DISSERTATION

Malaysian Sand for Proppant

by

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CERTIFICATION OF APPROVAL

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AZIZUL FIKRI BIN AHMAD NAZIRI 12538

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ABSTRACT

With the rise in hydraulic fracturing applications over the past decade, the market availability of proppants plays a more significant role in the global oilfield economy. As a result, the demand for commercially manufactured proppants is increasing, fueling the construction of new production facilities around the world. Currently, there are only a few numbers of well-known suppliers of manufactured proppants that dominate the business globally. This project aims to study the properties and characteristics of Malaysia local sand for possible use as proppant specifically local sand resourced from Sarawak area. Quality silica sand from certain areas of the Sarawak state was identified in order to collect the sample. This project includes the study on the recent development of proppant characteristics of local sand as compared to the commercial sand as the Ottawa and Brady sand. It is mostly known characteristic of proppant is its conductivity. Generally, the properties of the proppant which affect its conductivity are mainly roundness, size distribution, resistance to crush under the influence of closure stress, grain-size distribution and proppant density. These properties will be tested in the laboratory in compliance with the International Standard Organization (ISO 13503-2 and ISO 13505-5) for commercial proppant. The results obtained from the analyses will be compared to the existing sand based proppant in the market.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Hydraulic fracturing is the use of fluid and material to create or restore small fractures in a formation in order to stimulate production from new and existing oil and gas wells. Wells in low to moderate permeability reservoirs are candidates for hydraulic fracturing as a means of stimulating their performance. High volumes of fracturing fluids are pumped deep into the well at pressures above the fracturing pressure of the formation to create new fracture path or restore the small fractures in the reservoir rock (Economides et al. 2008). In the absence of a propping material, a created hydraulic fracturing will heal shortly after the fracturing pressure dissipates into the reservoir. Natural sand is the most commonly used proppant, especially in low-stress formations to hold the fracture open. Currently, there is still no local proppant manufacturer and supplier in Malaysia. Proppant used are commercially produced from overseas, especially in the United States and Canada. These circumstances lead to unsecured supply of proppant to the country and high cost of well stimulation.

Substantial silica-sand resources are found throughout Malaysia comprising largely of natural sand deposits and ex-tin mine tailings. The Department Mineralogy and Geoscience of Malaysia estimated that the country has some 148.4 million tonnes of silica-sand reserves located in the states of Johor, Perak, Terengganu, Kelantan, Sabah and Sarawak. Most of the silica are used in the manufacturing of glass products and to lesser extent in the production of ceramics, foundries, glasswool and water treatment materials(Malaysian Chamber of Mines, 2009). 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 and 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 most importantly reduced the cost of hydraulic fracturing.

By far, the most dominant proppant used worldwide is silica sand (Beckwith, 2011). In the late 1980s, Exxon patented the use of sintered bauxite which led to the development of a variety of ceramic proppants which provides higher strength, more uniformly sized and thermally more stable for deeper wells (Holditch, 2007).

1.2 Problem Statement

With the rapid increase of large volume hydraulic fracturing applications, the demand for fracturing sands and manufactured proppants has become very high. It is essential to advocate that local proppant sources be developed for use at least on the local level and possibly in the international market. With the proper resource utilization, it is possible for local supplier to manufacture quality proppant which should help minimize the current huge gap between supply and demand. Producing local sand would also avoid the situation where established large global suppliers could monopolize the proppant market.

1.3 Objective and Scope of Study

The objectives of this study are:

- To identify the location areas of Sarawak sand suitable for using as proppant for well stimulation (Field investigation)
- To investigate the properties and the characterization of the sampling sand
- To compare the properties and the characterization of the sampling sand with the commercial sand proppant

- To compare the performance of the silica with the commercial sand proppant

The scope of study includes:

- Conducting research on the latest development of proppant around the world which includes experiments or modifications done and technology used
- Conducting laboratory procedure and experiment to test the characteristics of the sampling sand using the latest international standard, ISO 13503-2

CHAPTER 2

LITERATURE REVIEW

2.0 Literature Review

The study is focusing on the characteristics of proppants and research on the laboratory experiments in testing the characteristics of Malaysian sand for proppant. Basically, the literature review will cover the fundamental theory and concept related to hydraulic fracturing and the proppants used.

2.1 Hydraulic Fracturing

Unconventional reservoirs, such as coalbed methane (CBM), shale oil/gas, and tight gas, have low permeability and require stimulation to produce hydrocarbons economically. Hydraulic fracturing has been extensively used throughout the last five decades and is still a preferred technique for stimulating a tight-rock formation. The purpose of hydraulic fracturing is to bypass formation damage, or overcome low formation permeability, and provide a long conductive flow channel for hydrocarbons to flow in the wellbore with minimum resistance, which increases the rate of oil or gas production (Kothamasu et al. 2012). Choudhary et al. (2012) stated in their paper that in a hydraulic fracturing process, a crack in the rock is created by pumping fluid through the tubing or casing at pressures higher than the rock fracture pressure. The fluid injection is continued into the induced crack fracture to make it grow larger, followed by pumping sand-laden fluid and creating a sand pack to keep the fracture open after hydraulic pressure is no longer being applied. Fracturing fluid often is a viscous fluid that has the capability to carry the proppant inside the fracture. Proppant is selected such that it can withstand the formation closure stress. Typical hydraulic fracturing consists of the following stages:

- Prepad stage – A clean (gelled or non-gelled) fluid (without proppant) is pumped by increasing the rate gradually. The wellhead and bottomhole pressure are continuously monitored to determine the breakdown pressure. Once breakdown pressure is noted, the rate is decreased, leading to shutdown, and behavior of the pressure decline curve is studied.
- Minifrac – Minifrac analysis is the study of the pressure-decline data as the fluid leaks off into the formation. The numerical simulators are used to study the pressure-decline behavior that gives information about the fluid efficiency and closure pressure. The fracturing-design model parameters are altered to account for measured closure pressure based on the analysis; a few changes can be made to the final job design before pumping. For example, if fluid efficiency during the test is observed lower than anticipated, then pad volume can be increased to generate the desired fracture geometry.
- Pad – A linerar viscous gel or highly viscous crosslinked fluid is pumped to open a fracture and propagate the fracture geometry. This is proppant-free stage.
- Proppant-laden fluid – The pad stage is followed by the proppant-laden stage commonly known as slurry. If proppant reaches the tip of the fracture, it starts to create a pack inside the fracture. The goal of the proppant pack is to keep the fracture open and provide good conductivity for the hydrocarbons to flow with least resistance.
- Flush – Flush is the final stage of fracturing procedure. The purpose if this stage is to displace all the proppant-laden fluid from the wellbore into the formation. It is generally not desirable to overflush, and the volume designed for this stage should be calculated to end with the final slurry stage just above the top perforation.

An unprecedented increase in hydraulic fracturing activities has resulted in increased demand for sand/proppant that provides conductivity for hydrocarbons flow. The huge demand for the quality sand required for hydraulic fracturing has widened the supply-demand gap (Kothamasu et al. 2012).

2.2 Proppants

From the beginning of fracturing in the late 1940's natural materials such as mined sand particles have been used to prop the created hydraulic fractures. Proppant is essential in hydraulic stimulation treatments. Proppants are used to maintain fracture-flow capacity after completion of a hydraulic fracturing treatment (Kothamasu et al. 2012). The amount of proppant used, the manner in which it is placed in the fracture, and the properties of the material itself all play a vital role in maintaining productivity throughout the life of the well (Martinez et al. 1987). All of the properties of proppant – mainly roundness, size distribution, resistance to crush under the influence of closure stress, grain-size distribution and proppant density – can affect the resultant fracture conductivity. Conductivity of a propped fracture is one of the most important factors that directly affect well productivity, along with the propped fracture area, reservoir permeability, and drainage radius (Montgomery et al. 1985).

According to a study (Halliburton,2005); proppants such as Ottawa and Brady sands represent approximately 90% of the fracturing sand used in the petroleum industry. Brady sand is mined from the Hickory formation which outcrops near Brady, Texas. Brady sand is slightly darker in color hence, name "brown" sand is often used when referring to Brady sand. Brady sand is considered to be high-quality frac sand which meets or exceeds the ISO or API specifications for sands to be used in hydraulic fracturing. Ottawa on the other hand is the general name for fracturing sands mined from deposits found in the northern portion of the United States. "White" and "northern" sands are other names used to identify Ottawa sand (Yang et al. 2012). 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 8000 psi, depending on the type of resin-coated sand (Economides et al. 2000). Over the past twenty years and increasingly after high-permeability fracturing became a relatively widespread well completion technique, synthetic proppants such a manufactured ceramics and higher strength proppants such sintered bauxite have been employed (Yang et al. 2012). According to Saldungaray et al. (2013), ceramics proppants were introduced as an alternative to sand to provide enhanced conductivity and ultimately, well productivity and hydrocarbon recovery under a wide range of reservoir conditions. Originally developed to address concerns with the inherent strength and temperature limitations of natural frac sand in the deeper gas wells being drilled in the 1970s, modern ceramic proppants have been proven to provide production benefits in nearly all types of completions and formations. Ceramic proppant is a manmade proppant, with high strength and uniform size and shape. This type of proppant provides higher performance than other types of proppant at elevated stresses (Vincent, 2002). See Figure 2.1 for photographs of both brown and white sands and also ceramic.

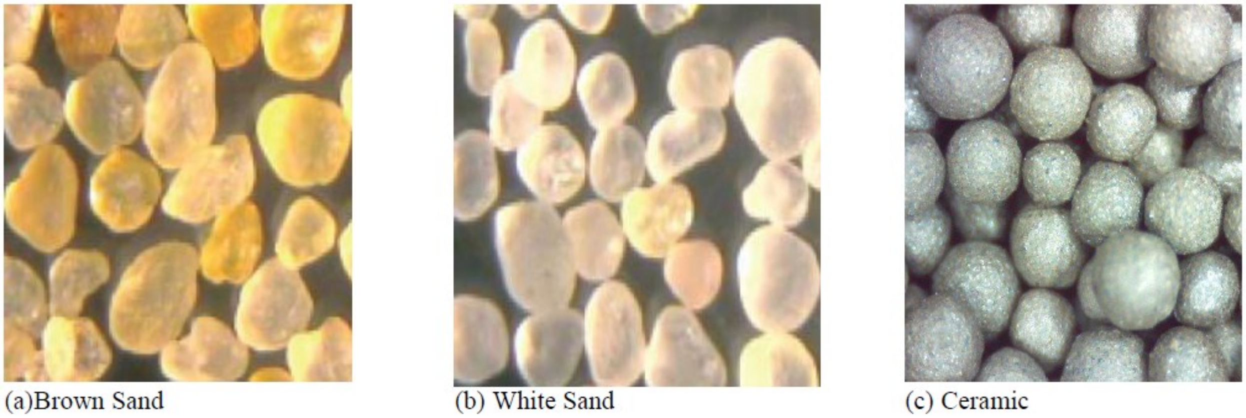

(a)Brown Sand (b) White Sand (c) Ceramic

Figure 2.1: Three types of proppants
(Yang et al., 2012)

Sand or resin-coated sand is less expensive than ceramic proppants and are used when the formation closure stress is below 5,000 psi. On the other hand, ceramic proppants which consist of three types; lightweight, intermediate strength and high strength can withstand higher formation closure stress. High-strength proppants, typically made from bauxite, can cover up to 15,000 psi regime (Kothamasu et al., 2012).

2.3 Resin Coated Proppant

Resin-coated proppants are commonly used in hydraulic fracturing to increase fracture conductivity, prevent proppant flowback, stop formation fines from migrating towards the wellbore, maintain a long-term fracture permeability, and prevent reduction in fracture permeability resulting from crushing and/or embedment (Dewprashad et al.,1993). Proppants are either pre-coated with resin in a factory and taken to location or coated "on the fly" in the field during a hydraulic fracturing treatment (Underdown et al., 1980). The resin coat is usually curable, and after a treatment, the well is shut-in to achieve cure. This results in a consolidated proppant bed with a coat of crosslinked polymer surrounding each grain. The performance of the proppant depends on the nature of the crosslinked polymer formed during cure. One of the most useful properties for characterizing a resin and determining its useful temperature range is the second-order transition temperature or glass transition temperature, T_g (Lee and Neville, 1967).

Epoxy or phenolic resins are most commonly used to coat proppants. Epoxy is a mixture of epoxide resin and amine hardener or crosslinker. Phenolic resins are usually a mixture of novalac resin and hexamethylenetetramine as a crosslinker. In both of these cases, the properties of the cured resin depend on the stoichiometry of resin and crosslinker. Maximum thermal properties are obtained when the stoichiometric amounts are used (Knop and Pilato, 1985). The properties are also dependent on the cure time and temperature. The carrier fluids may also effect these properties because these fluids are of varying pH and this may affect cure rate. Also, the possibility exists that the crosslinkers/hardeners could preferentially be leached by the aqueous carrier fluids as they have greater water solubility than the resin.

2.4 Proppant Selection

Selecting proppant to be used is important before conducting hydraulic fracturing. Cohen et al. (2013) conducted a study on optimum fluid and proppant selection for hydraulic fracturing found out that proppant size, proppant concentration and proppant injection sequence have significant effect on long term production.

In this parametric study, 4 types of proppant of different sizes and proppant pack are compared which are 80/100, 40/70, 30/25 and 20/40. Generally, proppant with larger grain size generate greater proppant pack permeability under low stress conditions. Nevertheless, as explained by Economides et al. (1994), larger sand grains are more fragile and are more likely to break under high stress, damaging the proppant pack permeability and reducing the proppant pack porosity. As a result of the experiment, the smallest proppant (80/100 mesh sand) is placed further into the hydraulic fracture network and maximizes the propped fracture length. In contrast, the biggest proppant (20/40 mesh sands) banks easily around the perforations and maximizes the averaged propped conductivity.

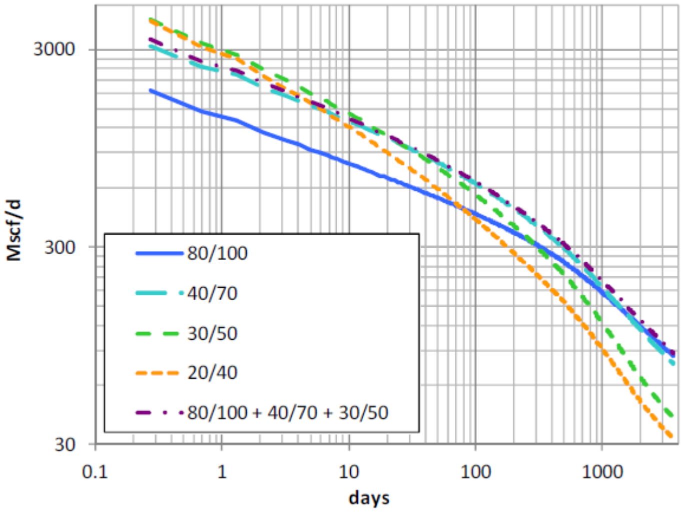


Figure 2.2: Production rate for different proppant size (Cohen et al. 2013)

The first observation is that the initial production increases when the proppant size increases. At early times of production, the rate is higher due to the high pressure differential close to the wellbore. Nevertheless the rate of production with the biggest proppant declines faster because the rate is mostly controlled by the matrix permeability (Moghadam et al., 2010). On the contrary, the slower initial decline of the rate for 80/100 mesh sand indicates that the flow is controlled both the matrix permeability and the conductivity of the fracture network. The second observation is that on the longer time scale the rate of production is greater with smaller proppant because the sudden change of slope occurs later. To summarize, large proppants would give better initial production and smaller proppants would give a slower production rate decline. Hence, it would be beneficial to utilize production by progressively increasing the proppant size during the injection.

As for proppant concentration, it is observed that the absolute maximum production increases with proppant concentration. It is supported by Coulter et al. (2004) when he had the same conclusion for Barnett shale as shown in Figure 2.3, meaning that the production increases with the increase in proppant concentration.

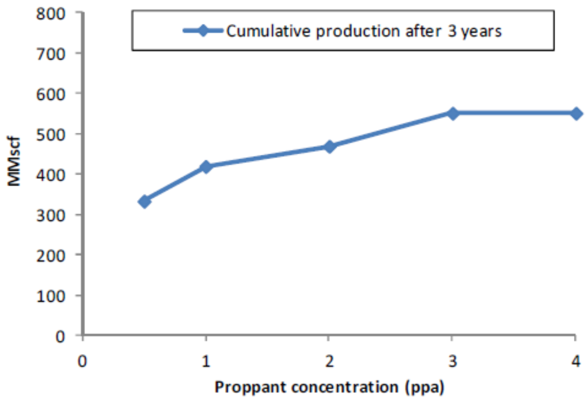


Figure 2.3: Maximum cumulated production as a function of the proppant concentration (Cohen et al. 2013)

2.5 Comparative Studies of Different Sand Samples

Selection of the best proppant is the key to a successful hydraulic fracturing job. Several types of proppants are available in the market for hydraulic fracturing stimulations. Those proppants are widely used all over the world, and a variety of published data is available. However, procuring global standard proppants for remote locations can be challenging in terms of both cost and time (Kothamasu et al., 2012). There are quite a number of studies were carried out to identify alternatives for the widely used Ottawa sand for hydraulic fracturing applications. Kothamasu et al. (2012) have conducted a study to compare eight samples from deposits in western India and one sample from deposits in Saudi Arabia. The sand samples were evaluated on parameters, such as sieve analysis, sphericity and roundness, acid solubility, turbidity, crush resistance and conductivity to compare with the commercial proppant, Ottawa. The results shows that two samples from the eastern hemisphere region have comparative results with widely used Ottawa sand and have the potential for hydraulic fracturing applications. Moreover, Mohd Saaid et al. (2011) conducted a study in Malaysia specifically those from Terengganu coastal area. Among the parameters tested were sieve distribution and grain size, bulk density, roundness and sphericity, turbidity, and mineralogy. Five samples were taken from different locations in Terengganu to be compared with several commercial proppants; ceramic proppant from China, Ottawa from United States and white silica sand from Saudi Arabia. The overall results shows that it is possible for Malaysia to produce their own local proppant with some essential adjustments through coating with suitable resin materials such as phenolic and novolac resins.

2.6 Development of Rod-Shaped Proppant

According to McDaniel et al. (2010), rod-shaped proppant technology was first introduced in Egypt in the western desert in 2009 with very successful results. The use of rod-shaped proppant in Arta field in the Egyptian eastern desert was followed, as other flowback control techniques failed to give the desired results in the field, resulting in additional rig time and costly workover operations.

Vreeburg et al. (1994) described proppant flowback as terms used to describe the problem of proppant being produced out of a hydraulically created fracture during treatment cleanup or reservoir production. Proppant removed from the fracture can also cause mechanical problems with downhole equipment, possibly compromising the safety of personnel. Several techniques have been employed in the industry to prevent proppant flowback from a hydraulic fracture, including resin-coated proppants, forced closure technique, and fiber technologies.

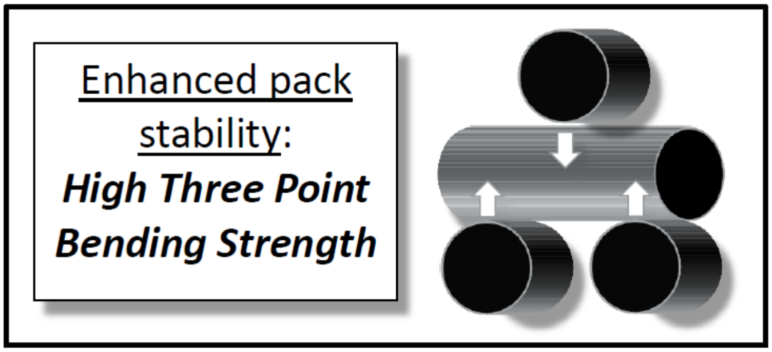


Figure 2.4: Rod-Shaped Proppant (Edelman et al. 2013)

Edelman et al. (2013) stated that the evolution and development of the rod-shaped proppant takes into account several limitations of the current techniques used in the industry. The technology of the rod-shaped proppant is not chemistry-limited as in the case of resin-coated proppants, there are no post-job fracture closure techniques to rely upon the limitation imposed by fiber addition and fiber flowback itself is eliminated. The excellent flowback control property of rod-shaped proppant is a primary consequence of changing the particle shape and impacting its packing behavior and the interaction between pellets. One of the main features of rod shaped proppant is its inherent proppant flowback control ability due to the unique interlocking of the rod-shaped particles (Figure 2.4). The second feature is that such a configuration of pellets obviously reduced the ability of the pellets to move relative to one another to minimize stress on the pack when compression is increased. This lower mobility of the rod pack is good on the one hand because it can help in maintaining the level of porosity. However, there can be a side effect that can result in a localized failure of particles that are subject to extremely high stresses. Indeed, it first requires a strong ceramic material that resists compression and bending. Meeting these requirements was achieved by using well refined bauxite which enables the rod-shaped proppant to exceed the results rested using various high-strength proppants mesh size.

2.7 Analysis of Silica Sand in Sarawak

A report on a detailed study of silica sand deposit was carried out at Kampung Sungai China, Rambungan, Lundu area under the Ninth Malaysian Plan, Sarawak Industrial Mineral Project by the Minerals and Geoscience Department Malaysia. It was part of the state wide silica sand resources study in Sarawak. The main objective of the project was to compile data on quantity and quality of the silica sand resources. Special emphasis was made to determine the suitability of the silica sand as raw material for the glass industry and other purposes including proppant for hydraulic fracturing.

The result of investigation indicates one potential silica sand deposit at Kampung Sungai China, Rambungan, Lundu. A total of 70 holes were augered with total depth of 115.5 metres and a spacing of 100 metres interval between holes.

The silica sand in the studied area is fine grain, moderate sorting with white to yellowish cream colour. The chemical analysis shows that the silica sand contains SiO_2 in range 98.10% to 99.50%. Based on the physical and chemical analysis, the raw silica sand meets the requirement of up to grade D silica sand which is suitable for flint glassware, sheet, rolled and polished glassware, window glassware, green glassware and amber glassware.

Figure 2.5: Study Location of Silica Sand at the Area of Kampung Sungai China, Rambungan, Lundu, Sarawak

Table 2.1: Chemical Composition of Silica Sand at Kampung Sungai China, Rambungan, Lundu

Chemical Composition (%)	No. of Sample				
	RMB045A	RMB045B	RMB042	RMB034	RMB080
SiO_2	98.90	99.00	99.59	98.10	99.00
Al_2O_3	0.09	0.10	0.10	0.18	0.10
Fe_2O_3	0.01	0.01	0.01	0.03	0.02
TiO_2	0.13	0.13	0.07	0.29	0.24
CaO	0.01	0.01	0.03	0.03	<0.01
MgO	0.01	0.01	0.01	0.02	<0.01
K_2O	<0.01	<0.01	<0.01	0.01	<0.01
Cr_2O_3	19	8	7	5	11
Na_2O	<0.01	<0.01	<0.01	0.01	<0.01
LOI	0.28	0.72	0.24	0.51	0.36

Table 2.2: Particle Size Distribution (%) of Silica Sand at Kampung Sungai China, Rambungan, Lundu

Particle Size (mm)	No. of Sample				
	RMB045A	RMB045B	RMB042	RMB034	RMB080
> 9.50	0.0	0.0	0.0	0.0	0.0
4.75 – 9.50	0.0	0.0	0.0	0.0	0.0
2.36 – 4.75	0.0	0.0	0.0	0.0	0.0
1.18 – 2.36	0.1	0.0	0.1	0.1	0.0
0.60 – 1.18	1.5	0.2	0.9	1.1	0.2
0.30 - 0.60	44.4	19.3	26.6	31.5	17.6
0.15 – 0.30	51.8	77.9	69.0	62.4	47.6
0.063 – 0.15	1.3	2.3	2.3	3.9	23.1
< 0.063	0.9	0.3	1.1	1.0	11.5

Another detailed study report by the Minerals and Geoscience Department Malaysia of silica sand deposit was carried out at Jalan Sungai Rait-Bakam, Bahagian Miri. The silica sand in the studied area is fine grain, moderate sorting with white to yellowish cream colour. The chemical analysis shows that the silica sand contains SiO_2 in range 97.90% to 99.00%. Based on the physical and chemical analysis, the raw silica sand meets the requirement of up to grade D silica sand which is suitable for flint glassware, sheet, rolled and polished glassware, window glassware, green glassware and amber glassware.

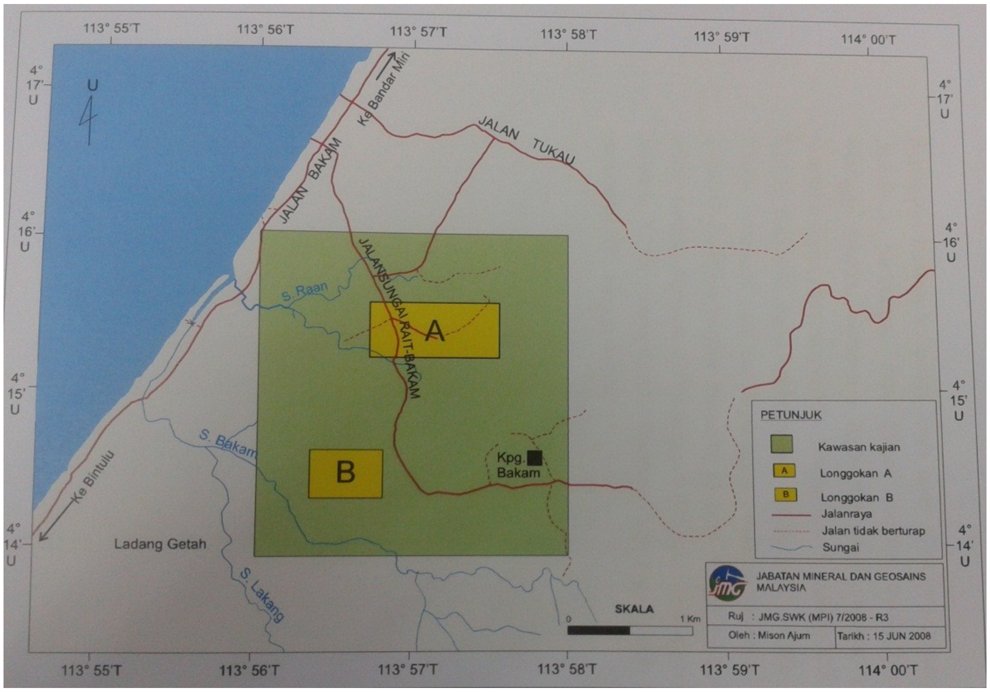


Figure 2.6: Study Location of Silica Sand at the Jalan Sungai Rait-Bakam area, Miri

Table 2.3: Chemical Composition of Silica Sand at Sungai Rait A, Jalan Sungai Rait-Bakam, Miri

Chemical Composition (%)	No. of Sample			
	SR010	SR016	SR038	SR080
SiO_2	98.40	98.20	99.00	97.90
Al_2O_3	0.17	0.16	0.10	0.41
Fe_2O_3	0.03	0.03	0.02	0.05
TiO_2	0.50	0.35	0.24	0.36
CaO	< 0.01	0.01	< 0.01	< 0.01
MgO	0.01	0.01	< 0.01	0.02
K_2O	0.02	0.02	0.01	0.07
Cr_2O_3	84	82	80	75
Na_2O	0.01	0.01	< 0.01	0.04
LOI	0.32	0.46	0.35	0.32

Table 2.4: Particle Size Distribution (%) of Silica Sand at Sungai Rait A, Jalan Sungai Rait-Bakam, Miri

Particle Size (mm)	No. of Sample			
	SR010	SR016	SR038	SR080
> 9.50	0.0	0.0	0.0	0.0
4.75 – 9.50	0.0	0.0	0.0	0.0
2.36 – 4.75	0.0	0.2	0.0	0.0
1.18 – 2.36	0.5	0.3	0.0	0.2
0.60 – 1.18	3.5	1.1	0.2	0.3
0.30 - 0.60	45.7	15.2	15.0	6.7
0.15 – 0.30	37.8	70.7	75.1	84.0
0.063 – 0.15	11.6	11.4	8.5	8.1
< 0.063	0.9	1.1	1.2	0.7

Moreover, there is another detailed study report by the Minerals and Geoscience Department Malaysia of silica sand deposit carried out at the area of Sungai Liku, Lambir, Miri. The silica sand in the studied area is fine grain, moderate sorting with white to yellowish cream colour. The chemical analysis shows that the silica sand contains SiO_2 in range 95.00% to 99.10%. Based on the physical and chemical analysis, the raw silica sand meets the requirement of up to grade D silica sand which is suitable for flint glassware, sheet, rolled and polished glassware, window glassware, green glassware and amber glassware.

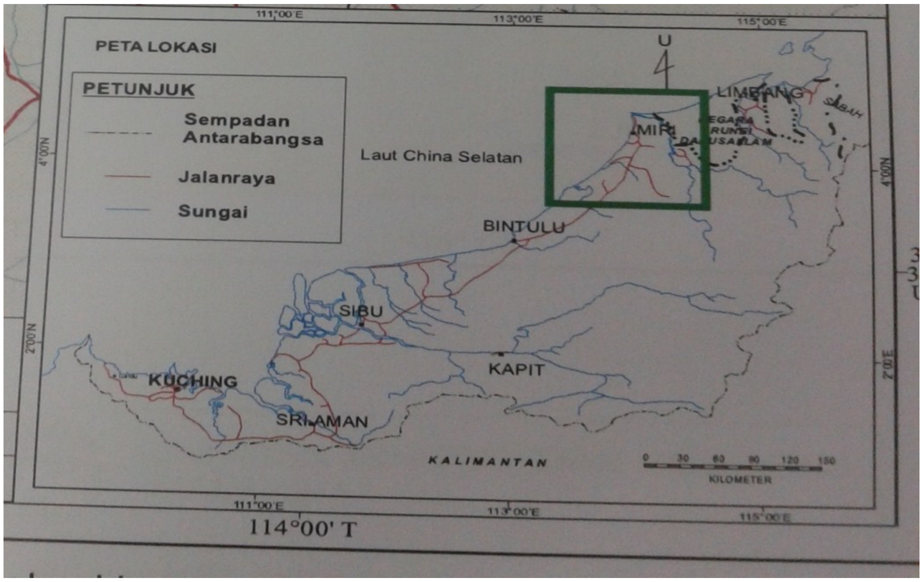


Figure 2.7: Study Location of Silica Sand at the Area of Sungai Liku, Lambir, Bahagian Miri, Sarawak

Table 2.5: Chemical Composition of Silica Sand at Sungai Liku, Lambir, Miri

Chemical Composition (%)	No. of Sample			
	B047	B068	B007 A	B007 B
SiO_2	99.10	98.80	98.40	95.00
Al_2O_3	0.13	0.16	0.18	1.30
Fe_2O_3	0.02	0.02	0.03	0.12
TiO_2	0.23	0.27	0.51	0.53
CaO	< 0.01	<0.01	0.01	< 0.01
MgO	< 0.01	< 0.01	0.01	0.03
K_2O	0.02	0.02	0.02	0.09
Cr_2O_3	26	43	62	76
Na_2O	0.01	0.01	0.01	0.01
LOI	0.16	0.40	0.14	1.99

Table 2.6: Particle Size Distribution (%) of Silica Sand at Sungai Liku area, Lambir, Miri

Particle Size (mm)	No. of Sample			
	B047	B068	B007 A	B007 B
> 9.50	0.0	0.0	0.0	0.0
4.75 – 9.50	0.0	0.0	0.0	0.0
2.36 – 4.75	0.0	0.0	0.0	0.0
1.18 – 2.36	0.1	0.1	0.0	0.1
0.60 – 1.18	0.4	0.4	0.1	0.2
0.30 - 0.60	16.8	22.2	3.3	4.5
0.15 – 0.30	75.4	73.8	81.2	72.5
0.063 – 0.15	7.0	3.2	14.0	20.5
< 0.063	0.3	0.3	1.4	2.2

2.8 Summary of Literature Review

The literature review shows that all of the properties of proppant mainly roundness, size distribution, resistance to crush under the influence of closure stress, grain-size distribution and proppant density can affect the resultant fracture conductivity. Other than that, it is proven that currently the most widely used proppant is the silica sand compared to resin coated and ceramic proppant. Hence, it indicates that Malaysia has potential in producing its own local proppant since it has an abundant resource of silica sand especially in Sarawak, Terengganu and Sabah. Previous study by Kamat et al. (2011) in Terengganu shows that silica sand samples in Terengganu were in agreement with API RP 56, API RP 58 and ISO 13503 standards. In Sarawak specifically, the identified areas has been analyzed to have a good quality of silica sand which can be used as glass manufacturing products as well as proppant for hydraulic fracturing. This research project is aimed to investigate the potential of Sarawak silica sand to be used as proppant and compare its performance to commercial proppants in accordance of API RP 56 and API RP 58 standards.

CHAPTER 3

METHODOLOGY

3.1 Project Methodology

Figure 3.1: Process flow of work

3.2 Key Milestone

Table 3.1: Key Milestone for Project

	WEEK	OBJECTIVES
FYP 1	5	Completion of preliminary research work
	7	Submission of extended proposal
	9	Completion of proposal defence
	12	Confirmation on lab material and equipment for conducting experiment/simulation
	13	Submission of Interim draft report
	14	Submission of Interim report
FYP 2	5	Finalized the experiment procedure
	6	Conducting in depth research, experiment and simulation
	7	Result analysis and discussion
	8	Submission of progress report
	9	Preparation for Pre-SEDEX
	11	Pre-SEDEX
	12	Submission of draft report
	13	Submission of technical paper and dissertation
	14	Oral presentation
	15	Submission of project dissertation

3.3 Gantt Chart

Table 3.2: Project Gantt Chart

	WEEK																														
	FYP 1															FYP 2															
ACTIVITIES	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Course Introduction	■	■	■																												
Project Topic Selection		■	■																												
Preliminary Project Work			■	■	■	■																									
Submission of Extended Proposal							■																								
Research Planning						■	■		■																						
Proposal Defence									■	■																					
Project Work Continues											■	■	■																		
Submission of Interim Draft Report														■																	
Submission of Interim Report															■																
Project Work Continues																■	■	■	■	■	■	■		■	■	■	■	■			
Submission of Progress Report																						■									
Pre-SEDEX																										■					
Submission of Draft Report																											■				
Submission of Dissertation (soft bound)																												■			
Submission of Technical Paper																												■			
Oral Presentation																													■		
Submission of Dissertation (hard bound)																															■

3.4 EXPERIMENTS AND TESTING PROCEDURE

There are several tests needed to be done to investigate and compare the properties of the sample sand with the commercial sands. The common tests are sieve distribution and grain size, bulk density, roundness and sphericity test, turbidity test and shear strength test. The following procedures are based on sand samples in accordance with API RP 56 and ISO 1350-3.

3.4.1 SAND SAMPLING

Sampling was carried out from identified sites in close consultation with Department of Mineral and Geoscience in Ipoh. Due to time and budget constraints, only one sample of sand was collected. The sample was obtained from a glass sand mining company namely “Syarikat Sebangun Sdn. Bhd.”. The company has been the biggest glass sand producer in Malaysia and it’s also one of the leading silica sand producers in South East Asia. It is a setback that the sampling method might not be done in a correct way but it can still be used as a start for proppant research in Sarawak area. The mining area of the sample was in the northern part of Sarawak (Bintulu).

Figure 3.2: Sand Sample

3.4.2 CHARACTERIZATION OF SILICA SILICA AS PROPPANT

Characterization of sample obtained was carried out in accordance with API standards (API RP 56 and API RP 58) including sieve distribution, Sphericity and roundness, acid solubility and turbidity.

3.4.2.1 Sieve Distribution and Grain Size

The size distribution of silica sand is important to the optimal design of proppants. Sieve shaker Ro-Tap RX-29 as shown in Figure 3.3 was used to sieve samples according to sieve size. It has 278 oscillations per minute and 150 taps per minutes as specified by ASTM standards. Approximately 100 g of the disaggregated sand sample was placed in a sieve stack and shaken until particle smaller than the sieve openings fall into the next smaller sieve size. The percentages of materials that passed through the sieve and the percentage retained by the sieve were calculated respectively. The cumulative weight should be within 0.5% of the sample weight used in the test. Minimum of 90% of tested sand sample should fall between the designated sieve size of 6/12, 12/20, 2040 and 30/50. For API 56 and API 58, not more than 0.1% of the total tested sand sample should be larger than the first sieve size and not more than 1.0% should be smaller than the last sieve size.

Figure 3.3: Testing sieve shaker and nest of U.S.A sieve pan

3.4.2.2 Sphericity and Roundness

Rounded proppant is recommended for all hydraulic fracturing operations. Roundness refers to the roughness of the surface or the sharpness of grain corners. On the other hand, Sphericity refers to the shape of the grain or how close a sand particle approaches a sphere. A perfect sphere will provide the greatest amount of pore space and minimum resistance for the hydrocarbons to flow (Gottschling 2005). Scanning Electron Microscopy (SEM) machine and microscope were used to examine sand particle in magnification of 20 x and 40 x. The results were then compared with the Krumbein Roundness Sphericity Chart as shown in Figure 3.4. The Sphericity and roundness were recorded and an average roundness and Sphericity were obtained. The average value of 0.6 or higher meets API RP 56 specifications.

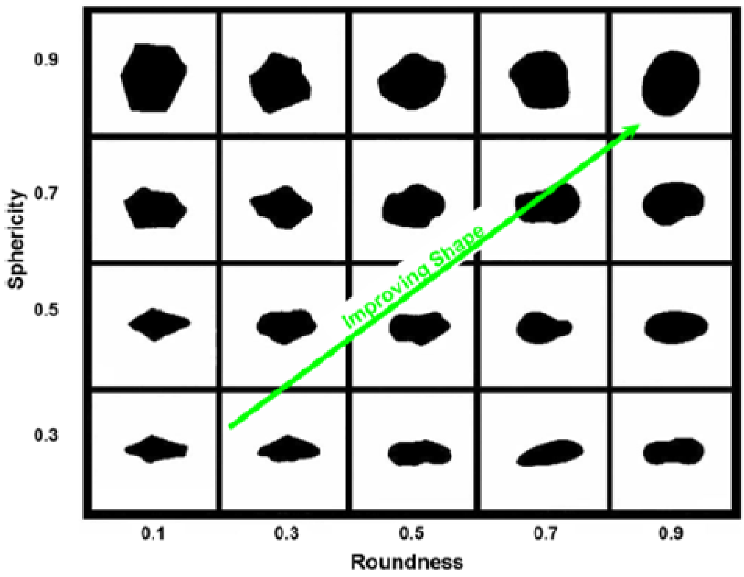


Figure 3.4: Krumbein Roundness and Sphericity Chart (ISO 2006)

3.4.2.3 Bulk Density

Bulk density describes the mass of proppant that fills a unit volume. An empty 100 ml measuring cylinder was placed on the electronic balance and recorded. Next, the measuring cylinder was filled with 100 ml sand sample and reweighted. Bulk density was calculated by dividing mass of the dry sand (grams) with volume of dry sand (centimetre cubic).

3.4.2.4 Turbidity Test

The purpose of this procedure is to determine the amount of suspended particles or other finely divided matter present. The turbidity tests were conducted in accordance with API 56 standard. First, 20 ml of sand sample is measured. Then, 100 ml of demineralized water is measured in a conical flask. The measured volume of sand sample is then transferred to the conical flask to mix shown in figure 3.5. It is then allowed to settle for 30 minutes. The mixture was shaked vigorously by hand for 20-45 seconds. Then, it is allowed to settle for 5 minutes.

Figure 3.5: Mixture of sand sample and demineralized water in conical flask

Pipete is used to extract the water-silt suspension from near the center of the water volume. The extract is transferred to the vial test shown in figure 3.6 and the turbidity is tested using the turbidimeter. The turbidity is measured in nephelometric units (NTU). The turbidity of the sand sample should meet the requirement of API 56 and API 58 Standard specifications which is less than 250 NTU.

Figure 3.6: Test vial fill with the water-silt suspension

Figure 3.7: Turbiditimeter

3.4.3 STRENGTH OF SILICA

All silica sand samples were subjected to the shear test to determine the strength of the silica. The test is useful to provide an estimate on the degree of damage that can be expected in unconsolidated sand. Test results should provide an indication of the stress level where proppant crushing is excessive and the maximum stress to which the proppant material should be subjected. This test may be used as an indicator of strength of silica, but is is not a substitute for long term conductivity testing.

3.4.3.1 Shear Strength

The shear strength experiment was aimed at generating reliable data on the normal and tangential forces and surface displacements during sliding contact between the solids and a smooth flat wall surface with a range of particular materials.

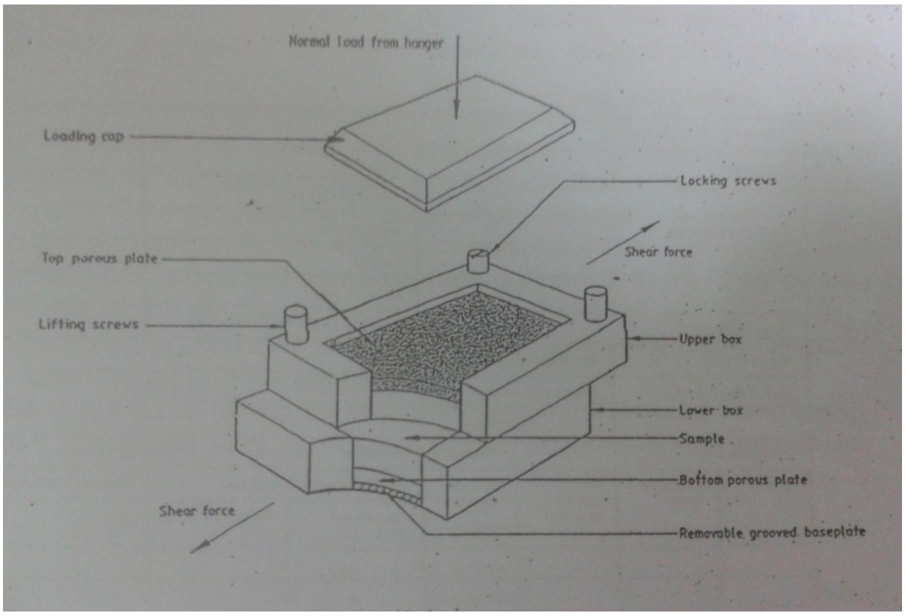


Figure 3.8: Schematic mechanism of direct shear box

The direct shear box in Figure 3.8 measures the direct strength of a soil by causing failure along horizontal shear plane. A direct shear box made by ELE was used in this investigation. The shear force was subjected to a compressive load normal to the shear plane. An increasing horizontal force split the box causing relative displacement of the two halves, which results in shearing the sample along the plane of the box.

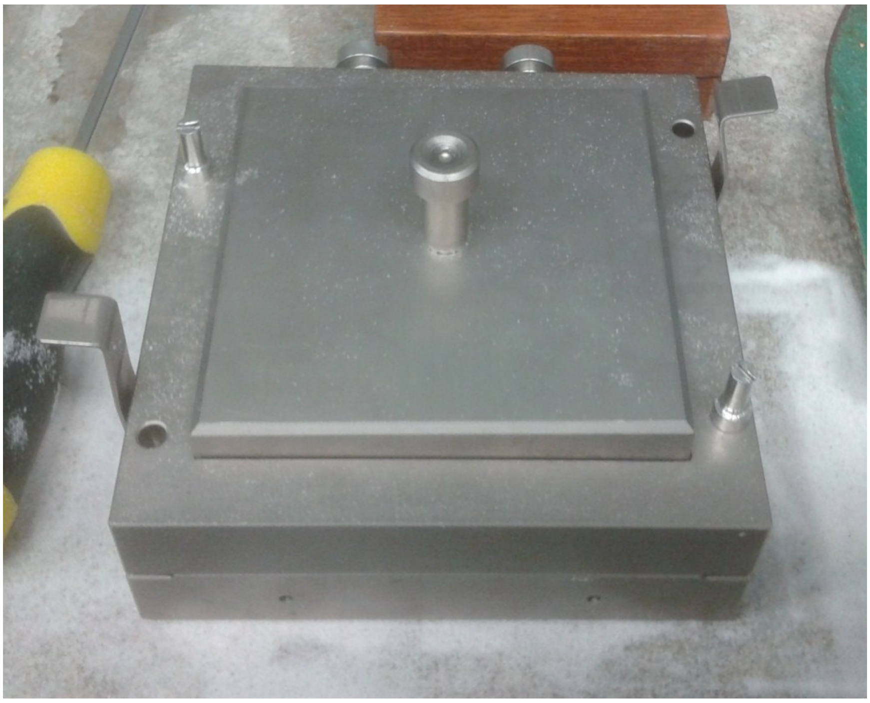


Figure 3.9: Shear box

The square 100 x 100 shear box as shown in Figure 3.9 was filled with 300 g of silica sand and assembled with the lid. The apparatus as shown in Figure 3.10 was equipped with a control closed loop motor with epicycloid reducers. At the beginning of each test, the machine performs an automatic and complete internal check, a position reset with the elimination of all possible positioning errors. All data were keyed in and a normal load was applied to the specimen and the specimen was sheared across the pre-determined horizontal plate between the two halves of the shear box.

Figure 3.10: Shear box test apparatus

Measurements of the shear load, shear displacement and normal displacement are recorded. The test was repeated under different normal loads such as 100N, 200N and 300N. These different normal loads were important to determine the angle of shearing resistance of soil. From the results, the shear strength parameters were determined. The strength of a soil depends on its resistance to shearing stresses. It is basically made up of the components of friction and cohesive. The two components were combined in Colulomb's shear strength (Hencer, 1989). Equation 3.1 estimates the angle of shearing resistance of soil, Θ, for the specimen by assuming the shear stress at failure is the maximum shear stress and the horizontal plane is the failure plane (Hencer, 1989). The test was repeated with different sizes.

$$\tau_f = c + \sigma_f \tan \Theta \tag{3.1}$$

τ_f = shearing resistance of soil at failure

c = apparent cohesion of soil

σ_f = total normal stress on failure plane

Θ = angle of shearing resistance of soil (angle of internal friction)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 CHARACTERIZATION STUDIES OF SAND PROPERTIES

This section presents characteristics of samples as examined by various techniques described in Chapter 3 in accordance to API RP 56 and API 58 standards.

4.1.1 Sieve Distribution and Grain Size

4.1.1.1 Analysis of Grain Size Distribution

The cumulative weight should be within 0.5% of the sample weight used in the test. Minimum of 90% of tested sand sample should fall between the designated sieve sizes. According to API standard, not more than 0.1% of the total tested sand sample should be larger than the first sieve and not more than 1.0% should be smaller than the last sieve.

Figure 4.1 shows grain size distribution of the sand sample and the average grain distribution for the sample is in the range of 0.3-0.063. If the grain size distribution contains high percentage of the smaller grains, the proppant-pack permeability and conductivity will reduce (Economides et al. 2000). Large proppants (16/20 or 12/18 products) are poor candidates for dirty formations and subject to significant 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 life of the well will be higher. When using larger proppant, it will only increase the initial conductivity of the well. Sarawak sand sectors belong to smaller category since the diameter ranges from 50/230 mesh size.

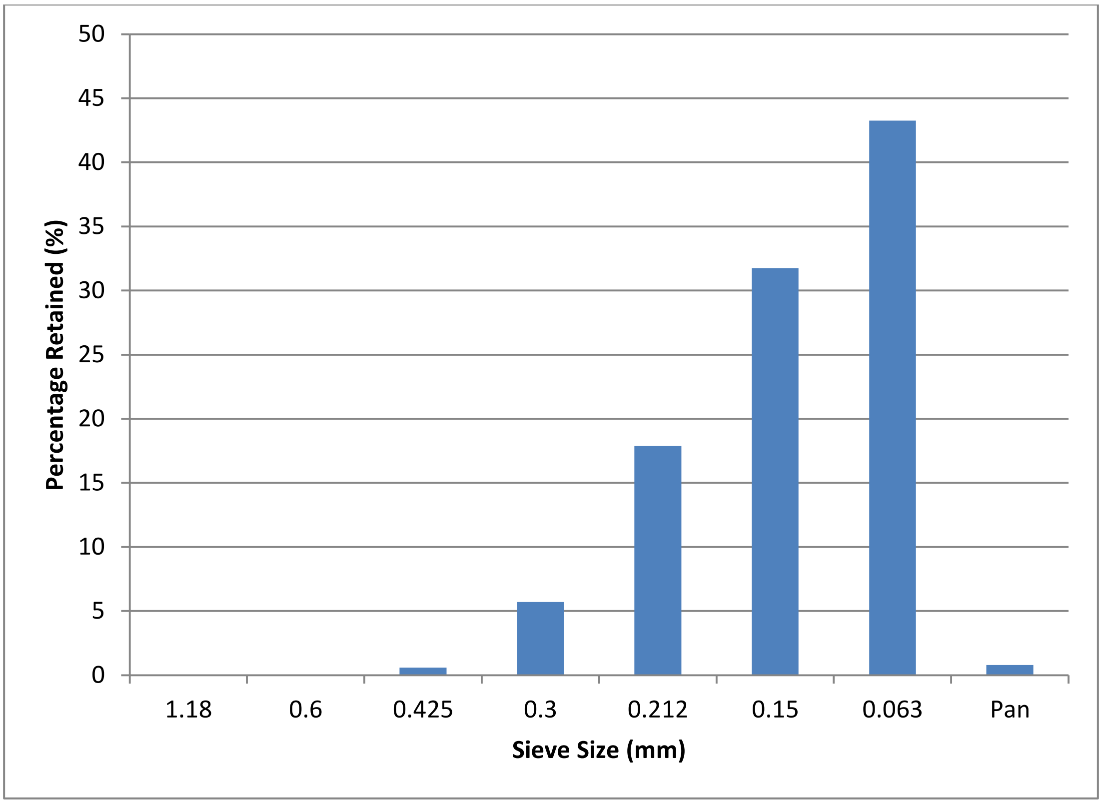


Figure 4.1: Particle size distribution

Table 4.1 shows that the Sarawak silica sample meets the API standards that require 90% of the sample to be retained within a designated size range.

Table 4.1: Summary of sieve analysis

Percentage Retained (% weight)		
Sieve Size (mm)	Sarawak Sample	Recommended API
1.18	0	<0.1
0.850	-	>90
0.600	0.05	
0.425	0.60	
0.355	-	
0.300	5.70	
0.250	-	
0.212	17.88	
0.150	31.76	
0.063	43.24	
Pan	0.78	<1

4.1.1.2 Grain Size Distribution with Different Size

Based on the results of percentage in size according to the API standard 56, all samples meet the standard with 90% of the sample retained in designated size. However, all samples have to be divided into specific mesh size which are 30/50 and 30/80. Table 4.2 shows the summary of percentage in size according to API Standard with different mesh size. Based on the results of percentage in size according to the API Standard 56, Figure 4.2 shows that the sample does not meet the standard with less than 90% of the sample retained in designated size. Proppant with larger grain size provide a more permeable pack.

Table 4.2: Percentage in size according to API 56 and 58 Standards

In size (% weight)(according API 58 & 56)	
30/50	30/80
6.35	84.11

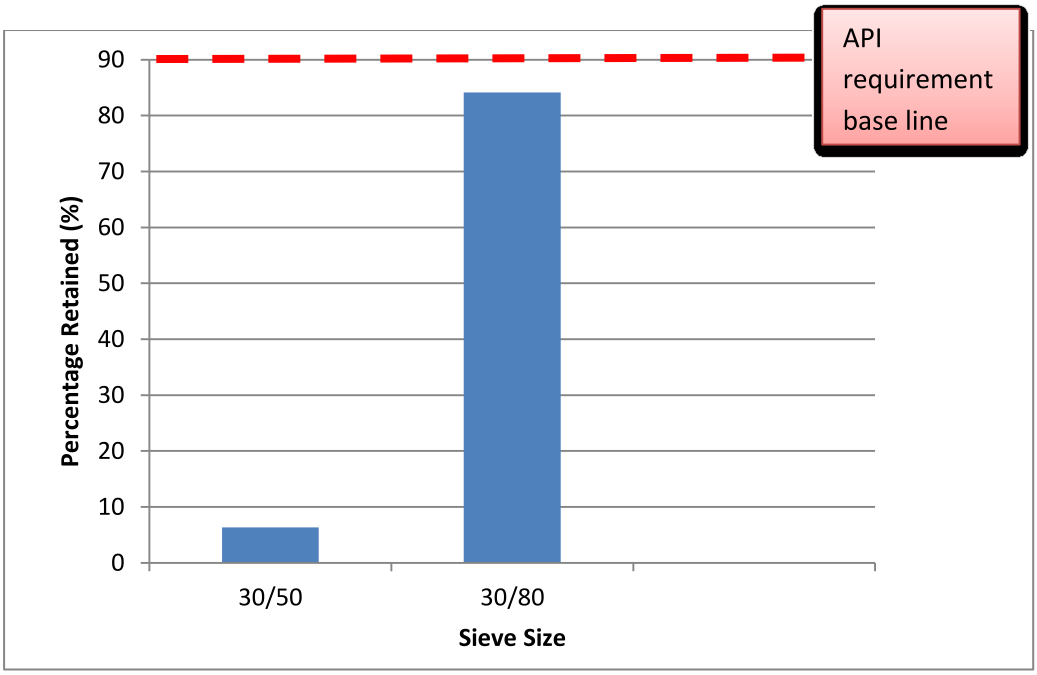


Figure 4.2: Percentage designated size for sample 30/50 and 30/80

4.1.2 Sphericity and Roundness

Sphericity and roundness were examined against Krumbein chart Roundness and Sphericity Chart. The chart is comparative where no mathematical formula is employed in obtaining the value of roundness and Sphericity. Figure 4.3 shows the overall average shape of the Sarawak sample sand under the magnification of 20 x microscope. The most average particle shape is then picked and compared to the Krumbein chart. Table 4.3 explains the comparison results of the sand sample to Krumbein Chart.

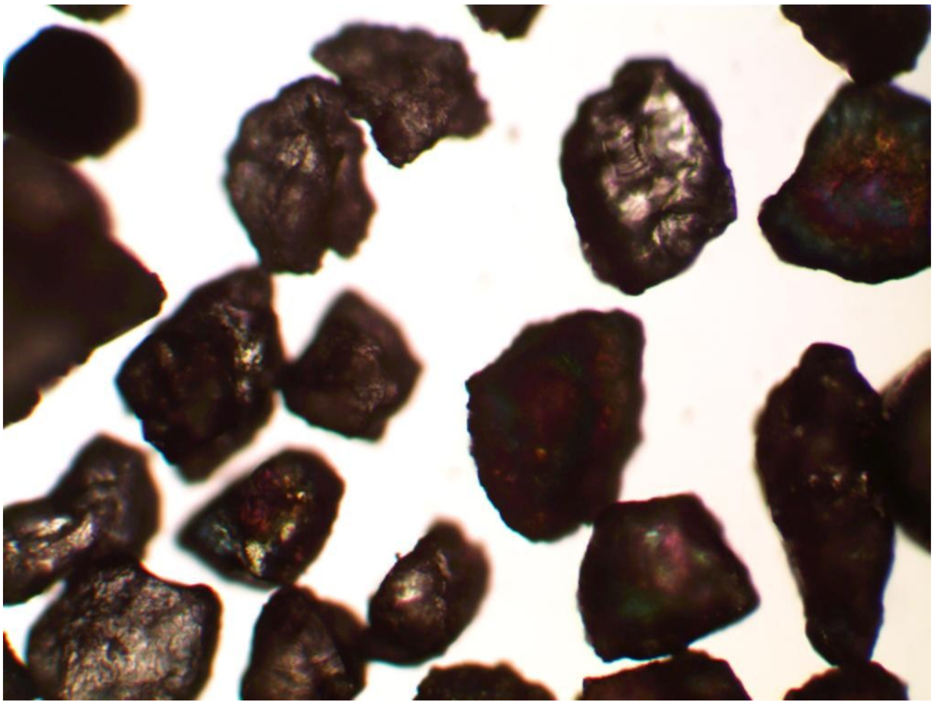
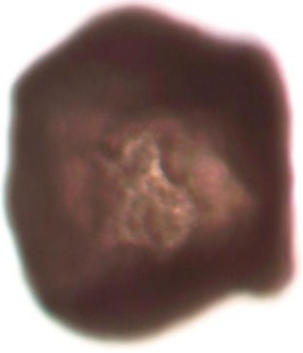


Figure 4.3: Overall average shape of the sample

Table 4.3: Roundness and Sphericity of the sample

Mag: 40x	Roundness	Sphericity
	0.5	0.7

Fracturing sand should have a Sphericity of 0.60 or greater and a roundness of 0.6 or greater. The Sarawak sample meets the requirement for desired Sphericity, but failed to meet the roundness specification of API 56 minimum of 0.6 with values of about 0.5. However, the minimum roundness for B500 (Non-API) consideration is 0.50 which shows that the sample meet the non API standards.

4.1.3 Bulk Density

The bulk density of the Sarawak sample has been measured without the closure stress. This means that the bulk density will increase substantially if the proppant is under the reservoir condition. Result in Table 4.4 below shows that the Sarawak Silica sand has the value of 1.46 g/cc.

Table 4.4: Bulk density calculation of sand sample

Bulk Density Measurement	
Mass of empty 100 ml cylinder	131.2820 g
Mass of 100 ml cylinder + sand sample	276.848 g
Mass of sand sample	(Mass of 100 ml cylinder + sand sample) – (Mass of empty 100 ml cylinder) = 276.848 – 131.2820 = 145.566
Bulk Density of sand sample	$Density = \frac{Mass}{Volume}$ $= \frac{145.566\text{ g}}{100\text{ ml}}$ = 1.46 g/cc

Proppant density has an influence on proppant transport and placement. High density proppants are more difficult to suspend in the fracturing fluid and to transport in the fracture. The density of Ottawa and Brady proppant are 1.54 g/cc and 1.57 g/cc respectively (CarboCeramic, 2011). Hence, it can be concluded that commercialize proppant possess 5.5% higher in bulk density compared with Sarawak silica sand sample.

Proppant is typically purchased by mass. On the other hand, the benefit of a proppant is based on its volume. For example, a fracture containing 100 000 pounds of Sarawak silica sand will occupy more volume than a fracture containing 100 000 pounds of Ottawa sand. For a typical hydraulic fracturing treatment, the density of the proppant will significantly impact the achieved fracture width.

4.1.4 Turbidity Measurement

Table 4.5 shows the results of turbidity measurement for the Sarawak silica sand according to API 56 and API 58 standards. The turbidity of the sand sample should meet the requirement of API 56 and API 58 Standard specifications which is less than 250 NTU.

Table 4.5: Turbidity measurement of the sand sample

Mesh Size	Turbidity (NTU)
30/50	27.2
30/80	25.7
40/230	55.9

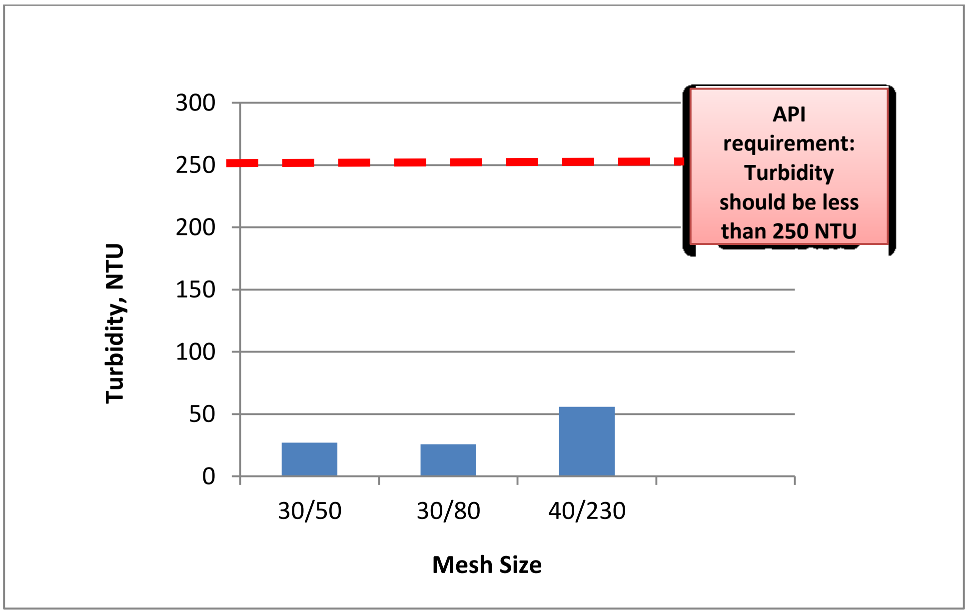


Figure 4.4: Turbidity Measurement for the sample with different size

Figure 4.4 shows that the mesh size of 40/230 has highest value of turbidity which is 55.9 NTU which is much lower than the API requirement. The turbidity of both mesh size 30/50 and 30/80 indicates a lower value than 40/230 with readings of 27.2 NTU and 25.7 NTU respectively. For a given volume and sand sample, the turbidity increases as the particle size decreases. In this case, it is shown that mesh size 40/230 indicates the highest turbidity reading compared to the bigger mesh size which are 30/50 and 30/80. Bigger particles have lesser surface area as compared to the smaller particles for a given volume. Surface area is proportional to the clay, silt or microorganisms coated to the particles. Bigger particles have higher contact with the water, thus, washing cleans the bigger particles better as compared to the smaller particles of the same volume.

4.2 PERFORMANCE ASSESSMENT OF SARAWAK SILICA SAND

The performance assessment of the Sarawak silica sand consists of the strength assessment which is the shear strength.

4.2.1 STRENGTH ASSESSMENT

4.2.1.1 Shear Strength

The Sarawak silica sample was tested with different shearing stage and every stage was stopped when the change in shear stress became almost minimal with an increase in shear displacement. The sample was then unloaded to zero shear stress and the normal stress was increased to the next level. Figure 4.5 shows the behavior of shear stress of the Sarawak sample.

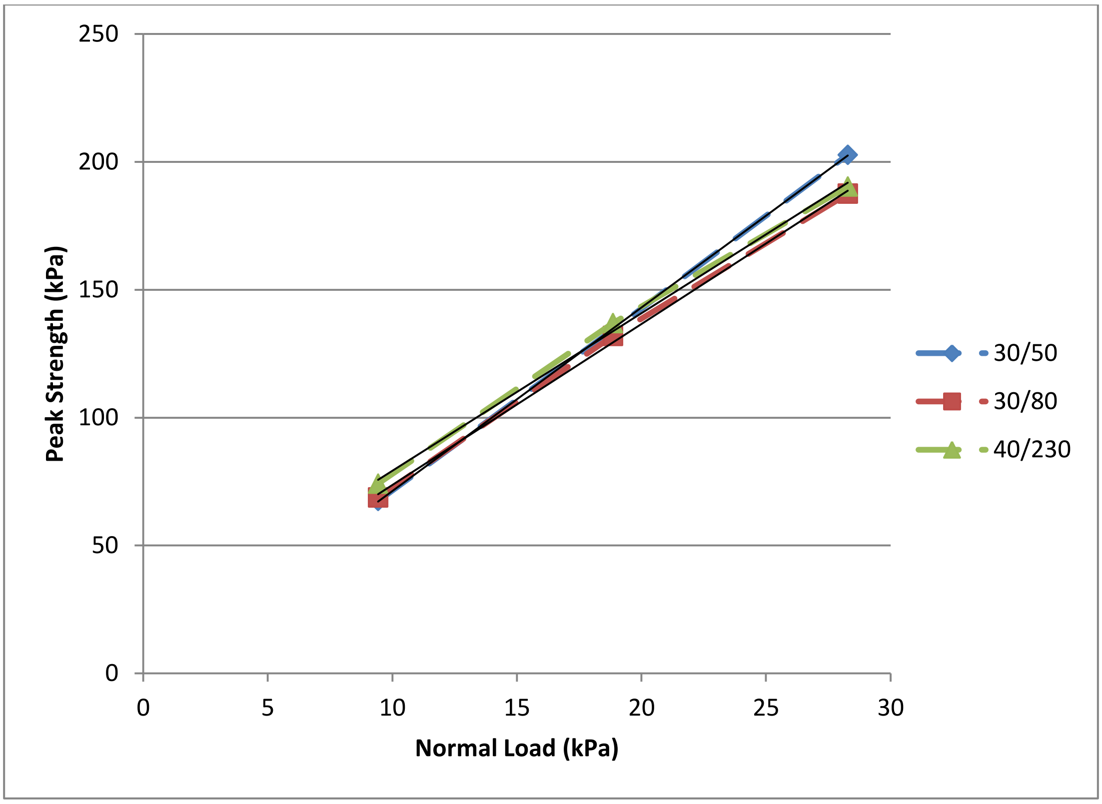


Figure 4.5: Shear Stress of Sarawak Sample with different size range and normal stress applied

From the figure 4.5, the behavior of the shear stress of mesh size 30/50 and 40/230 are not constant since at normal load of 9.429kPa and 18.858kPa, the highest shear stress is portrayed by 40/230 but at the normal load of 28.287 kPa, the highest shear stress is portrayed by 30/50. Sample size 30/80 consistently shows the lowest shear stress throughout the entire normal load applied.

Table 4.6 shows the summary of shear strength of a soil measurement in the shear box experiment. Angle of shear resistance of sample size 30/50 was the highest followed by 30/80 and 40/230 and it shows the measure of shear strength of soil due to friction. Cohesion of sand explained about the cementation between the grain size (Haggerty et al. 2009).

Table 4.6: Shear Strength of each size of the sample

Characteristics	Mesh Size		
	30/50	30/80	40/230
Angle of shear resistance, Θ	82.07	80.98	80.78
Shear strength, τ_f , (kPa)	406.14	356.39	348.53

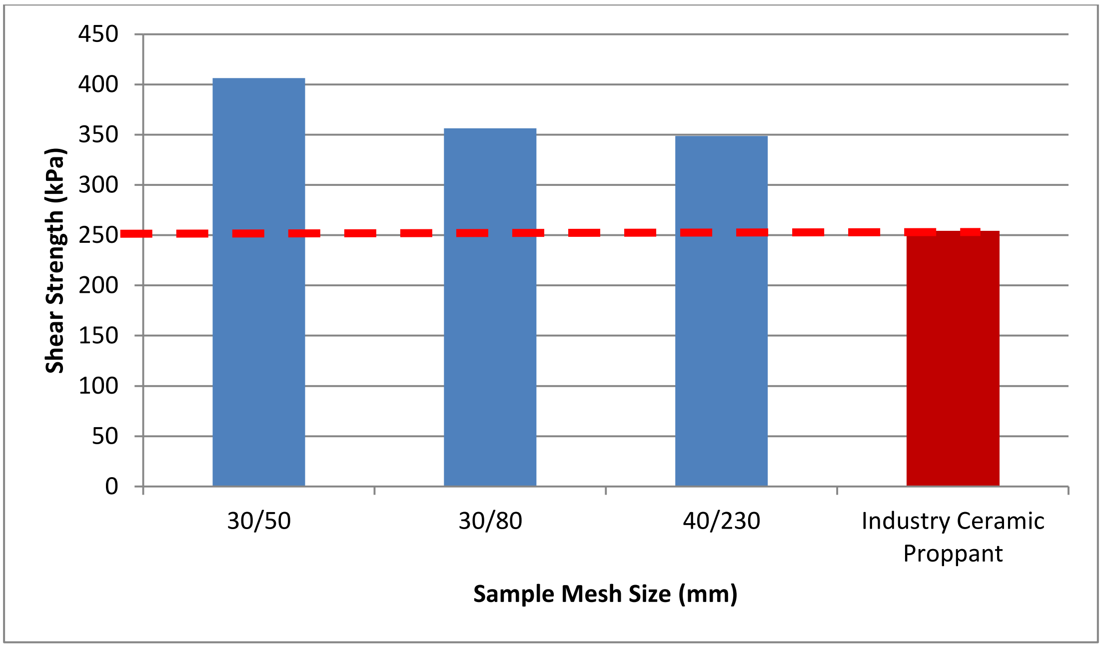


Figure 4.6: Shear Strength of sand sample with different mesh size

Figure 4.6 shows the summary of shear strength of sand sample with different mesh size. Mesh size of 30/50 shows the highest shear strength which is 406.14 kPa followed by 30/80 and 40/230 with the shear strength of 356.39 kPa and 348.53 kPa respectively. The industry ceramic proppant was 254.32 kPa and this shows that the Sarawak silica sand possessed significantly higher shear strength than the industry ceramic proppant. The shear strength decreases when silica size decreases due to the interlocking between particles is much higher when the surface are of interaction is reduced. This is proven by the highest shear strength portrayed by the biggest mesh size which is 30/50.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

In summary, the characterizations of Sarawak silica sand as proppant meets the requirement of API RP 56, API RP 58 and ISO 13503 standards except for the sieve distribution and grain size which do not meet the API standards since the sand size is too fine and small to be used as common mesh size of 20/40, 30/50 and 30/80. Furthermore, the roundness of the sample does not meet the API standard which requires the sand to be 0.6 for both roundness and Sphericity. However, the minimum roundness for B500 (Non-API) consideration is 0.50 which shows that the sample meet the non API standards. Other than that, the turbidity measurement and bulk density are in par with the commercial proppant such as the Brandy and Ottawa sands of the United States.

The performance assessment of the Sarawak silica sand was based on its shear strength assessment. The result indicated that the shear strength of the sample for all the mesh size 30/50, 30/80 and 40/230 are significantly higher than the industry proppant. The highest shear strength is portrayed by the 30/50 mesh size which is 406.14 kPa followed by 30/80 and 40/230 with 356.39 kPa and 348.53 kPa respectively.

Hence, it can be concluded that the Sarawak silica sand show promising result for possible use as proppant. The sieve distribution and grain size showed that the Sarawak silica sand is too fine to be used as proppant. However, it may be useful for dirty formation applications because they can resist the invasion of fines hence avoiding plugging and rapid reduction in the permeability. Besides, there are several more study needed to be done to enhance the reliability of this research such as the acid solubility of the sand, sand mineralogical analysis and the crush resistance test.

5.1 Future Research

This research could have been done more thoroughly through a good sampling method at the identified locations of high silica grade in Sarawak area. This project can be more convincing by having sand sample from several more locations in Sarawak to be compared with one another in terms of their characterizations and performance. In addition, further study on the usability of Sarawak sand in gravel packing can also be done in the future.

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