SPHERICITY OF SAND SAMPLES

Sample	Mag: 40x	Roundness	Sphericity
Sample 1		0.50	0.67
Sample 2		0.54	0.67
Sample 3		0.53	0.72
Sample 4		0.47	0.61
Sample 5		0.50	0.62
Sample 6 (China)		0.90	0.90
Ottawa		0.51	0.68
Jordan		0.69	0.71

D. Turbidity

Turbidity in water is the results of suspended clay, silt or finely divided inorganic matter being present. Properly washed and processed fracturing sand should pass the turbidity test. The turbidity of the proppant sample should be less than 250 FTU (Formazin Turbidity Units). Turbidity measurements are indication of widespread contamination. All samples exceed the maximum turbidity limit which is 250 FTU as per API RP 56 guidelines as shown in Fig. 6. High turbidity results indicate significant contamination in each sample.

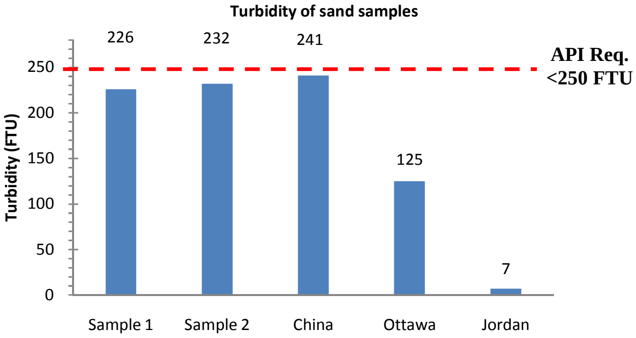


Fig. 6 Turbidity Comparative Graph

E. X-Ray Fluorescence Test

A survey from The Department of Mineral and Geosience Malaysia (JMG) from 1978 to 1989 [11]-[14] have provided the present study with the initial information on the chemical composition possessed by the sand samples of Kampung Meraga and Kampung Batu Tampin. Results from XRF analysis were tabulated as in Table V below.

TABLE V
SAND SAMPLE COMPOSITION

Chemical Composition	Mean (%)							
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Ottawa	Jordan
SiO_2	99.2	98.5	99.2	99.7	99.7	46.1	98.7	99.8
Fe_2O_3	0.04	0.04	0.002	0.002	0.02	1.05	0.1	0.01
TiO_2	0.03	0.03	0.002	0.002	0.02	2.24	0.1	0.03
Al_2O_3	0.54	1.27	0.06	0.06	0.18	49.5	1.1	0.10
L.O.I	0.22	0.16	0.03	0.10	0.12	1.17	1.3	0.06

Fig. 7 shows the mean content of SiO_2, Fe_2O_3, and Al_2O_3 respectively for all samples in comparison with commercial proppants. Iron and alumina content in Malaysian sand have far exceeded the requirement for high grade silica sand.

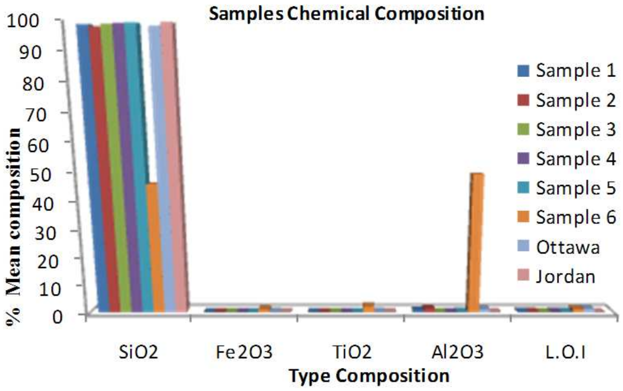


Fig. 7 Chemical Composition Comparative Graph

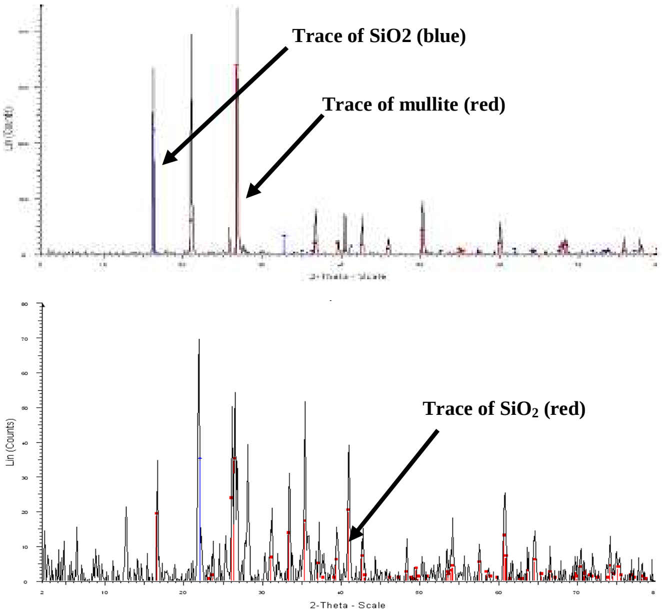
Table VI shows the content of alumina in Sample 1 is more than other samples. For high grade glass sand, the Fe_2O_3, content should be less than 0.025%, or expensive decolorizers must be used.

TABLE VI
SAND SAMPLES COMPOSITION (XRF ANALYSIS)

Content (Weight %)	**Sample 6 (China)**	**Sample 1**	**Sample 2**
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

F. X-Ray Diffraction Test

Sample 6 shows traces of mullite as shown in Fig. 8, an important constituent in porcelain. Mullite, $Al_6Si_2O_{13}$ is used widely as a protective coating due to its high strength of 6 – 7 Mohs Scale Hardness and its insolubility in acid, including HF [20]. The presence of mullite in China indicates that Ceramic Proppant had been treated before it is sold in the market.



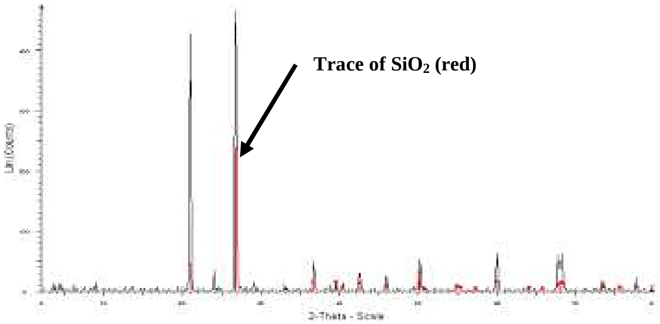


Fig. 8 XRD Analysis of Sample 6, Sample 1 and Sample 2

IV. CONCLUSION

The Malaysian sand samples do possess some of the required proppant characteristics to withstand crush resistance in maintaining desired permeability and meet API standards which require 90% of the sample to be retained within a designated size range with greatly uniform. The grain-size distribution is within the range of 0.425-0.212 mm. The bulk density of Malaysian sand is less if comparing with US Silica, China proppant and Jordan.

Malaysian sand samples and commercial proppant meet the sphericity specification, but fail to meet the roundness specification of API minimum of 0.6 with values of about 0.52. However, the minimum roundness for Non-API standards consideration is 0.5.

The turbidity of Malaysian sands agrees with the turbidity of the proppant from China, US silica sand and API RP 56 standards. On the basis of chemical composition, Iron and alumina content in Malaysian sands have far exceeded the requirement for high grade silica sand. Based on the results, it is possible for Malaysia to produce our own local proppant with some essential adjustments through coating with suitable resin materials such as phenolic and novolac resins.

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