Investigation Study on the Strength Properties of Local Sand as Proppant

by

Priveetha Manogaran

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)

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CERTIFICATION OF APRROVAL

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Petroleum Engineering Programme

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Approved by,

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January 2012

CERTIFICATION OF ORIGINALITY

I hereby declare that the project titled "**Investigation Study on the Strength Properties of Local Sand as Proppant"** is my own work and to the best of my knowledge. Any contribution made to the research by others, with whom I have worked for this project, explicitly acknowledged in the thesis.

I also certify that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic is acknowledged.

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PRIVEETHA MANOGARAN

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I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals and organizations. I would like to extend my sincere thanks to all of them.

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ABSTRACT

This project presents literature review and experimental work on local sands for possible use as proppant especially sand samples from the Terengganu coastal area. Currently, there is no local proppant manufacturer in Malaysia and Malaysia has to import proppant from overseas especially from United States and Canada. This leads to the high well stimulation costs in Malaysia. If the local sand in Malaysia qualifies to be used as proppant, Malaysia can produce its local proppant manufacturer which may reduce the well stimulation costs in Malaysia. Thus, in this project, the characteristics of the Terengganu local sand will be examined and compared to the characteristics of the existing proppant used in current market. The present study found that the size distribution, sphericity, turbidity and bulk density of Terengganu sands are at similarity with some of commercial proppants. Thus, in this project additional research and experimental work will be done to further identify the possible use of Terengganu sand as proppant. These samples will be tested upon the sphericity, roundness, bulk density, shear strength, turbidity, acid solubility and suspension of particles in the slurry.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

1.1.1 Hydraulic Fracturing

In the year of 1947, the first hydraulic fracturing treatment was executed on a gas well operated by Pan American Petroleum Corporation in the Hugoton field. This well had a low productivity even though it had been acidized. Thus, the hydraulic treatment was approached to see the outcome of it as compared to the outcome of the acidizing treatment. Onwards from this year, hydraulic fracturing has been playing a very significant rote in increasing the productivity of oil and gas wells (Department of Energy - Hydraulic Fracturing White Paper, 2004).

Hydraulic fracturing is a stimulation treatment executed in low-permeability reservoirs (Schlumberger Oilfield Glossary, 2012). In hydraulic fracturing, viscous fluid known as carrier fluid containing proppant is injected into the wellbore under high pressure causing a vertical fracture to open shown in figure 1. Proppant, such as grains of sand or ceramic of a particular size, is mixed with the carrier fluid to keep the fracture open after hydraulic fracturing is executed (Schlumberger Oilfield Glossary, 2012). This treatment enhances the flow into the wellbore by evading the damaged zone that may exist near the wellbore area.

Research done has estimated that about 60 to 80 percent of all wells drilled in the United States in the next ten years will require hydraulic fracturing to continue operating (Hydraulic Fracturing: The Process, 2012). This treatment is very essential to be used in mature oil and natural gas fields. Geologists once believed that production from tight shale formations shown in Figure 2 were impossible (Hydraulic Fracturing: The Process, 2012). However, currently hydraulic fracturing is used to produce oil and gas in these fields. In 1995, the U.S. Geological Survey (USGS) estimated that the Bakken formation consist of 151 million barrels of recoverable oil. However, after the hydraulic fracturing has been executed in the year of 2008, the estimate of recoverable oil in the Bakken increased drastically by 25 times (Institute for Energy Research, 2012). This show how significant is hydraulic fracturing in the oil and gas field.

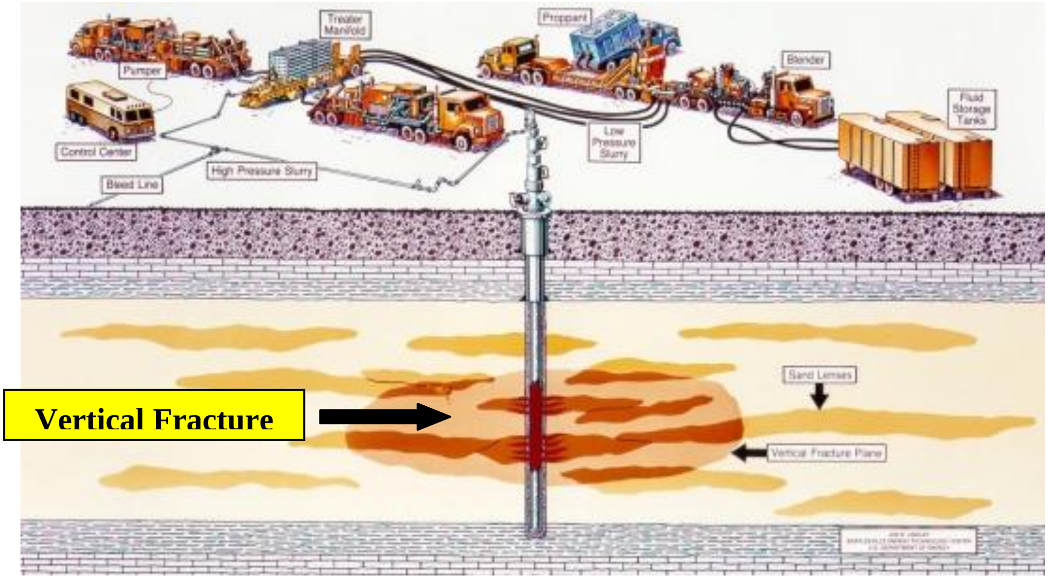


Figure 1: Fracture induced by hydraulic fracturing treatment

Figure 2: Tight shale formations in Unites States

The hydraulic fracturing process includes the acquisition of source water, well construction, well stimulation, and waste disposal. In hydraulic fracturing, once the hydraulic fluid pumped with high pressure, the pressure should exceed the rock strength and the fluid opens or enlarges fractures in the rock. As the formation is fractured, proppant is pumped to keep the fractures open and then the pumping pressure is reduced. Next, the hydraulic fluid is returned back to the surface.

Usually, the wells used in for this treatment are drilled vertically, vertically and horizontally, or directionally. Commonly used fracture in the formations is a single, vertical fracture. This type of fracture spreads in two directions from the wellbore and the fracture “wings” are 180^{o} away from each other. They are generally identical in shape and size. However, there are cases also whereby multiple fractures are induced in naturally fractured or cleaved formations, such as gas shales or coal seams (Department of Energy - Hydraulic Fracturing White Paper, 2004).

More often than not, water is used in this treatment. The carrier fluid or the hydraulic fluid commonly consist of water and sand which make up 98 to 99.5 percent of the fluid whereas the rest is made up of chemical additives (Hydraulic Fracturing: The Process, 2012). However, there are also hydraulic fluids that are oil and foam based. The selection of hydraulic fluid and the type of additives to be added are based upon the formation. For a well in a coalbed formation, this treatment requires fifty thousand to 350,000 gallons of water to create fracture whereas on the other hand to create fracture of a well in shale formation, two to five million gallons of water may be necessary (Hydraulic Fracturing Research Study, 2010). Hydraulic fluid and proppant are designed appropriately as it is very significant to ensure that there is no interaction between the reservoir rock and the hydraulic fluid that may create barriers for the hydrocarbon to flow into the wellbore.

1.2 Problem Statement

Malaysia has been importing proppant from overseas especially from United States which is the world leader in providing high conductivity ceramic proppant to the oil and gas industry. Malaysia also imports proppant from China, India and Canada to stimulate the well and to use them in gravel packing operations because currently in Malaysia, there is no local proppant producer exists. This in conjunction increases the well stimulation operation cost in Malaysia.

Moreover, Malaysia has an abundant source of silica sand. Most of the silica sand is used in the manufacturing of glass products besides in the production of ceramics, glass wool and water treatment materials. Thus, this shows that Malaysia silica sand can possibly used as proppant in hydraulic fracturing and gravel packing if it meets the requirements to be proppant.

Besides that, there is not any research done up to today on the use Malaysia local sand especially sourced from Terengganu as proppant. Thus, this is a great opportunity to develop research and experimental work to test the Terengganu sand samples characteristics.

1.3 Objective

The main objective of this project is to study and evaluate the sand sourced from Terengganu area for possible use as proppant. The present study found that the size distribution, sphericity turbidity and bulk density of some samples of different location in Terengganu sands are similar to the commercial proppant. However, extensive research and experimental work will be carried out to further determine the local sand properties. Besides that, this project provides a platform to compare the characteristics between the local sand in Terengganu and the existing proppant used in the oil and gas industry.

Moreover, the objective of this project is to provide an alternative for Malaysia to become a proppant manufacturer if the local sand has been identified as possible use as proppant. This indirectly helps for the growth of Malaysia economy. Malaysia can also export the local sand as the current demand for proppant is high.

1.4 Scope of Study

Currently, in Malaysia there is not any research done up to today on the use Malaysia local sand especially sourced from Terengganu as proppant. The present study shows some samples have similar bulk density, sphericity and roundness with the current proppant existing in the market. Thus, this opportunity will be used to evaluate the strength of Malaysia local sand sourced from Terengganu as possible proppant compared to the existing proppant in market. The characteristics of local sand from Terengganu as well as the current proppant used in market will be tested based on bulk density, sphericity, roundness, turbidity, shear strength, acid solubility and suspension of particles in the slurry. These characteristics are then compared for both the local sand and the existing proppant to determine if the local sand in Terengganu qualifies to be used as proppant.

1.5 Relevancy and Feasibility of the Project

This project is relevant to the author's field of study since it focuses in one of the areas in Petroleum Engineering. In this project, the author examined and evaluated the characteristics of local sand in Malaysia to be potential proppant which is used in the hydraulic fracturing treatment. Proppant has become a very essential material in hydraulic fracturing. Proppant keeps the fracture created open during the well stimulation work. On the other hand, in gravel packing operations, proppant also plays a very important role in controlling the sand production of wells. Thus, as a Petroleum engineer, the author carried out some experimental work to determine the strength of Terengganu area sand to prove its possible use as proppant.

The project is feasible since it is within the scope and time frame. The author completed the research and literature review and the laboratory experimental work for this project. Besides that, this project requires some equipment to operate which are readily available at the university Lab (Block 14 and 15) and thus there was no wastage of time in ordering and waiting for their arrival. The author conducted the lab experiments by following the procedures cautiously.

CHAPTER 2

LITERATURE REVIEW

2.1 Proppant

The utilization of proppant materials is not new to the oil and gas industry. However, the demand for proppant is rapidly growing which has led to shortages according to Robin Beckwith in his online article titled “Proppants Shortage”. Demand on proppant by Unites States is anticipated to increase 14 percent annually through 2014 (Well Stimulation Materials to 2014 , 2012). Proppant is significant and required to keep the fracture open once the pumps are shut down and the fracture begins to close (Department of Energy - Hydraulic Fracturing White Paper, 2004). The appropriate proppant to be used in the well stimulation must be strong, resistant to crushing, resistant to corrosion, have low density and readily available at low cost.

Figure 3: White fractured sand

Figure 4: Resin coated sand

Figure 5: Ceramic

2.2 Proppant Physical Properties

Proppant physical properties are grain size and grain-size distribution, quantities of fines and impurities, density, roundness and sphericity, turbidity, shear strength, acid solubility and carrier fluid compatibility. The grain size and grain size distribution play an essential role on the proppant pack permeability. Large grain size will provide greater permeability at low closure stress. However, as the closure stress increases, larger grain size is prone to fines migration problem and is easily crushed compared to smaller grain size at high closure stress. Thus, grains of smaller size maintain the pack conductivity compared to larger grains size when they are in contact of high closure stress. As an example, Figure 6 shows that as closure stress increases, the conductivity of the proppant of mesh size 12/18 decreases drastically compared to proppant of mesh size 30/50 (Physical Properties of Proppants, 2012).

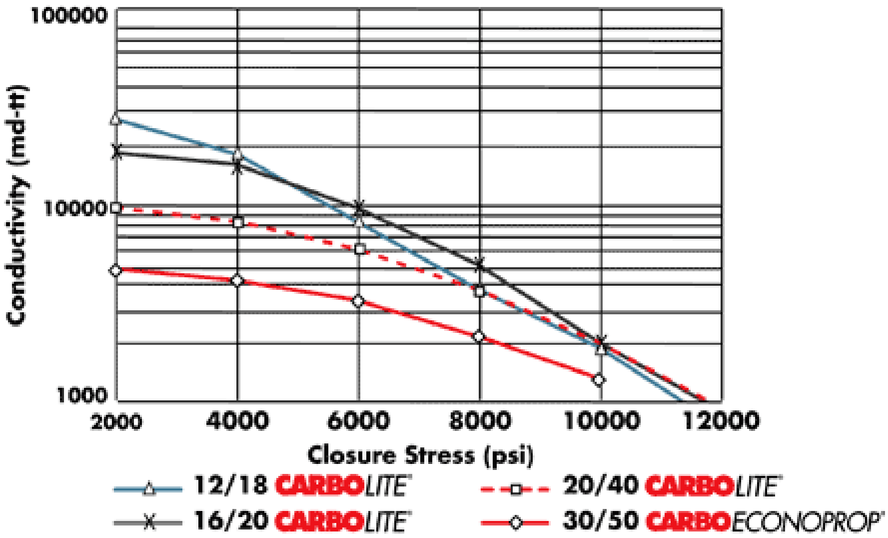


Figure 6: Reference long-term fracture conductivities

Figure 7 and 8 show the evenly and unevenly packed grain sizes. The evenly distributed grain size has higher permeability compared to the unevenly distributed grain size.

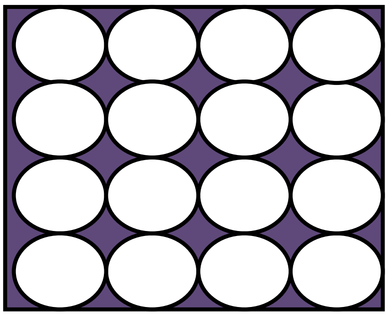


Figure 7: Evenly distributed grain size

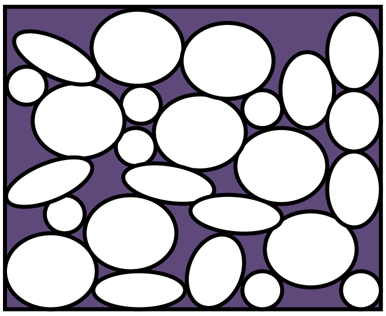


Figure 8: Unevenly distributed grain size

The quantities of fines and impurities such as feldspar affect the conductivity of the proppant pack. Fines that are generated can plug the pore spaces in between the grains and thus leads to lower permeability. Proppant density is one of the proppant selection factors. This is because higher the density of the proppant, it is more difficult to be suspended in the carrier fluid and to be transported to the wellbore. For typical fractures that are allowed to close on the proppant, the density of the proppant will significantly impact the achieved fracture width. For a given proppant concentration in the fracture there will be a proportionate decrease in fracture width for a denser proppant. Thus, to conclude, higher density proppants create narrower fracture width.

Roundness and sphericity are important properties or proppant because they impact the porosity and packing of the proppant pack. Grain roundness is a measure of the relative sharpness of grain corners, and particle sphericity is a measure of how closely the grain approaches the shape of a sphere (Sedimentation and Stratigraphy Laboratory: Roundness and Sphericity, 2011). Improved roundness and sphericity will enable greater porosity and permeability than a pack made up of an angular proppant after stress is applied and grain rotation occurs. Besides that, at higher closure stresses, the rounder particles will distribute the load better and have less crush and fines production. Proppant manufacturers refer to the Krumbein shape factor for roundness and sphericity. Figure 9 shows the roundness and sphericity chart.

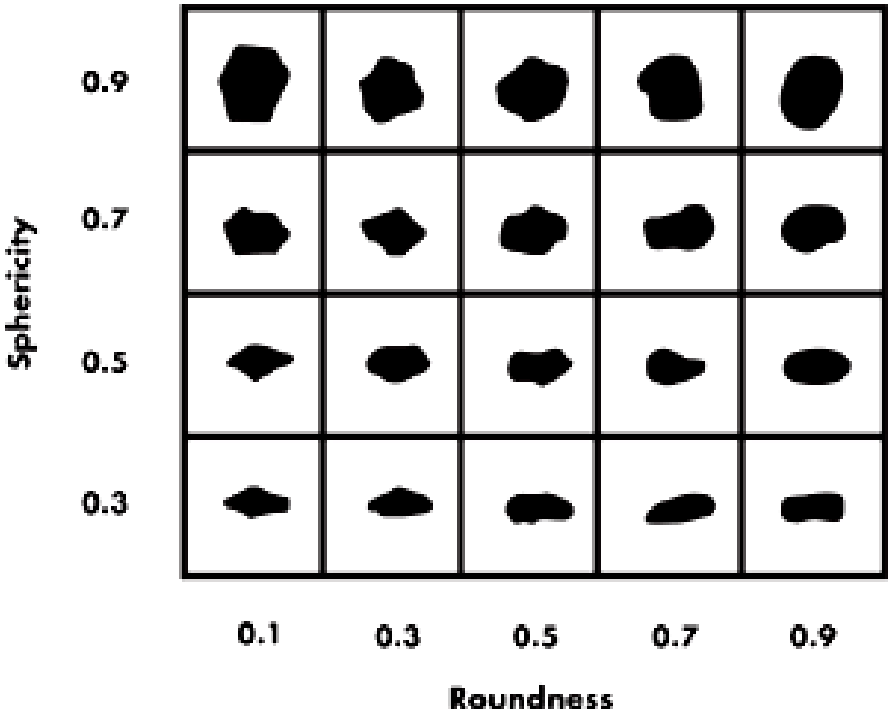


Figure 9: Krumbien roundness and sphericity

Another property of proppant that is essential is the turbidity. Turbidity is measure of the suspended clay, silt or finely divided inorganic matter being present in the samples. High turbidity reflects improper proppant manufacturing and/or handling practices. The turbidity value increases if the proppant is handled more harshly.

The proppant strength is a very essential property because the proppant must have the ability to withstand the pressure and temperature within the reservoir. Strength can be measured by shear stress (shear strength) and compressive normal stress known as crushing strength (Dusseault). The force is applied in the horizontal direction for shear stress whereas in the case of compressive normal stress, the force is applied in the vertical direction. Strength comparisons for proppant used by the industry are shown in the Figure 10.

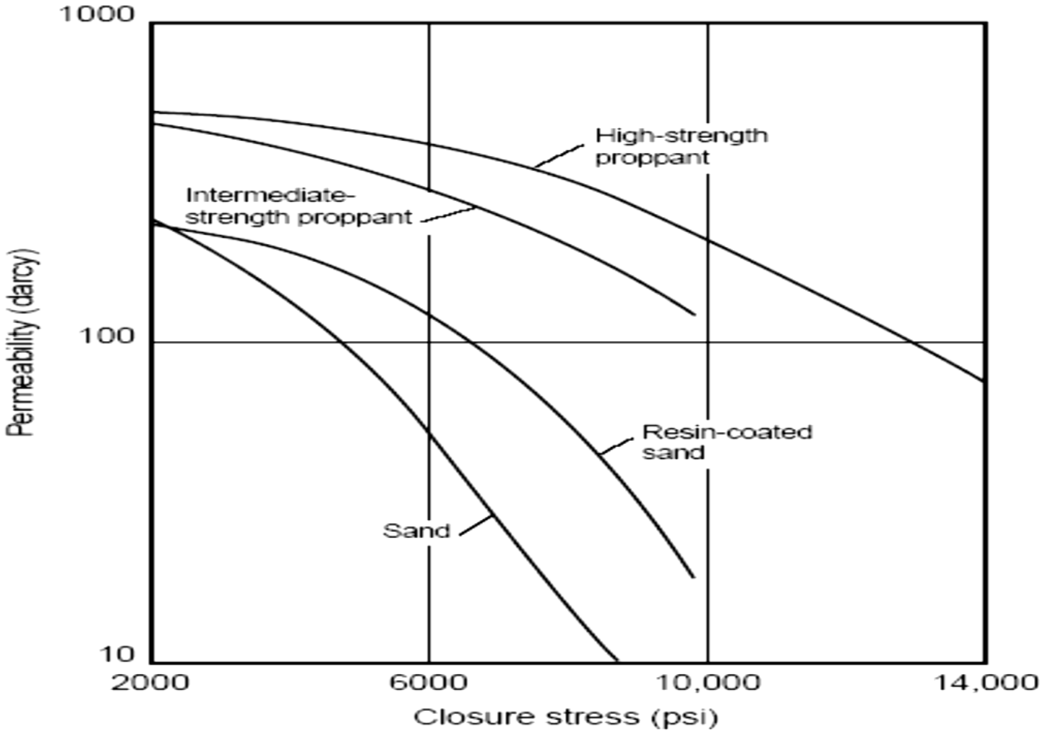


Figure 10 : Strength comparison of various types of proppant

Acid solubility of proppant is very important because during well stimulation work, HCL and HF acids are pumped down-hole to remove near wellbore damage. Thus, proppant should be able to withstand and not be soluble in acid. Proppant might react with acid when they come in contact to produce finer particles in conjunction effecting the proppant size distribution and mechanical strength of the proppant pack. Thus, this property of proppant should be examined appropriately to ensure the maximum solubility of proppant in acid is not more than the limit specified in the standard.

The proppant should also be compatible with the carrier fluid that transports the proppant to the fracture. The hydraulic fluid used in the field consists of water base fluids, oil base fluids, acid base fluids and foam fluids. However, the common fracturing fluid used is the water base fluid which has density near to 8.4 ppg but however, the density of the carrier fluid may vary according to the requirement. The proppant should be able to suspend in the fracturing fluid as it should not settle in the pipe and transportation lines that transport the slurry and plug them. Besides that, proppant settling might occur under stagnant conditions such as during shut-in after pumping the slurry. Thus, the settling rate should not be high.

2.3 Present Study on Malaysia Silica Sand

Study on grain size distribution, bulk density, sphericity and roundness has been conducted on a few samples from Terengganu and commercial proppant from China as shown below in Table 1 (Dahlila Kamat, 2011). However, further research has not been executed to prove these sand samples to be possibly used as proppant. Thus, this project has given the author the opportunity to carry out further experimental work to be executed on these sand samples and additional samples from Terengganu as well as commercial proppant from India.

Table 1: Samples from Terengganu, Malaysia

Samples	
Sample 1	Kampung Meraga, (Malaysia)
Sample 2	Kampung Batu Tampin, (Malaysia)
Sample 3	Kampung Rantau Abang B (Malaysia)
Sample 4	Kampung Kuala Abang (Malaysia)
Sample 5	Bukit Senyamok, Dungun (Malaysia)
Sample 6	Ceramic Proppant (China)

Table 2 shows the mean diameter, percentage in size and the bulk density for Malaysia sand samples and commercial proppant. The mean diameters of Malaysian sand samples area in the range of 0.17 – 0.28 mm (Dahlila Kamat, 2011). However, the bulk densities of the sand samples from Terengganu are lower than the density of the commercial proppant from China. Figure 11 shows the grain size distribution of the Malaysian sand samples and commercial proppant. By comparison, the average grain size distributions for all samples are in the range of 0.150 -0.425 mm. The sphericity and roundness values for all the samples are shown in Table 3. As for the sphericity, Malaysian sand samples and commercial proppant meet the sphericity specification. However, all the Malaysia sand samples roundness did not meet the roundness specification in the standard that requires a minimum value of 0.6 to qualify.

Table 2: Mean diameter and percentage in size

Sample	Mean Diameter	In Size (%)	Density (g/cm^3)
Kampung Meraga, (Malaysia)	0.25	90.55	1.49
Kampung Batu Tampin, (Malaysia)	0.28	91.02	1.46
Kampung Rantau Abang B (Malaysia)	0.18	90.05	1.56
Kampung Kuala Abang (Malaysia)	0.17	92.85	1.64
Bukit Senyamok, Dungun (Malaysia)	0.27	92.92	1.75
Ceramic Proppant (China)	0.28	99.96	1.81

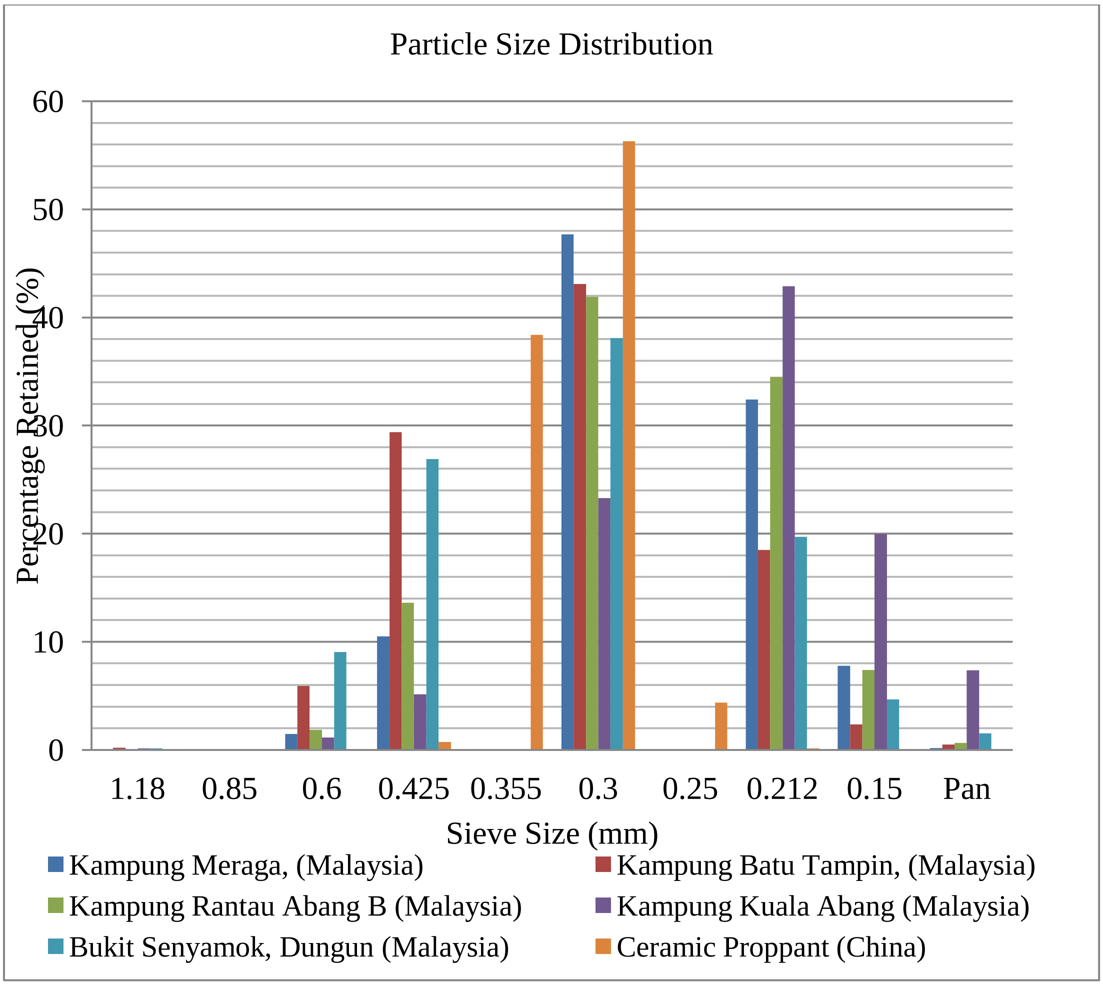
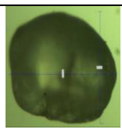
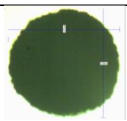


Figure 11: Particle size distribution of Terengganu sand and commercial proppant

Table 3: Sphericity and roundness

Sample	Image(Mag 40x)	Roundness	Sphericity
Sample 1		0.50	0.67
Sample 2		0.54	0.67
Sample 3		0.47	0.61
Sample 4		0.56	0.74
Sample 5		0.50	0.62
Sample 6		0.86	0.90

2.4 Silica Sand Reserves in Malaysia

The Department of Mineral and Geoscience (DMG) has estimated that the country has 148.4 million tonnes of silica-sand reserves (Mineral Resources , 2011). Most of the silica sand is used in the manufacturing of glass products besides in the production of ceramics, glass wool and water treatment materials. Figure 12 shows the silica sand reserves in a few states throughout Malaysia. As we can see, a Terengganu sand reserve is the second highest among the other states.

Pamela Percival (2010) quoted that "there have been some new sand mines that have opened up over the last couple of years in North America and some expansions of current facilities in different areas to mine fractured sand". Thus, if our local sand in Terengganu is qualified to be proppant, Malaysia can produced its own local proppant manufacturer and also export the local sand as proppant to the worldwide market. This in conjunction will help develop our Malaysia economy.

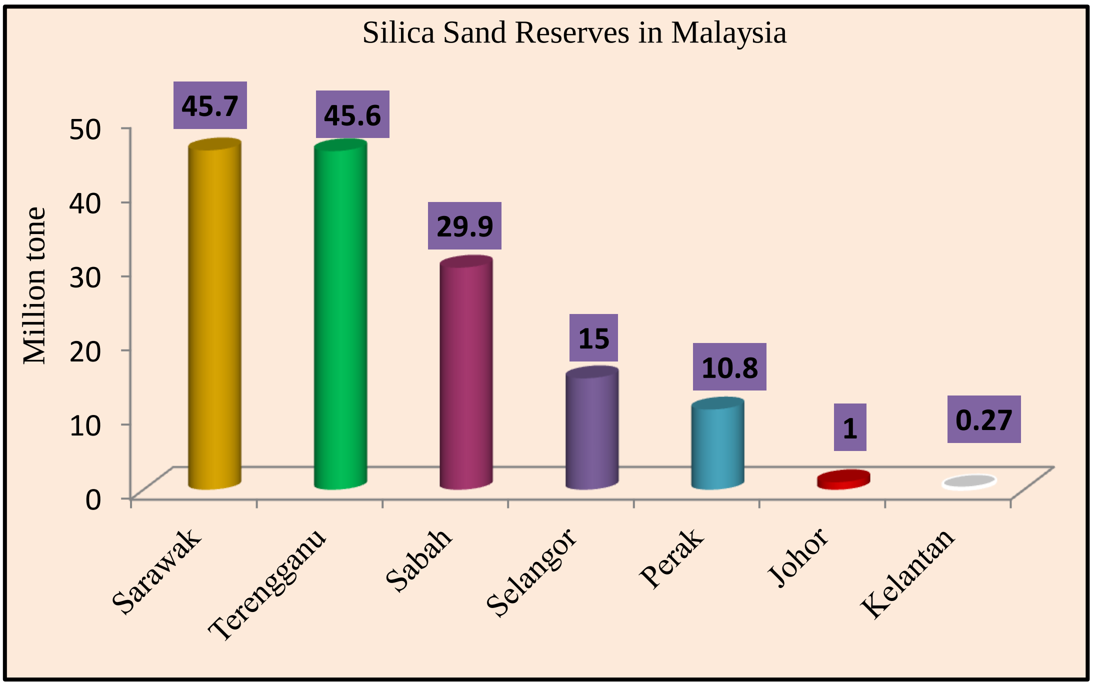


Figure 12: Silica sand reserves throughout Malaysia

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Project Flow

The experiments conducted were based on the equipment provided by the university laboratories. To comply with the equipments availability, some adjustments were done to the Recommended Practice API RP 56. The methodology for the experimental work will further be explained in the next subtopic.

Figure 13: The methodology of the project

3.2 Research Methodology

3.2.1 Sand Sampling

The sand samples were collected from a few sites in Terengganu coastal area. Sand samples are collected from 0.6 meter to 1.0 meter depth from the surface as required by Geological Survey Department of Malaysia. The silica sand layer is usually the second layer below the overburden layer 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. The commercial ceramic and silica sand were collected from the industry.

Figure 14 below shows the samples of Terengganu sand and commercial proppant. Samples labelled 1 to 6 are the samples from Terengganu meanwhile sample labelled 7 and 8 are the commercial proppant. The Terengganu sand samples were sieved according to the mesh sizes 20/40, 30/50 and 30/80. As for the ceramic proppant from China, the sample consists of mesh sizes are 20/40 and 30/50 meanwhile the silica sand from India consists of mesh sizes 20/40, 30/50 and 30/80. The tests were performed on all the sand samples with these varying sizes. Sample 1,2,3,5 and 8 are the same samples used in the present study mentioned before while sample 4 and 6 are new samples taken from Terengganu. This project gives an opportunity to the author to do further research on these samples.

Sample 1	• Kampung Meraga
Sample 2	• Kampung Batu Tampin
Sample 3	• Kampung Rantau Abang
Sample 4	• Kampung Kuala Abang
Sample 5	• Bukit Senyamok, Dungun
Sample 6	• Jambu Bongkok
Sample 7	• Silica Sand (India)
Sample 8	• Ceramic (China)

Figure 14: Terengganu sand samples and commercial proppant

3.2.2 Bulk Density

First, an empty 100 ml graduated cylinder was weighed on the electronic balance and recorded. Then, the graduated cylinder was filled with the sand sample until the reading reached 100ml. The graduated cylinder filled with sample was weighed again and bulk density was calculated from the equation below:

$$\text{Bulk Density} = \frac{\text{Weight of dry sand (g)}}{\text{Volume of dry sand (cm}^3\text{)}}$$

3.2.3 Sphericity and Roundness

As mentioned before, roundness and sphericity are important properties or proppant because they impact the porosity and packing of the proppant pack. In this study, the sphericity and roundness are measured using the polarizing microscope with 40x magnification. The images of the sample particles are taken and the shapes are compared to the Krumbein chart. According to the API RP 56, sand should have roundness and sphericity of 0.6 or greater.

3.2.4 Shear Strength Test

The shear test method is performed to determine the shear strength of a sand material in direct shear. The shear strength test is performed using the shear box 100 × 100 shown in Figure 15 below which is readily available in university lab at building 14. The test is executed by deforming the sand material across the horizontal plate between two halves of the shear box while applying normal load. In this test, each sand samples were tested few times with varying normal load which are 98.1kPa, 196.2kPa and 294.3kPa. The objective of this is to determine the effects upon shear resistance and displacement besides strength properties. The strength of the sand depends on its resistance to shearing stresses which is basically made up of friction and cohesion. These two components were used in Coulomb's shear strength equation given below:

$$\tau_f = c + \sigma_f \tan\theta$$

τ_f = shearing resistance of soil at failure, kPa

c = apparent cohesion of soil

σ_f = total normal stress on failure plane, kPa

θ = angle of shearing resistance of soil (angle of internal friction), degree

The shear stress measured for each normal load was plotted against the normal load and the angle of shear resistance was calculated after gaining the best fitting line for the graph as shown in Appendix A. Then, the shear strength was calculated using the Coulomb's equation whereby the cohesion is zero since the samples are loose sand and there is no cementation between the particles of the sample. The total normal stress is calculated as below:

$$\sigma_f = (98.1+196.2+294.3)\ \text{kPa} = 588.6\ \text{kPa}$$

Thus, the equation used to calculate the shear strength for these samples is given as below:

$$\tau_f = 588.6 \tan \theta$$

Figure 15: Shear box 100 x 100

3.2.5 Acid Solubility Test

The sand samples were tested with a solution of hydrochloric and hydrofluoric acid. This test is used to determine the suitability of proppant for the use of applications where proppant may come into contact with acids. According to the new API/ISO procedures for proppant testing, the solution of hydrochloric and hydrofluoric acid mixed according to the ratio of 12:3 (hydrochloric: hydrofluoric) by mass. 5 grams of sand sample was weighed on the filter paper and added to the beaker containing the acid solution without stirring and was left in the water bath set at temperature 65.6ºC for 30 minutes. Then, the sand sample was filtered on a filter paper (weight of filter paper is measured) in a funnel using the distilled water (shown in Figure 17) and was dried in the oven at 105ºC for an hour. The dried sand sample was cooled and then weighed. The mass percentage of the sand soluble in the acid was then calculated using the equation given below:

$$S = \frac{(W_s + W_f - W_{fs})}{W_s} \times 100$$

Where,

S = Sand solubility, weight percent

W_s = Sand weight before test, grams

W_f = Weight of filter, grams

W_{fs} = Weight of filter containing sand after test, grams

The sand samples should comply with the specifications given in Table 4 for the acid solubility test.

Table 4 : API Standard for Acid Solubility Test

Sand Size (Mesh)	Max Solubility (Weight %)
6/12 To 30/50	2
40/70 To 70/140	3

Figure 16: Sand in acid solution after 30 minutes placed in the water bath

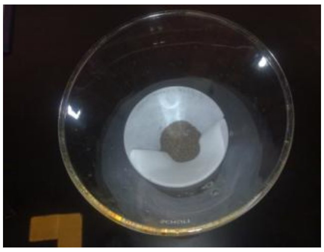


Figure 17 : Sand Filtered Using Distilled Water on a Filter Paper

3.2.6 Turbidity Test

The sample for turbidity measurement was prepared according to the API 56. First, 20ml of sand sample was measured. Then, 100ml of demineralized water was measured in a conical flask. The measured volume of sand sample was then transferred to the conical flask to mix shown in Figure 18. It was then allowed to settle for 30 minutes. The mixture was shaked vigorously by hand for 20 to 45 seconds. Then, it was allowed to settle for 5 minutes. Pipette was used to extract the water-silt suspension from near the center of the water volume. The extract was transferred to the vial test and the turbidity is tested using the turbidimeter shown in Figure19. The turbidity was measured in nephelometric turbidity units (NTU). Turbidity of tested sand should be 250 FTU or less according to the API RP 56.

Figure 18 : Mixture of sand sample and demineralized water in conical flask

Figure 19: Test vial fill with water-silt suspension on the left and the turbidimeter on the right

3.2.7 Suspension Test

Carrier fluid which acts as a medium to transport the sand to the wellbore will also be tested in this project. Usually, the carrier fluid is prepared by mixing crosslinked gel and other additives with the base fluid. However, in this project, guar gum which is the crosslinked gel was mixed with water as the base fluid. Other additives were not added in the carrier fluid because this experiment was executed to compare the suspension properties between local sand and the commercial proppant. The density calculation and amount of products used in the preparation of the carrier fluid is shown in the Appendix B. Then, the 100ml of graduated cylinder was filled with 20ml of sample.

The carrier fluid was then added to fill the graduated cylinder up to 100ml and mixed vigorously. Since some of the fluid has seeped through the void spaces between the particles, some volume of carrier fluid was added to top up to 100ml of total volume of carrier fluid and sample. The graduated cylinder was again shaked vigorously for 30 seconds and leave the slurry under static condition. The volume of suspended particles was measured at interval of 5 minutes beginning from 0 minute. Figure 20 shows the suspension of Terengganu local sand in the carrier fluid (guar gum and water as the base fluid) after an hour of total time.

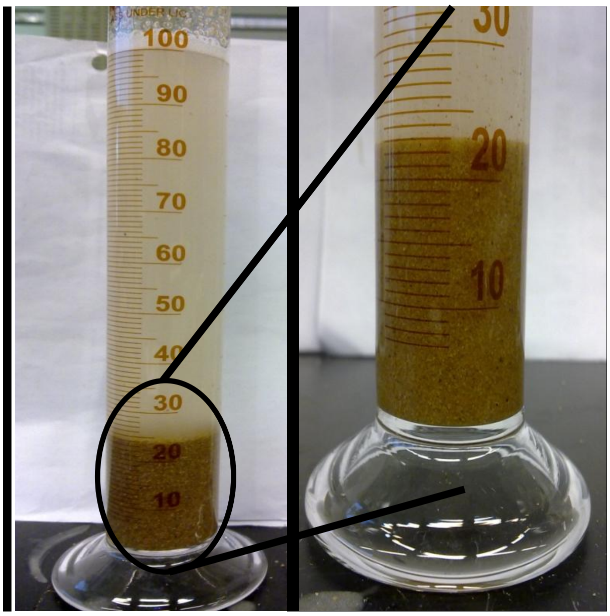


Figure 20: Terengganu local sand suspended in the carrier fluid

3.3 Project Activities

Table 5: Project activities planned for Final Year Project

Activities	Starting Month	Finishing Month
Studies on theory related to proppant properties	September 2011	November 2011
Prepare proper procedure for experiments	November 2011	December 2012
Execute the experiments	January 2012	March 2012
Analyse and discuss the results	March 2012	April 2012
Report documentation	April 2012	April 2012

3.4 Gantt Chart and Key Milestone

Table 6: Gantt chart through the Final Year Project

Activities	2011				2012			
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Selection of FYP title	■							
Preliminary research work		■	■	■				
Literature Review		■	■	■				
Requisition of the components/ tools.				■				
Prepare the methodology				■				
Prepare the proper procedure and run the experiment.					■	■	■	
Complete result and discussion							■	■
Report documentation								■

Table 7: Key milestone for Final Year Project

Activities	2011				2012			
	Sept	Oct	Nov	Dec	Jan	Feb	Mar ch	Apr
Submission of proposal report								
Submission of Prelim Report								
Oral Presentation								
Submission of Progress Report								
Poster presentation								
Technical Paper								
Submission of soft bound								
Oral Presentation								
Submission of hard bound								

CHAPTER 4

RESULT AND DISCUSSION

4.1 Bulk Density

Figure 21 shows sample 8 which is the ceramic proppant from China has the highest bulk density. Sample 2 gives the lowest bulk density measurement. However, the local sand bulk densities are almost in par with the density of silica sand from India. The higher the density of the proppant, the more difficult it is for the proppant to be suspended in the carrier fluid and to be transported to the wellbore.

Table 8 : Bulk density of local sand and commercial proppant

Sample	Bulk Density (g/cm^3)
Sample 1	1.49
Sample 2	1.46
Sample 3	1.64
Sample 4	1.48
Sample 5	1.75
Sample 6	1.58
Sample 7	1.57
Sample 8	1.81

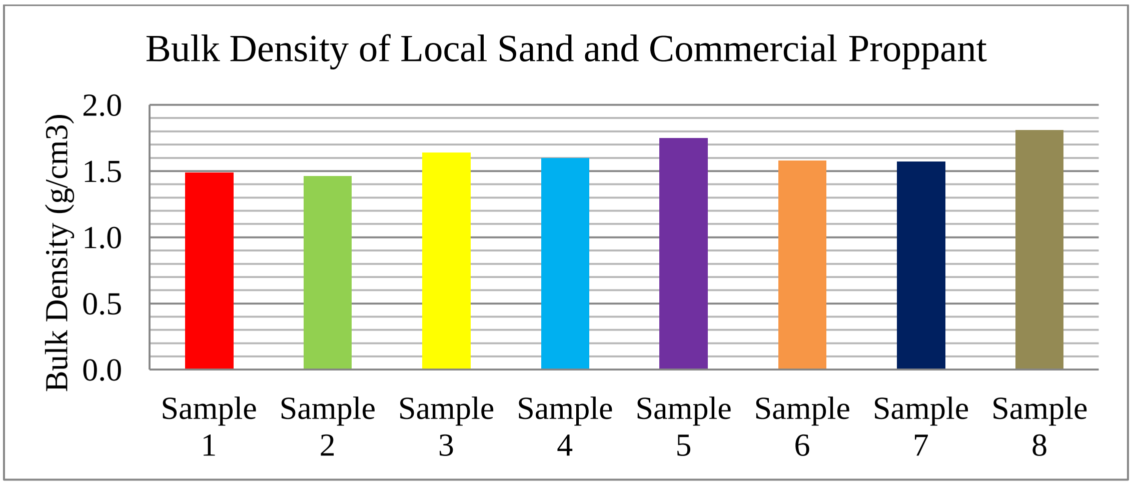
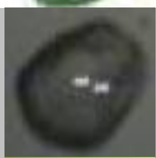
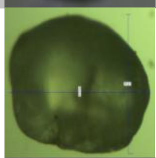
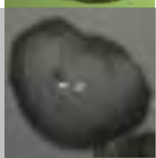
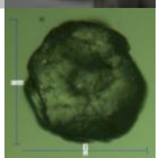
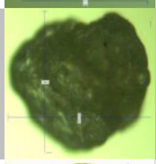
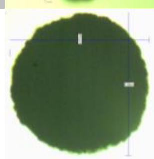


Figure 21: Comparison for bulk density of local sand and commercial proppant

4.2 Sphericity and Roundness

Ceramic has the highest value for both sphericity and roundness as shown in figure 22. The minimum value for both roundness and sphericity is 0.6 for sample to be qualified as proppant. The local sand samples did not meet the roundness specification. However, they meet the sphericity value. Comparing to the sample 7 which is the silica sand from India, the local sand gives almost the same value for both sphericity and roundness.

Table 9: Roundness and sphericity

Sample	Image (Mag 40x)	Roundness	Sphericity
Sample 1		0.50	0.67
Sample 2		0.54	0.67
Sample 3		0.47	0.61
Sample 4		0.56	0.74
Sample 5		0.50	0.62
Sample 6		0.58	0.72
Sample 7		0.54	0.66
Sample 8		0.86	0.90

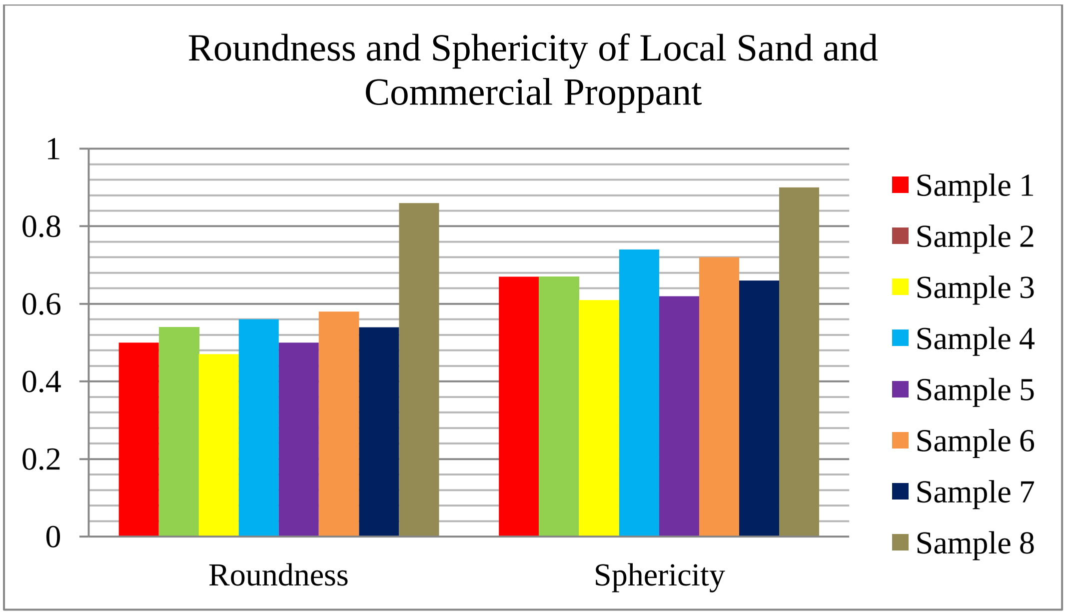


Figure 22: Comparison of roundness and sphericity

4.3 Shear Strength

4.3.1 Shear Stress of All the Samples

All the samples were tested with three different normal loads which are 98.1 kPa, 196.2 kPa and 294.3 kPa. For each shear stage, the stage was stopped when the change in shear stress became almost minimal with an increase in shear displacement. Once the stage was stopped, the sample was then unloaded to zero shear stress and the normal stress was increased to the next level. Figure 23 shows the characteristics of shear stress of sample 1. The mesh size 30/80 gives the highest shear stress followed by mesh size 20/40 size and 30/50 size. Mesh size 30/80 gives high shear stress maybe due to the interlocking of the particle since mesh size 30/50 consists of small particle sizes and produce high interlocking.

Figure 24 shows the behavior of shear stress of sample 2. This figures shows that mesh size 30/50 gives the highest shear stress followed closely by mesh size of 30/80 and 20/40. At normal stress 196.2 kPa, mesh size 20/40, 30/50 and 30/80 have almost the same shear stress. However, when 294.3 kPa normal load is applied, it can be seen clearly the difference of shear stress between all the mesh sizes.

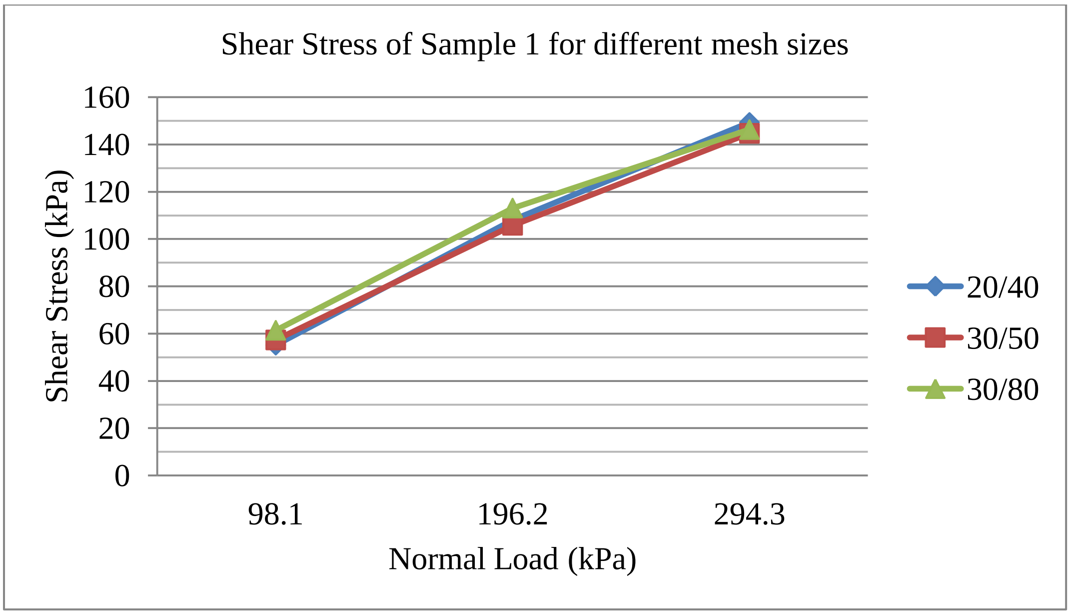


Figure 23: Shear stress of sample 1 with different mesh size and normal stress applied.

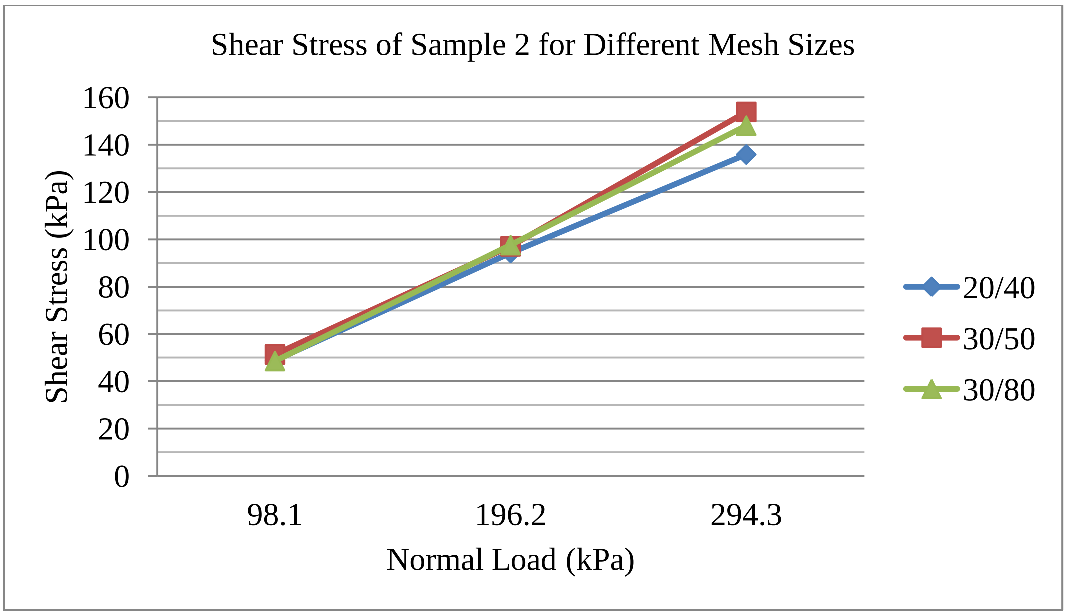


Figure 24: Shear stress of sample 2 with different mesh size and normal stress applied.

From Figure 25, mesh size 30/80 of sample 3 gives the highest shear stress followed by mesh size 20/40 and 30/50. However, initially when 98.1 kPa load is applied, mesh size 30/80 gives the lowest shear stress. Figure 26 shows the shear stress of sample 4 for different mesh sizes. From this figure, mesh size 30/80 of sample 4 behaves similarly to the mesh size 30/80 of sample 3 whereby initially when 98.1 kPa normal load was applied, the mesh size 30/80 gives the lowest shear stress. Mesh size 30/80 gives the highest shear stress followed by mesh size 20/40 and 30/50 for sample 4.

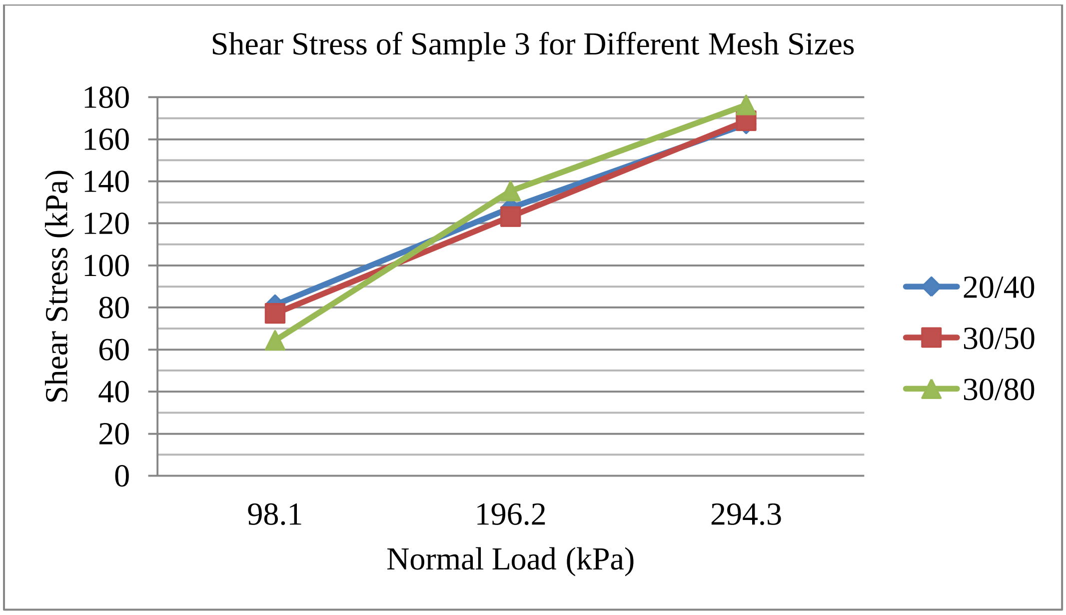


Figure 25: Shear stress of sample 3 with different mesh size and normal stress applied.

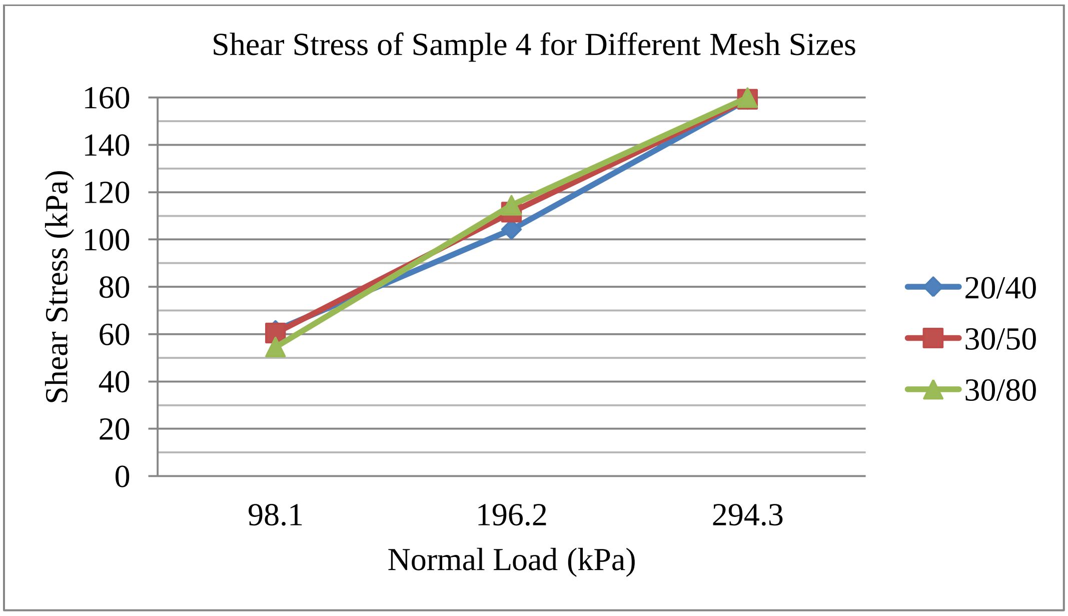


Figure 26: Shear stress of sample 4 with different mesh size and normal stress applied.

Figure 27 shows the shear stress of sample 5. From this figure, it shows that mesh size 20/40, 30/50 and 30/80 behaves similarly when normal load of 98.1 kPa is applied. Besides that, the differences between the shear stress of mesh size 20/40, 30/50 and 30/80 were small when normal load 196.2 kPa and 294.3 kPa were applied. As for shear stress for sample 6 shown in Figure 28, mesh size 20/40, 30/50 and 30/80 behaves in the same way when normal load 98.1 kPa and 196.2 kPa. As 294.3 kPa was applied, the differences of shear stress between the three mesh size distributions were small.

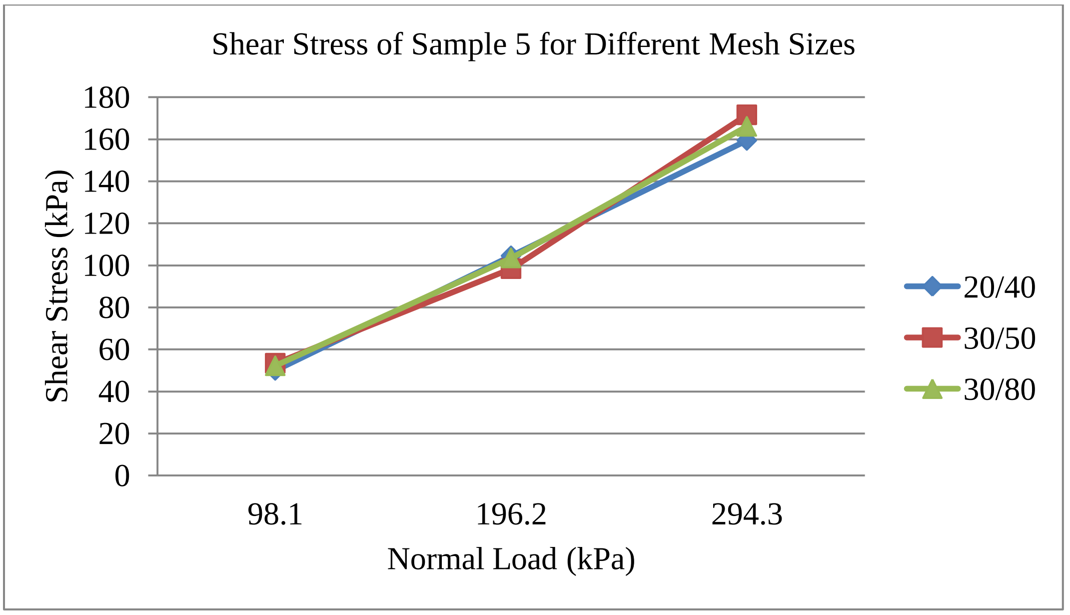


Figure 27: Shear stress of sample 5 with different mesh size and normal stress applied.

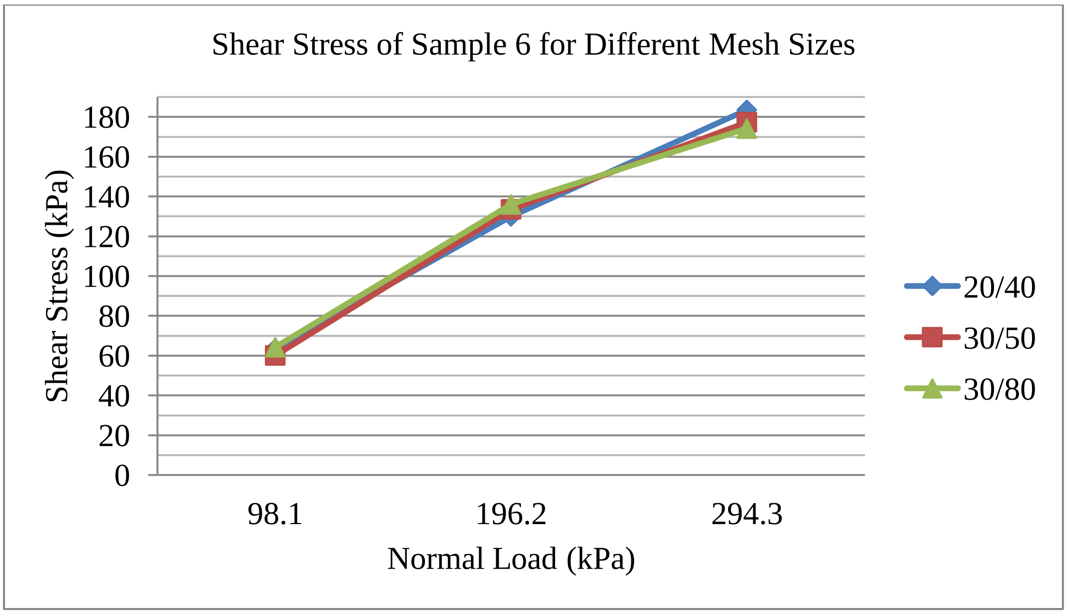


Figure 28: Shear stress of sample 6 with different mesh size and normal stress applied.

Figure 29 shows the shear stress of India sample. Mesh size 20/40 gives the highest shear stress followed by mesh sizes 30/80 and 30/50. As for the China sample, the shear stress is shown in Figure 30. When 196.2 kPa and 294 kPa normal load were applied, mesh size 20/40 and 30/50 behave the same way. However, there was slight difference in shear stress when 98.1 kPa was applied. Comparing both the commercial proppant, sample 7 gives higher shear strength compared to the China sample.

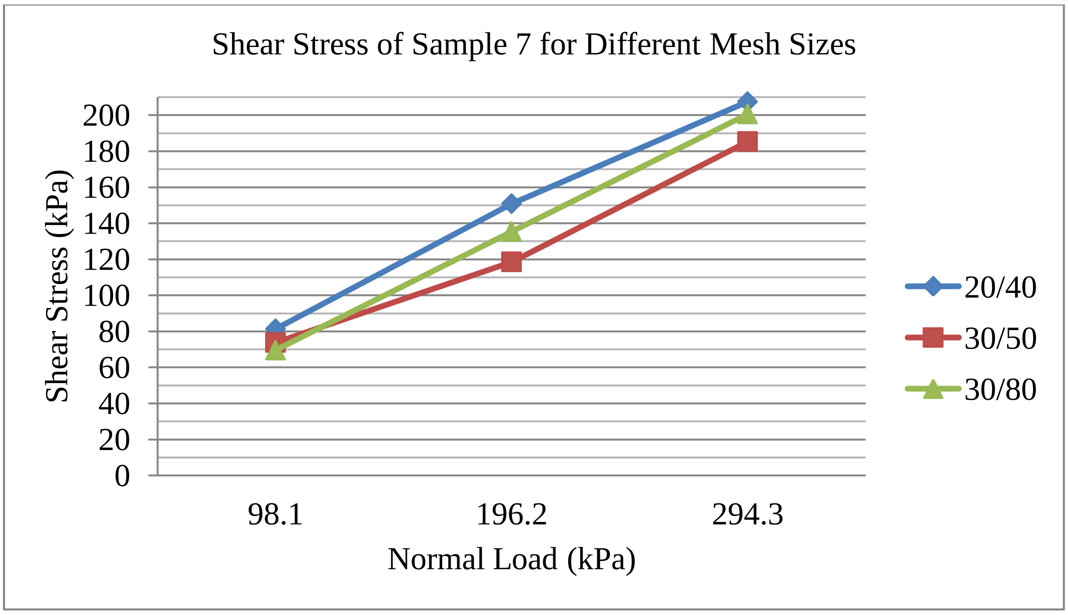


Figure 29: Shear stress of sample 7 with different mesh size and normal stress applied.

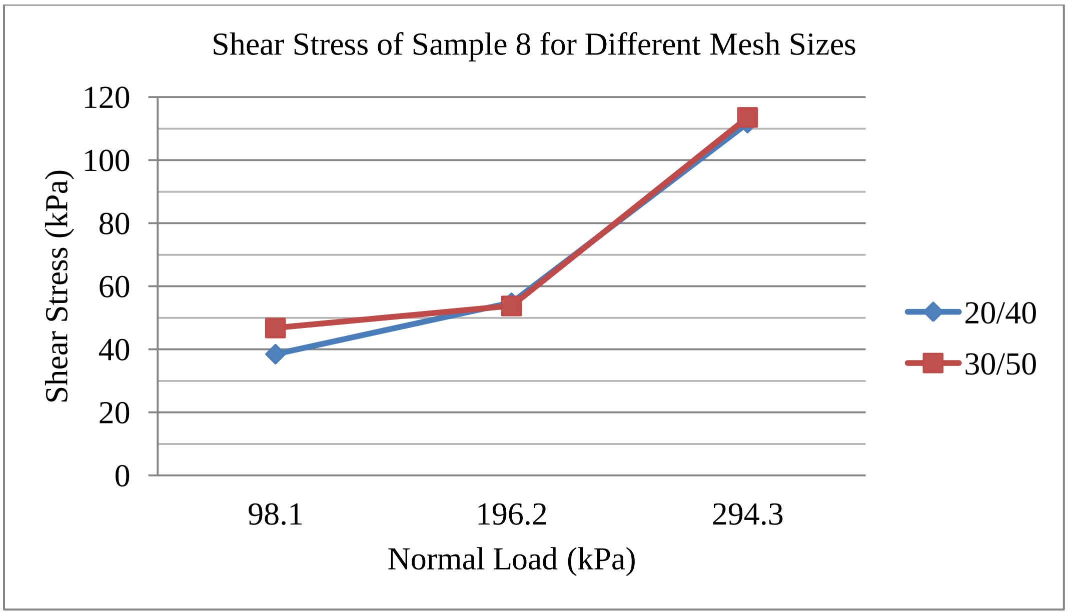


Figure 30: Shear stress of sample 8 with different mesh size and normal stress applied.

4.3.2 Shear Strength of All the Sample with Different Mesh Size Distributions

Table 10 shows the summary of shear strength of all the samples. Angle of shear resistance of sample 7 for mesh size 20/40, 30/50 and 30/80 were the highest among the samples whereas sample 8 which is the sample from China gives the lowest angle of shear resistance for mesh size 20/40 and 30/50. The shear strength was calculated using the Coulomb's equation. The cohesion of all the samples is zero as these samples are unconsolidated and there is no cementation between the particles of the samples.

Table 10: Shear strength of all the samples

Sample	Mesh size	Angle of Shear Resistance, θ (Degrees)	Cohesion, *c* (kPa)	Shear Strength , $\tau_{f,}$ (kPa)
Sample 1	20/40	27.64	0	308.24
	30/50	27.11	0	301.33
	30/80	27.88	0	311.38
Sample 2	20/40	25.16	0	276.47
	30/50	27.25	0	303.15
	30/80	26.61	0	294.88
Sample 3	20/40	31.39	0	359.14
	30/50	31.14	0	355.63
	30/80	32.18	0	370.37
Sample 4	20/40	28.57	0	320.52
	30/50	29.01	0	326.40
	30/80	29.07	0	327.21
Sample 5	20/40	28.23	0	316.00
	30/50	29.12	0	327.88
	30/80	28.88	0	324.66
Sample 6	20/40	32.48	0	374.69
	30/50	32.04	0	368.37
	30/80	32.03	0	368.23
Sample 7	20/40	36.22	0	431.11
	30/50	32.27	0	371.67
	30/80	34.47	0	404.08
Sample 8	20/40	19.34	0	206.59
	30/50	19.83	0	212.26

The graph of shear strength was plotted versus the mesh size distribution as shown in Figure 32 for comparison purpose. Sample 7 gives the highest shear strength for all the mesh size distributions due to the highest friction angle. The

Terengganu sand samples have lower shear strength than the India sample for all the mesh size distributions. However, the shear strength of these samples is higher than the ceramic propant from China. Mohr-Coulomb failure criteria mention that a material fails because of a critical combination of normal stress and shear stress. Shear strength in these samples depends primarily on interactions between particles.

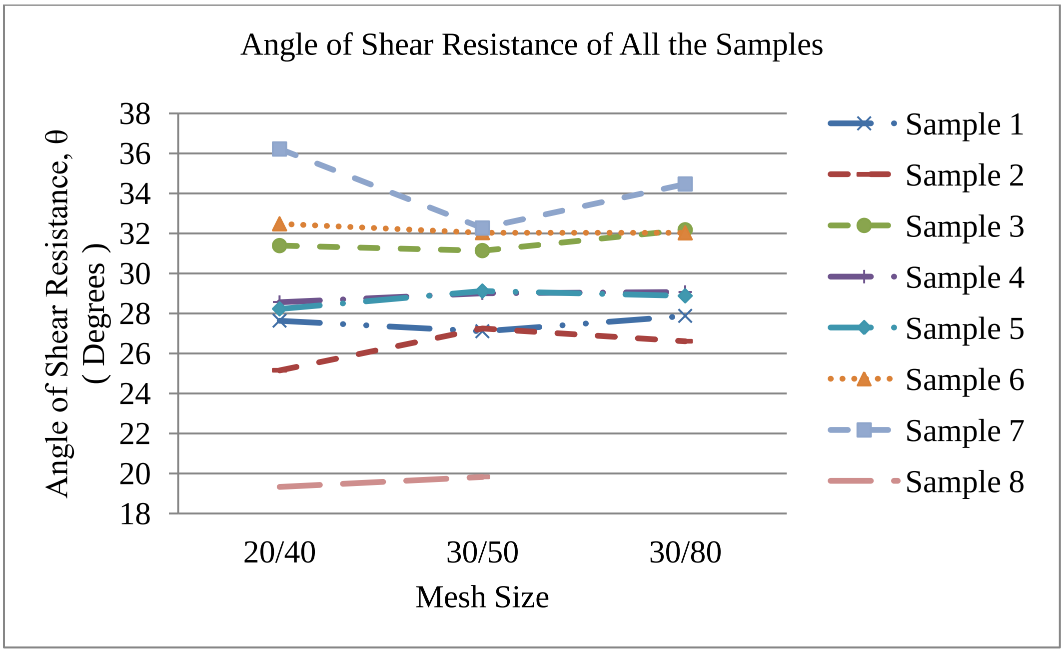


Figure 31: Angle of shear resistance of all the samples with different mesh size distribution

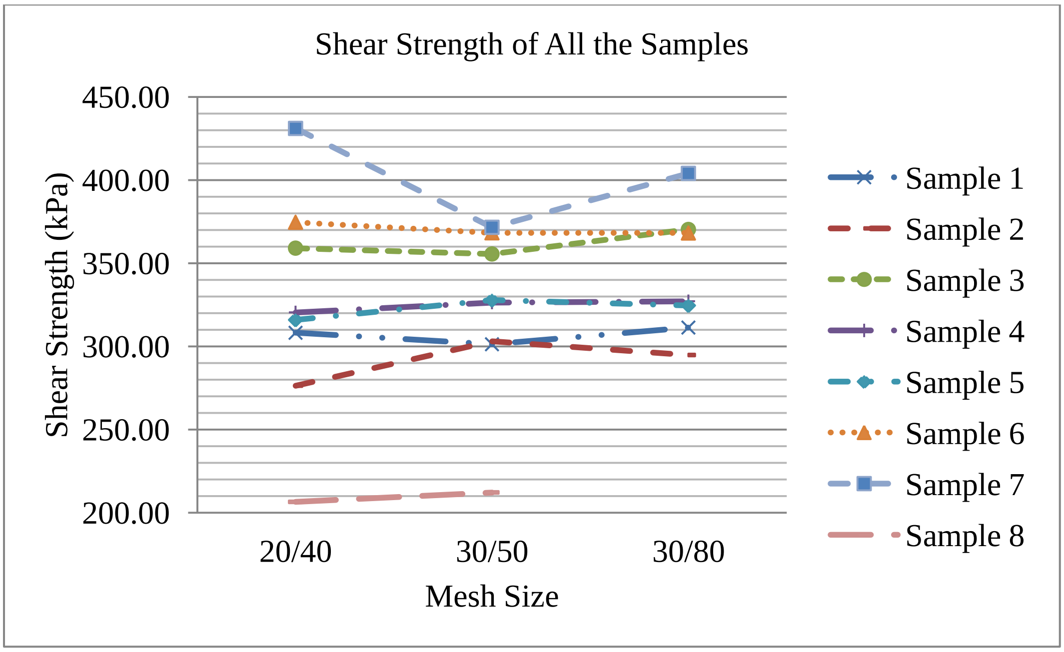


Figure 32: Shear strength of all the samples with different mesh size distribution

Sample 7 gives a very significant difference between the shear strength off mesh size 20/40, 30/50 and 30/80 meanwhile the other samples have almost the same shear strength for the same mesh size distributions. Comparing between the Terengganu sand samples, sample 6 has the highest shear strength followed by sample 3. Sample 4 and 5 behaves similarly in terms of shear strength.

4.4 Acid Solubility

Figure 33, 34 and 35 shows the acid solubility of mesh size 20/40, 30/50 and 30/80 for all the samples. Sample 1 shows the highest solubility in acid followed by sample 7, the commercial proppant for mesh size 20/40. As for mesh size 30/50 and 30/80, sample 7 shows the highest solubility in acid.

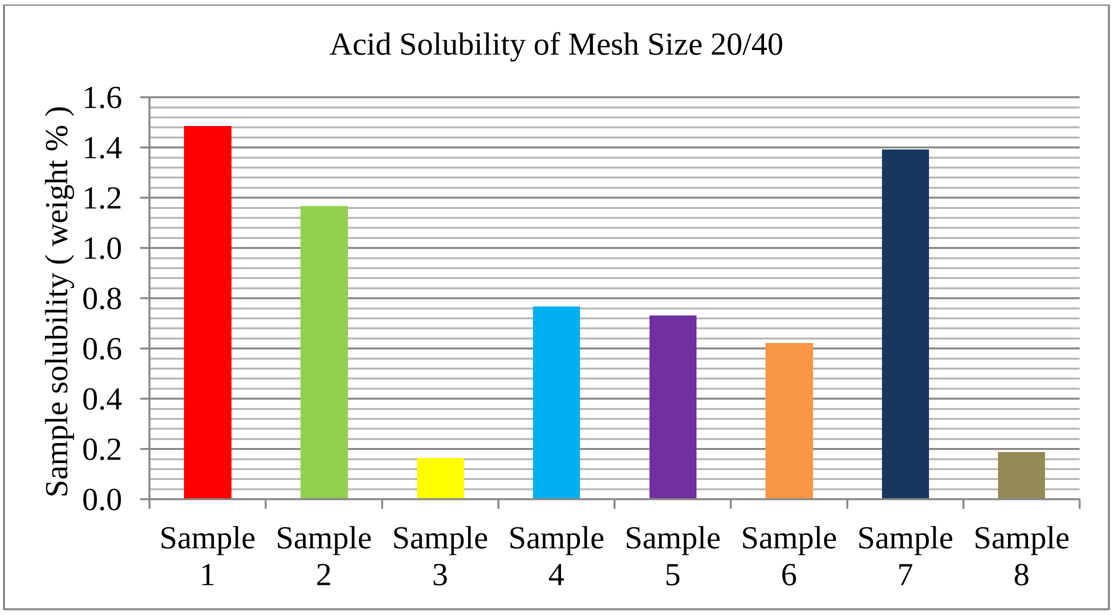


Figure 33: Comparison of acid solubility of mesh size 20/40 between local sand and commercial proppant

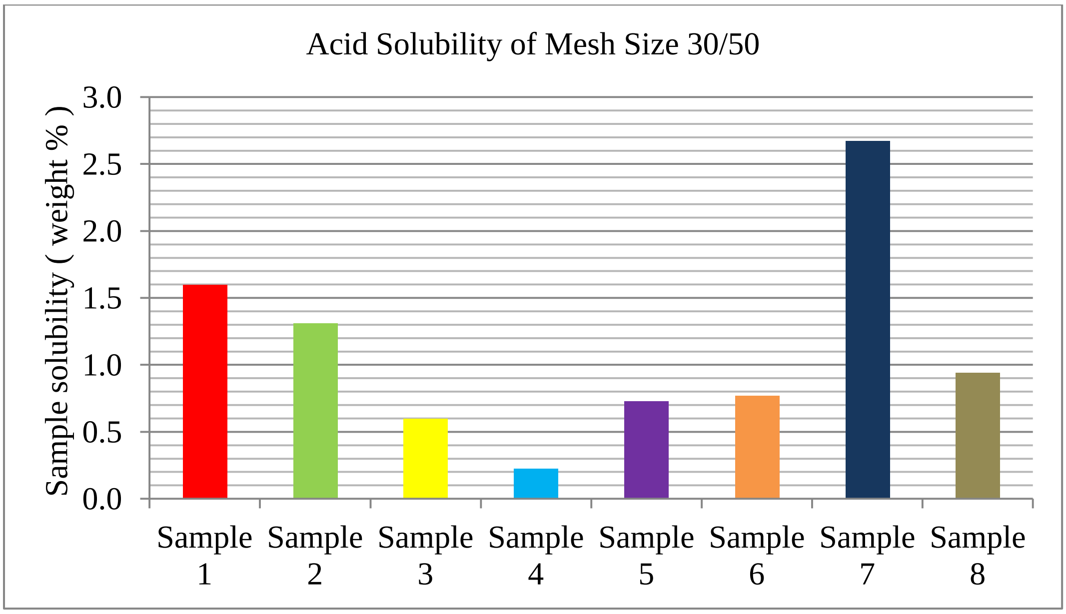


Figure 34: Comparison of acid solubility of mesh size 30/50 between local sand and commercial proppant

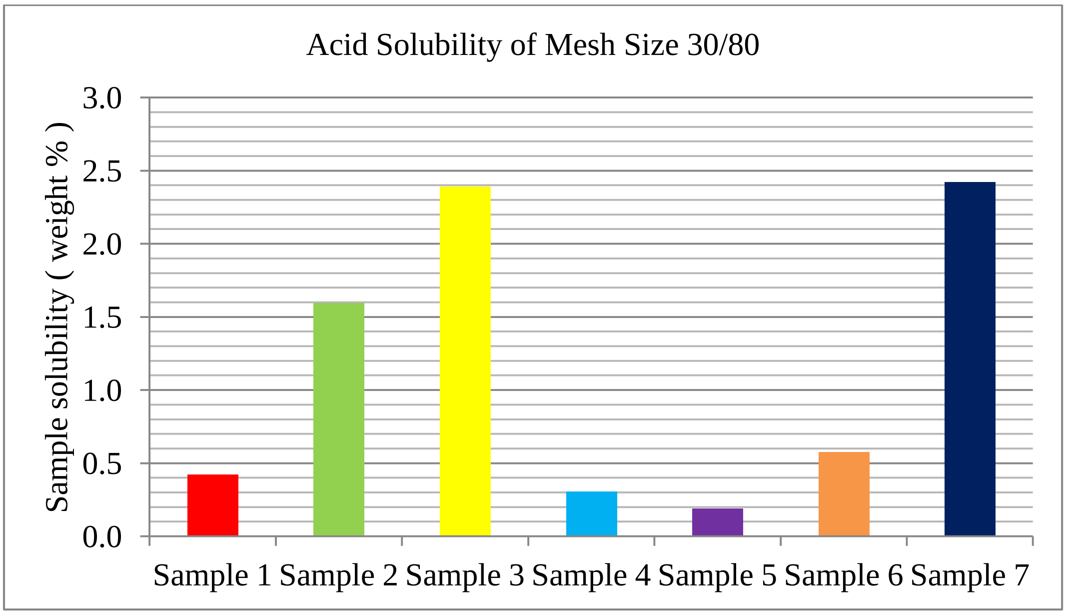


Figure 35: Comparison of acid solubility of mesh size 30/80 between local sand and commercial proppant

Figure 36 shows that the acid solubility of sample 2, 3, 5 and 8 is increasing as the mesh size increases. This means the smaller the particles are, the higher the solubility they have in acid because the smaller the particles for a constant weight of samples, the higher the surface area that may be in contact with the acid. However, as the mesh size increases, the other samples did not have an increase in the reduction on weight of the samples after the test because some particles might interlock among themselves providing less surface area for the acid to react. Sample

7 has the highest solubility in the acid compared to the other samples. According to API RP 56, the acid solubility of mesh size 6/12 to 30/50 should not exceed 2%. In this case, sample 7 did not meet the standards whereas the other samples meet the standard. For the mesh size of 30/80 the acid solubility of all the samples meets the specification.

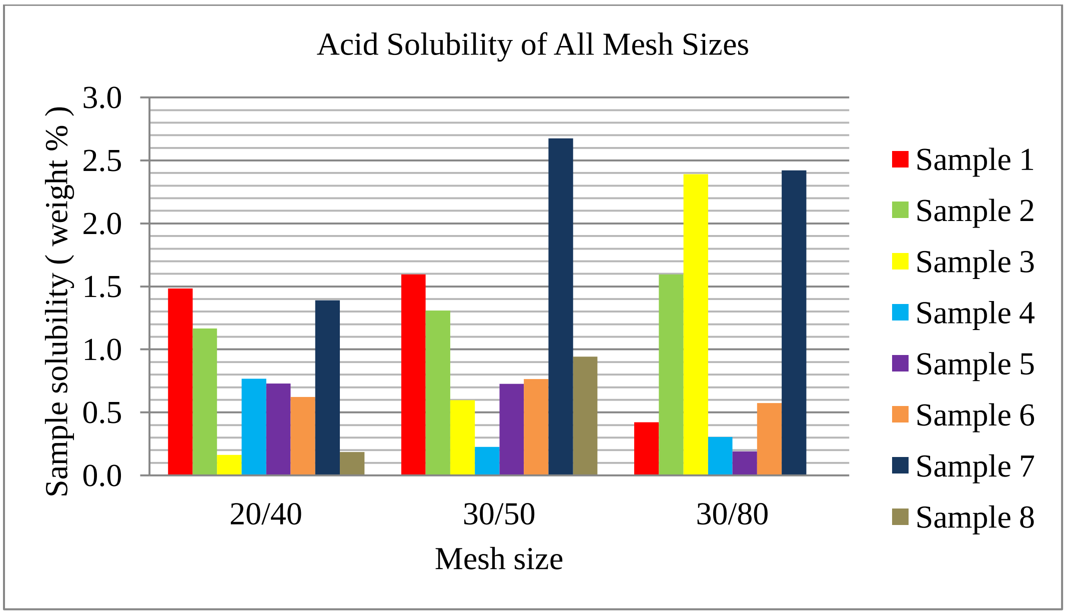


Figure 36: Comparison of acid solubility of all mesh sizes between local sand and commercial proppant

4.5 Turbidity

4.5.1 Turbidity before properly washed and processed

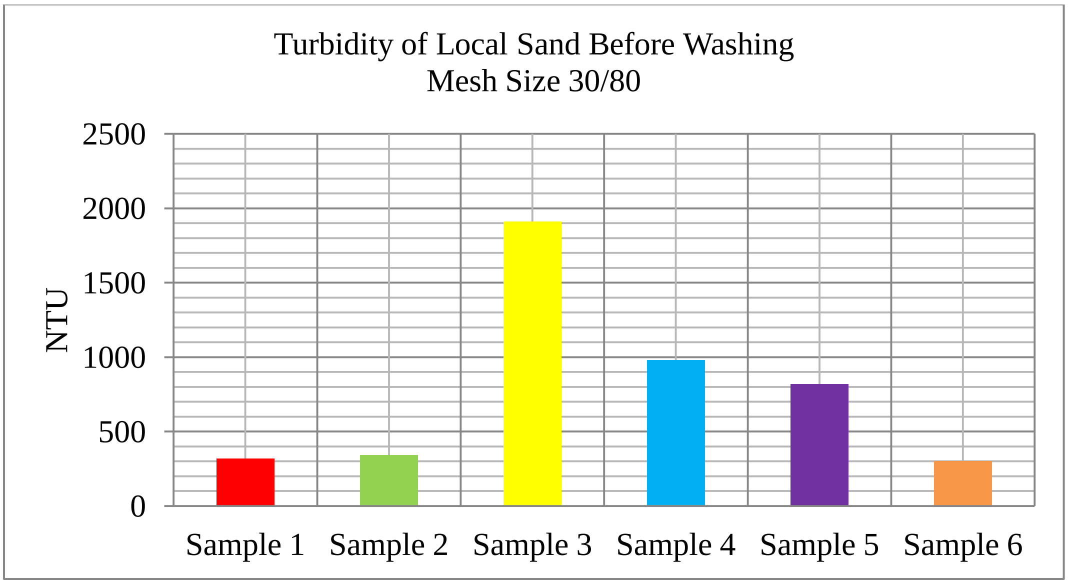


Figure 37: Turbidity of local sand before washing mesh size 30/80

The turbidity results for the local sand before washing is shown in Figure 37. The turbidity of sand sample should be 250 NTU or less. The samples did not meet the standard before washing as all the readings were above 250 NTU. Sample 3 gives the highest turbidity value due to the highest clay or silt content compared to the other samples. Thus, these sand samples were properly washed and processed to remove the impurities and tested over again for turbidity.

4.5.1 Turbidity after properly washed and processed

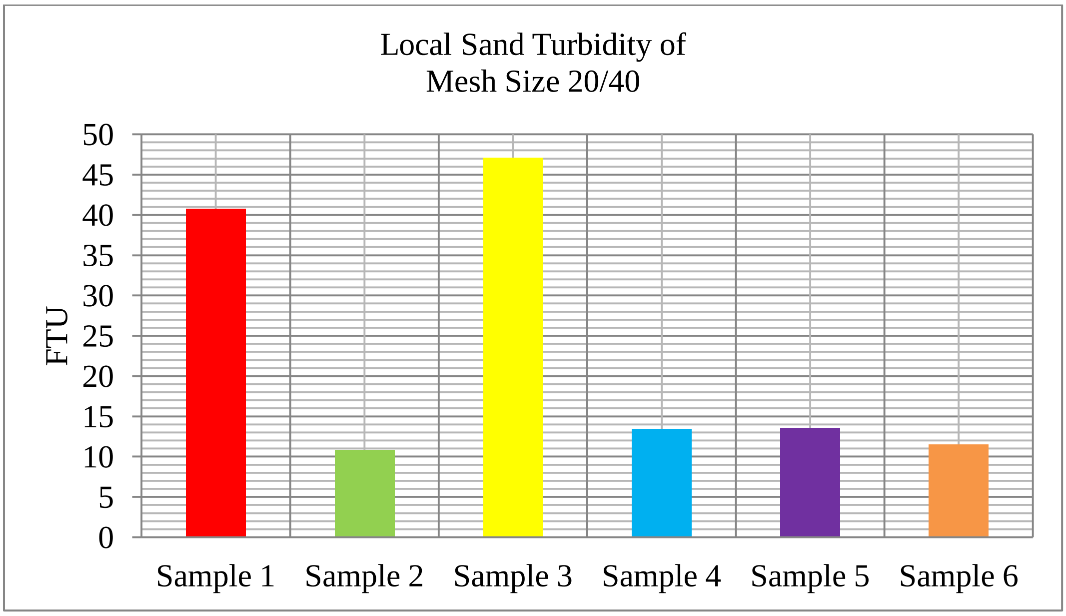


Figure 38: Local sand turbidity of mesh size 20/40

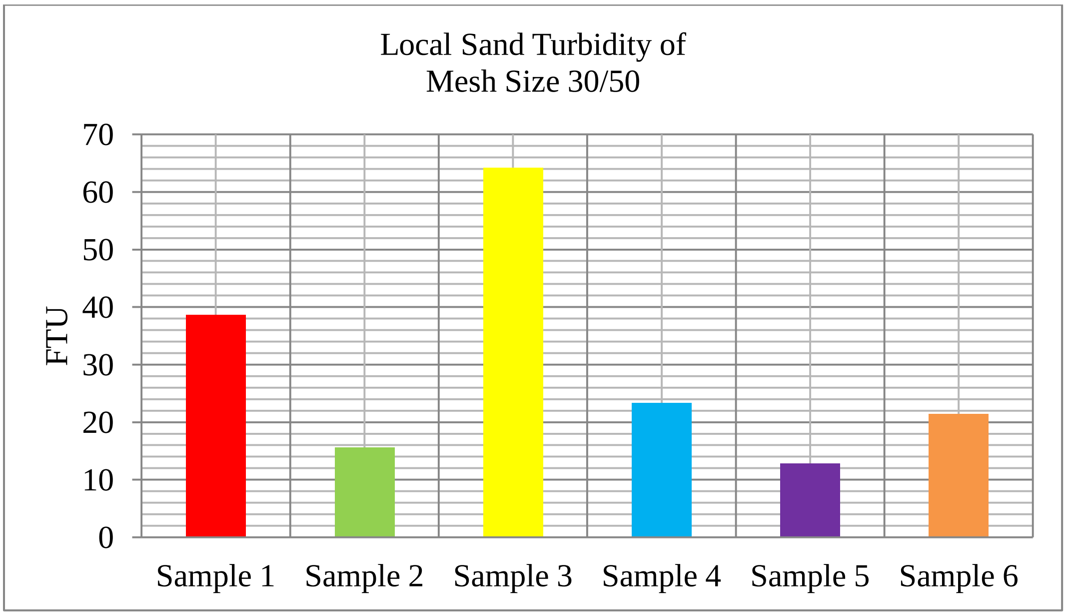


Figure 39: Local sand turbidity of mesh size 30/50

Figure 38 shows that sample 3 has the highest turbidity value followed by sample 1 for the mesh size distribution 20/40. Meanwhile, the minimum turbidity value for this size distribution is sample 6. The maximum value for the turbidity is around 47 NTU which is way lower than the standard. All the sand samples pass the turbidity test for the mesh size distribution of 20/40. As for the mesh size distribution of 30/50, the maximum value of turbidity is about 64 NTU for sample 3 as shown in Figure 39. For this mesh size again all the sand samples meet the requirement.

From figure 40, the highest value of turbidity for mesh size distribution of 30/80 is tested to be below 140NTU which again meets the requirement. The sand samples of all mesh size distribution for Terengganu sand is summarized and shown below in Figure 41. This figure shows that the turbidity increases from 20/40 to 30/80 mesh size. For a given volume of sand sample, the turbidity increases as the particle size decreases. Bigger particles have less surface area compared to the smaller particles for a given volume. Thus, surface area is proportional to the clay, silt or microorganisms coated to the particles. Bigger particles has higher contact with the water, thus washing removes the clay or silt content and cleans the bigger particles better as compared to the smaller particles of the same volume. Thus, this proves that the mesh size 30/80 has higher turbidity compared to mesh size 20/40.

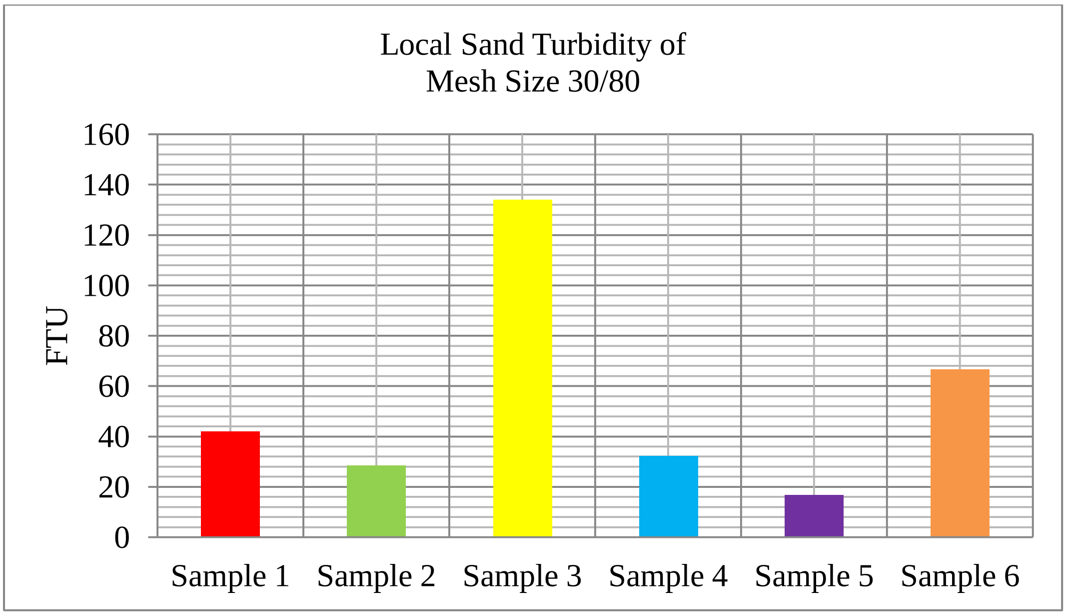


Figure 40: Local sand turbidity of mesh size 30/80

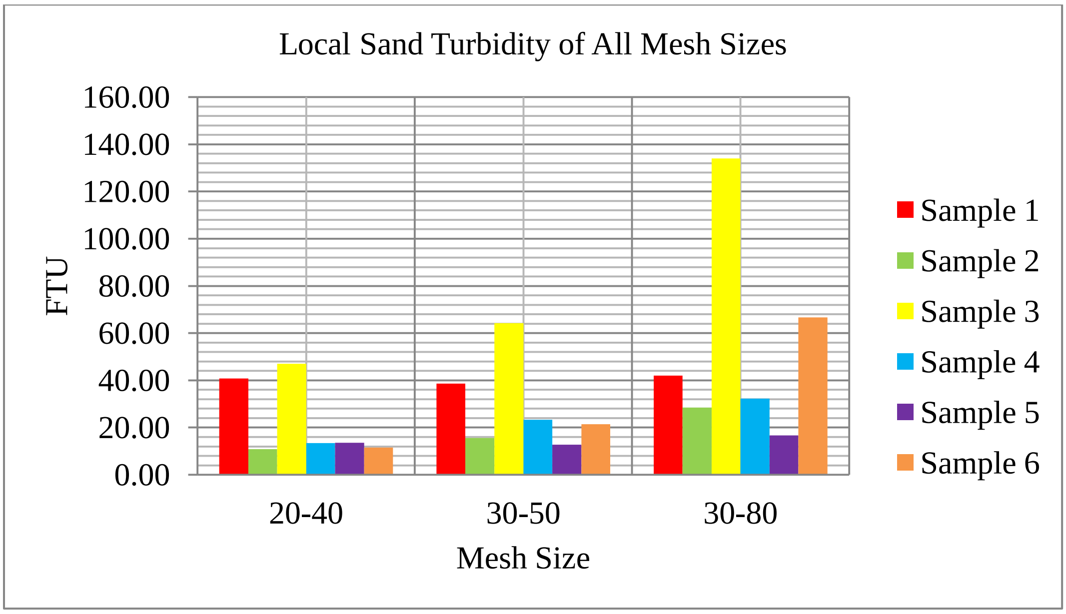


Figure 41: Local sand turbidity of all mesh sizes

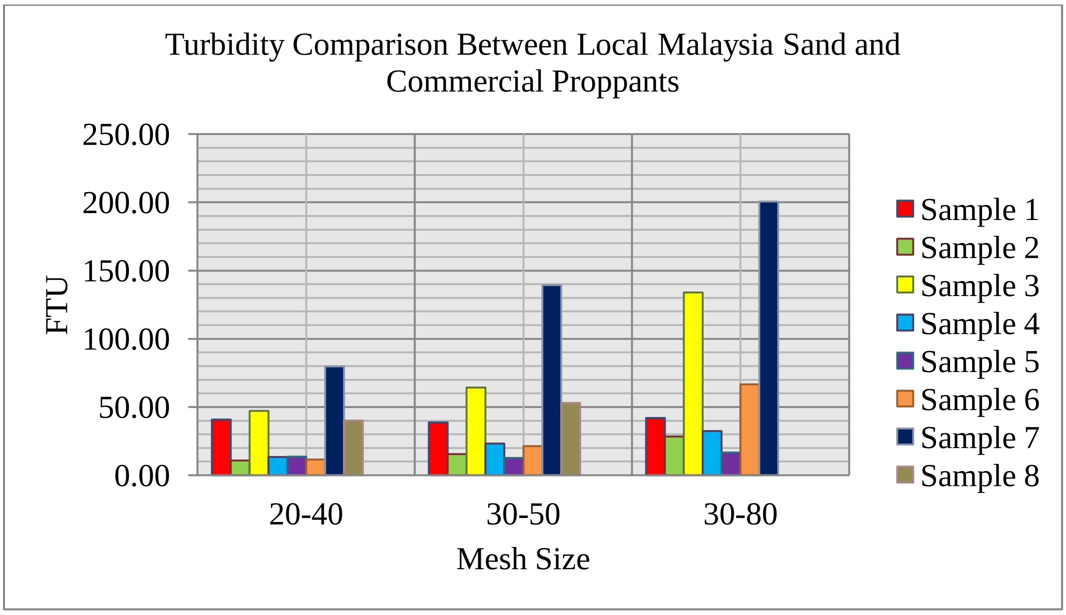


Figure 42: Turbidity comparison between Terengganu sand and commercial proppant

Figure 42 shows the turbidity ccomparison between Malaysia sand after proper washing and processing and commercial proppant. As the particle size of India and China samples decreases, the turbidity increases. The turbidity is inversely proportional to the particle size. The India sample has the highest turbidity for all three various size distributions. Thus, the comparison shows that the turbidity of local sand samples after washing has meet the standards and proves way better turbidity value compared to sample 7 and are in par with the turbidity of sample 8.

4.6 Suspension

The suspension test for mesh size 20/40 is summarized in Figure 43. Sample 8 has the shortest suspension time followed by sample 3 and 5 whereas sample 1 took the longest time to suspend. This is because ceramic has the highest density among the samples. Density is inversely proportional to the suspension time. The higher the density of the particles, the faster the particles suspend.

Figure 44 shows the suspension comparison between local sand and commercial proppant for mesh size 30/50. This figure shows that as the particle size decreases, the suspension time also increases. For example, sample 8 took about 17 minutes to suspend up to 24% of total volume of slurry for mesh size 30/50 meanwhile took about 15 minutes to suspend for mesh size 20/40.

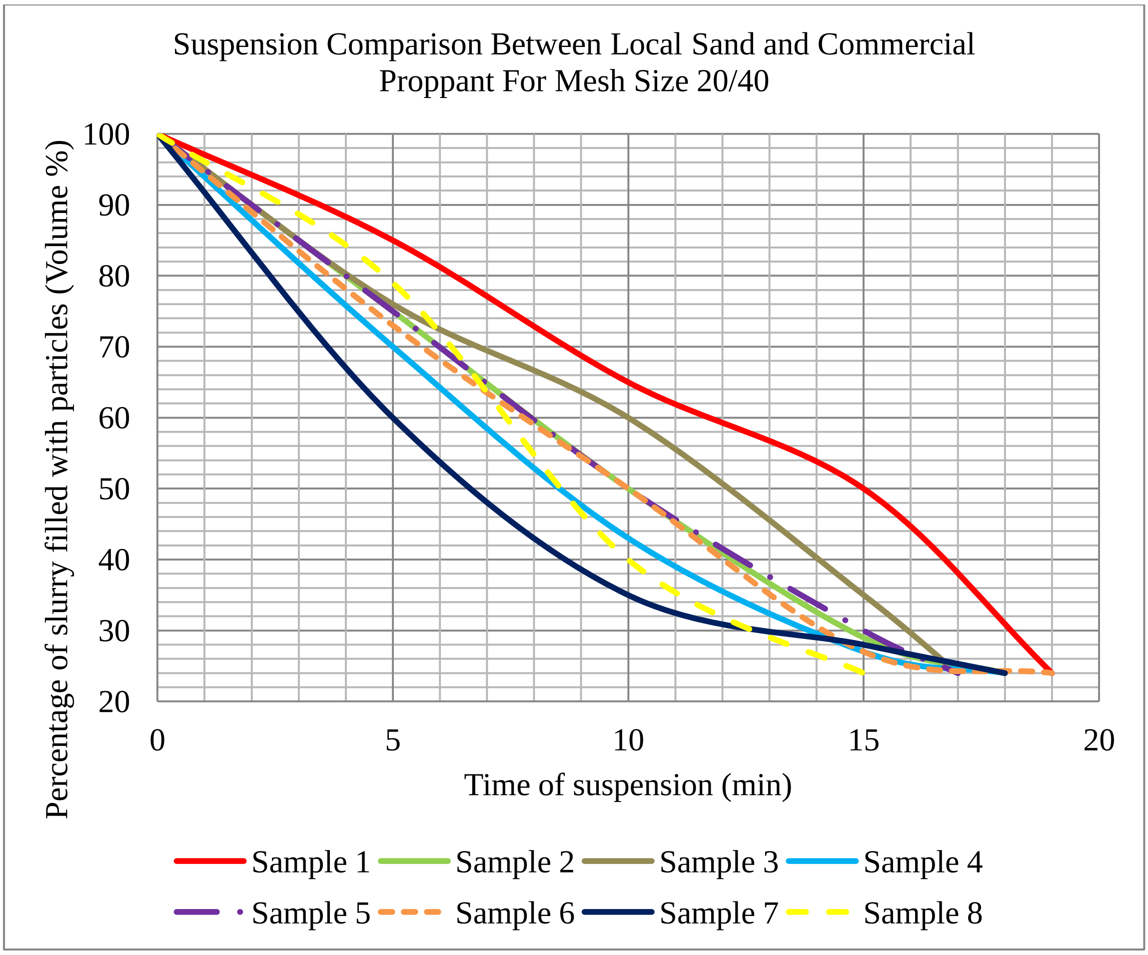


Figure 43: Suspension comparison between local sand and commercial proppant for mesh size 20/40

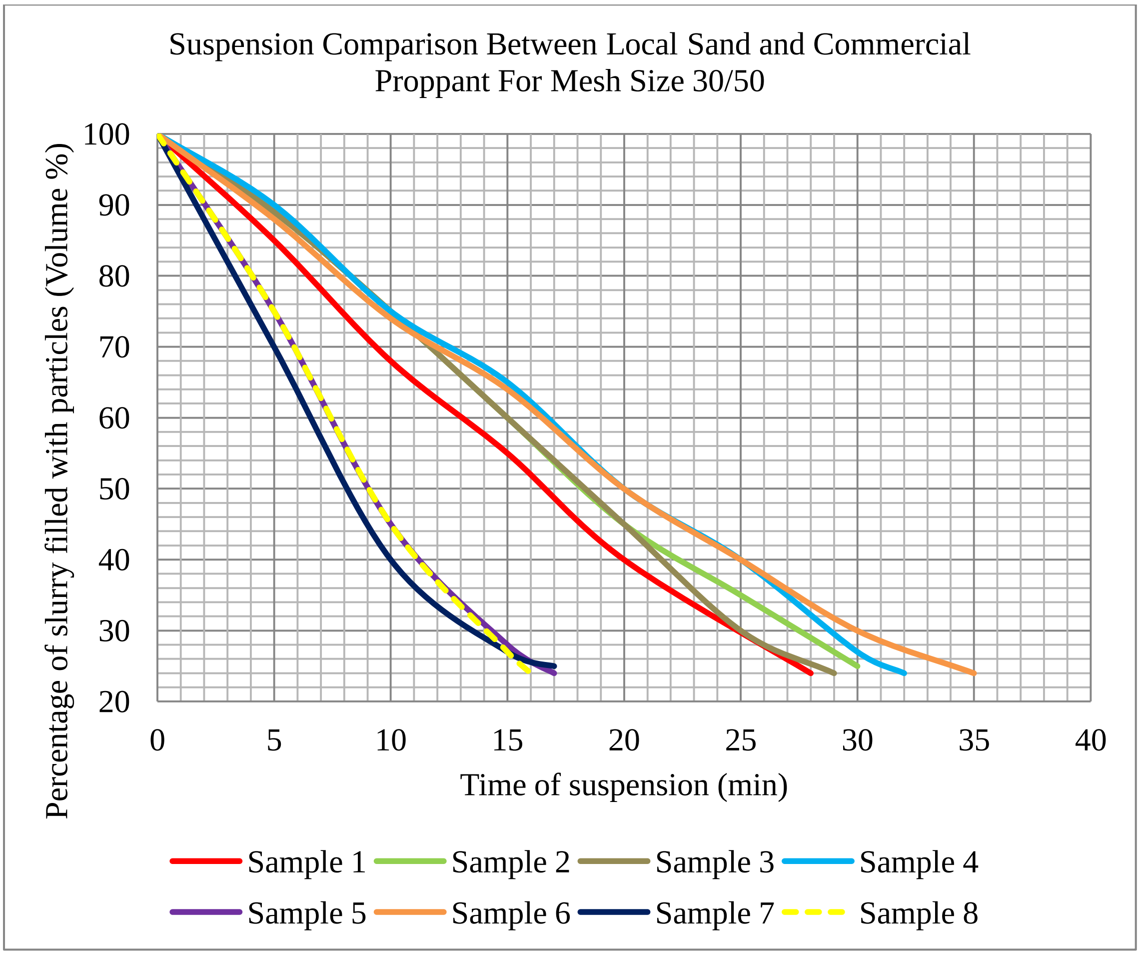


Figure 44: Suspension comparison between local sand and commercial proppant for mesh size 30/50

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The local sand bulk densities are almost in par with the density of silica sand from India although lower than the density of the ceramic proppant from China. As for the sphericity and roundness, the local sand samples did not meet the roundness specification but meet the sphericity standard. Shear strength of Terengganu sand is very high compared to the ceramic proppant. However, the silica sand from India possesses the highest shear strength. For each Terengganu sample, the shear strength of mesh size 20/40, 30/50 and 30/80 shows almost the same value. There is no significant difference between the shear strength of different mesh sizes. Sample 6 gives the highest shear strength compared to the other Terengganu sand samples.

The acid solubility of Terengganu sand samples meets the standards. The acid solubility for mesh size 20/40 and 30/50 where lower than 2% while for mesh size for 30/80 where lower than 3%. The turbidity results of the Terengganu sand samples were very high and exceeded the standard which is 250NTU. However, after properly washed and processed, the turbidity of all the Terengganu sand samples were lower than 250NTU which meet the standard. The Terengganu sand samples have longer suspension time compared to the ceramic proppant. The density of the samples affects the suspension time. Heavier particles have the shorter the suspension time. The smaller the particles size for a constant volume, the suspension time is longer than the larger particles. Thus, to put the matter in a nutshell, the Terengganu sand samples do possess some of the required proppant characteristics.

5.2 Recommendation

Based on the results, it is possible for Malaysia to produce its own local proppant with some essential adjustments through coating with suitable resin materials. Further research on the crush resistance test should also be executed on these samples. Besides that, suspension test should also be carried out using different types of carrier fluid, varying the density and pounds proppant added (PPA). The effects of these can also be further studied.

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APPENDIX

Appendix A

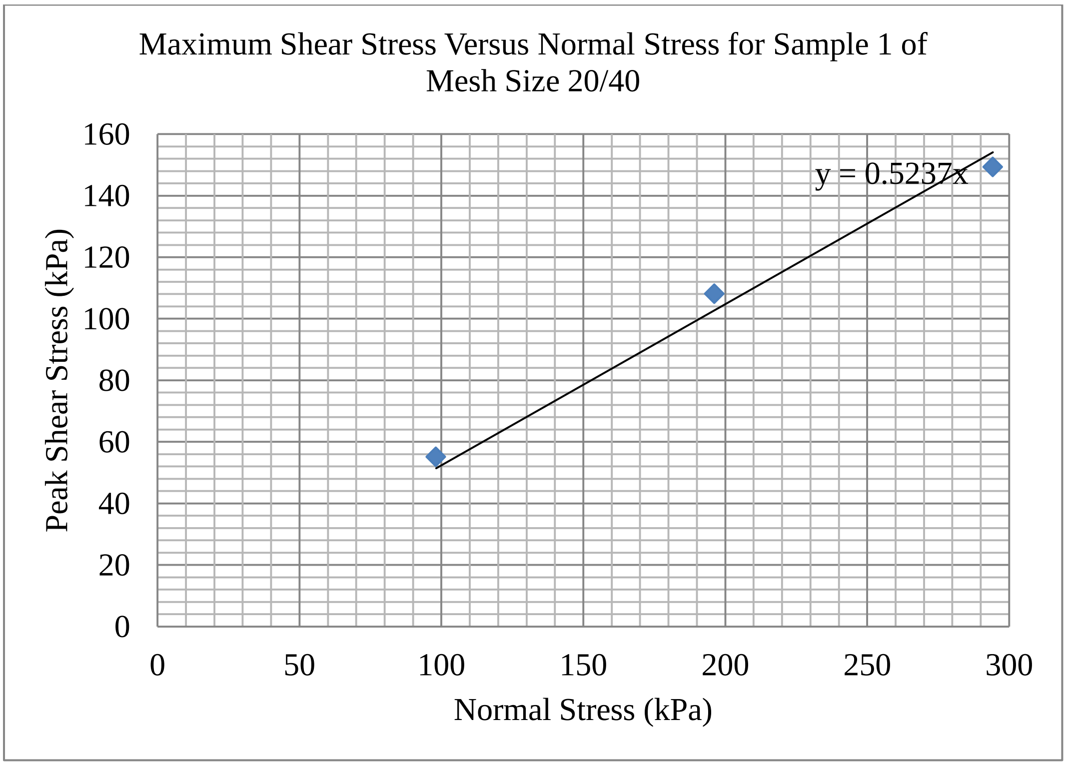

Figure A 1: Maximum shear stress versus normal stress for sample 1 of mesh size 20/40

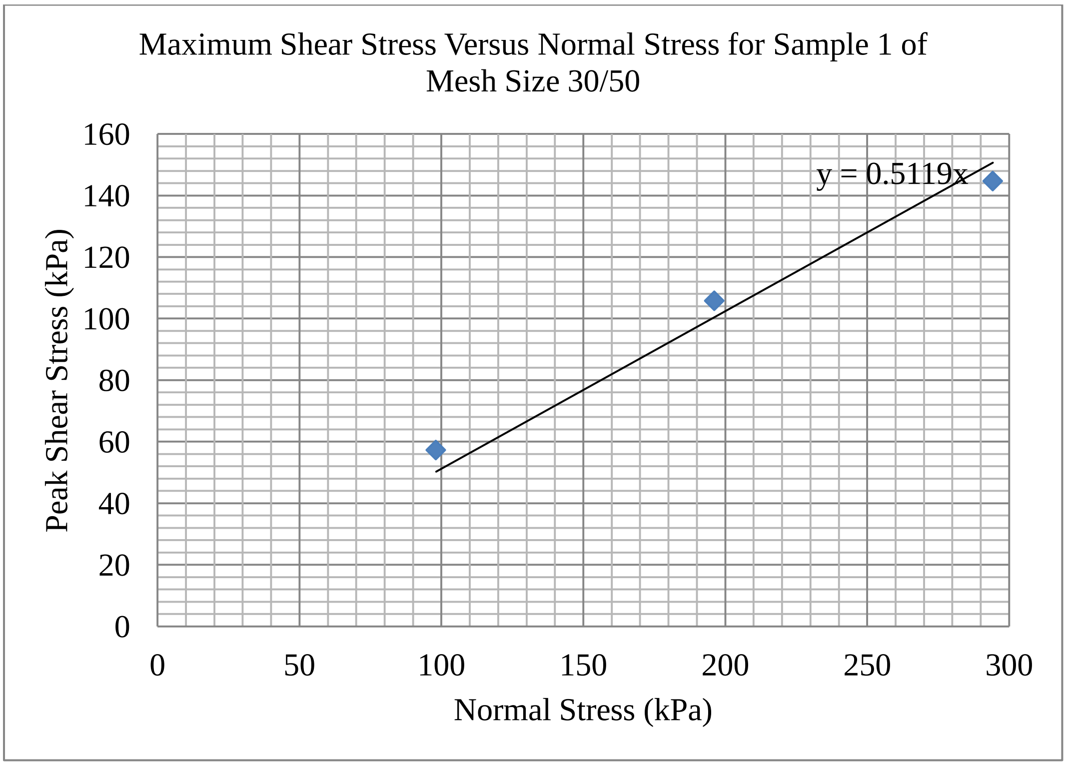

Figure A 2: Maximum shear stress versus normal stress for sample 1 of mesh size 30/50

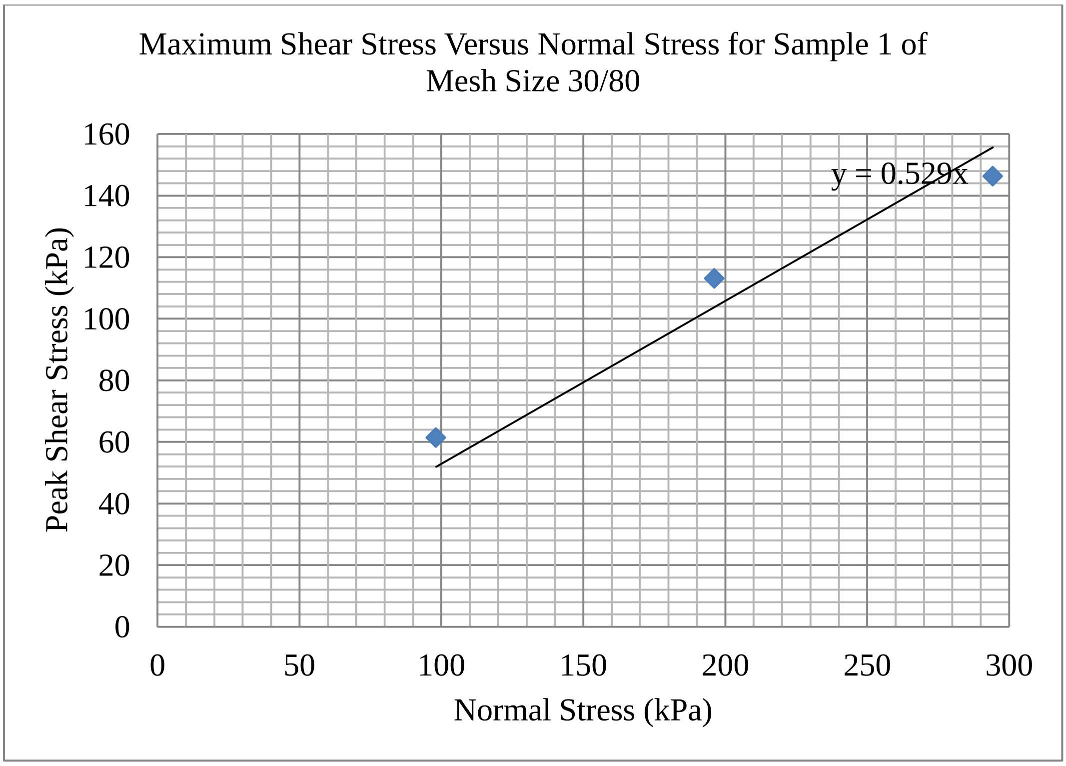

Figure A 3: Maximum shear stress versus normal stress for sample 1 of mesh size 30/50

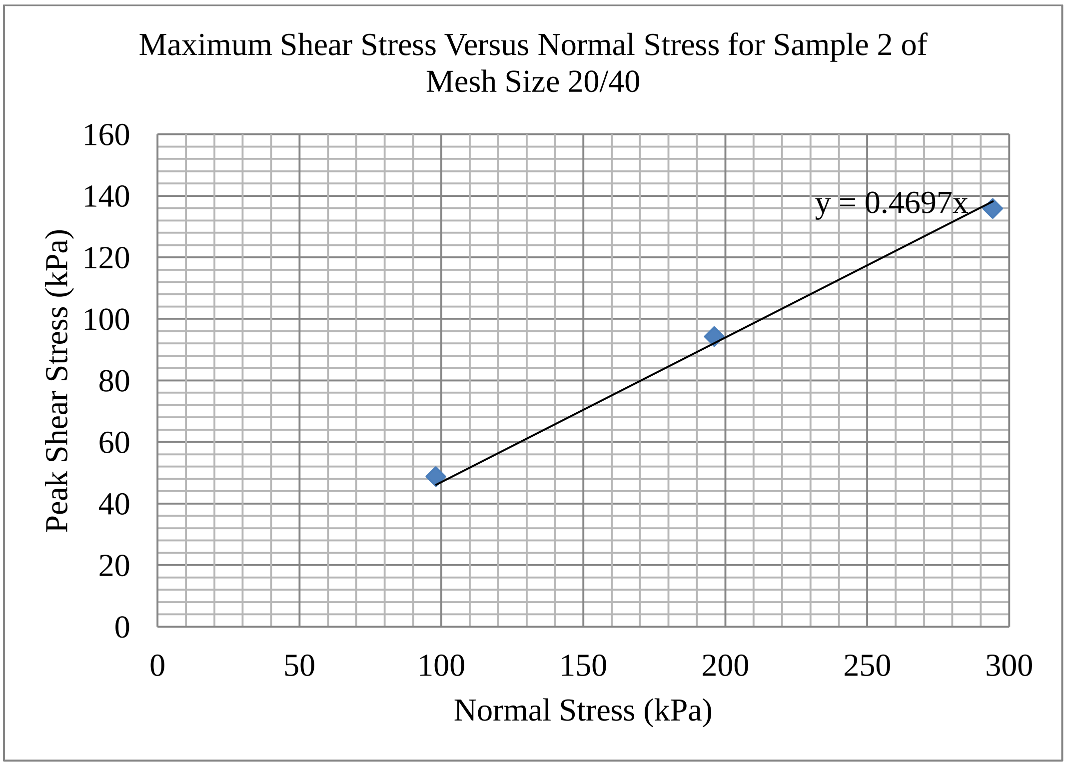

Figure A 4: Maximum shear stress versus normal stress for sample 2 of mesh size 20/40

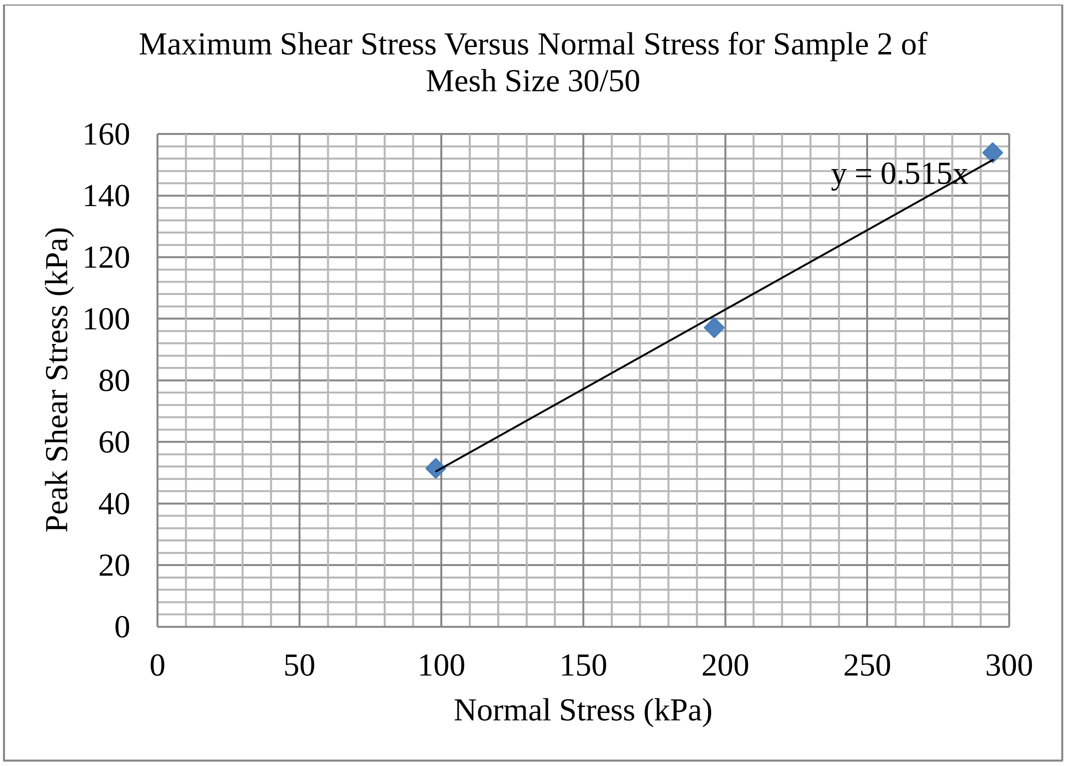

Figure A 5: Maximum shear stress versus normal stress for sample 2 of mesh size 30/50

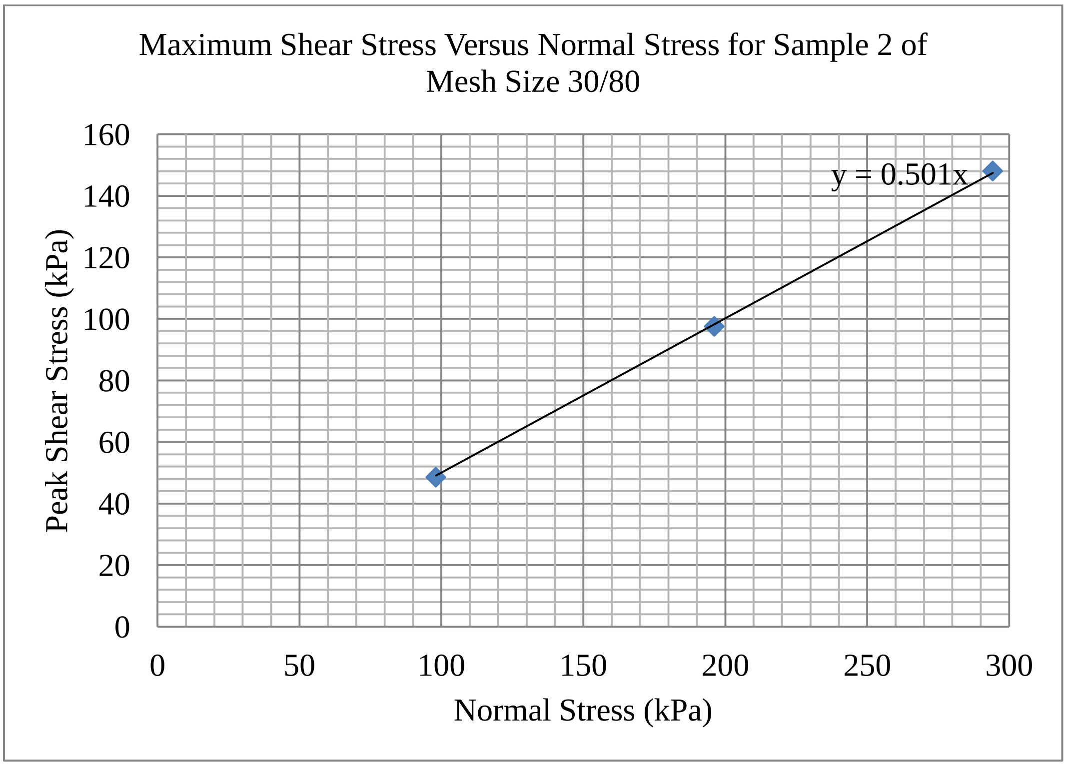

Figure A 6: Maximum shear stress versus normal stress for sample 2 of mesh size 30/80

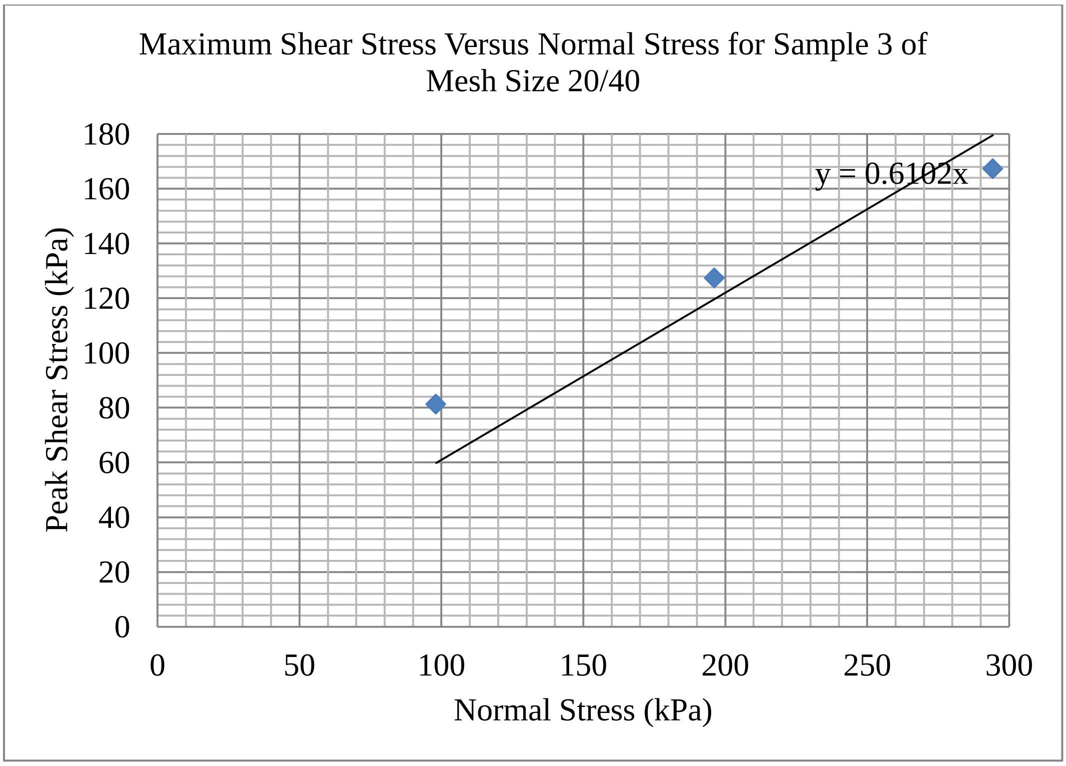

Figure A 7: Maximum shear stress versus normal stress for sample 3 of mesh size 20/40

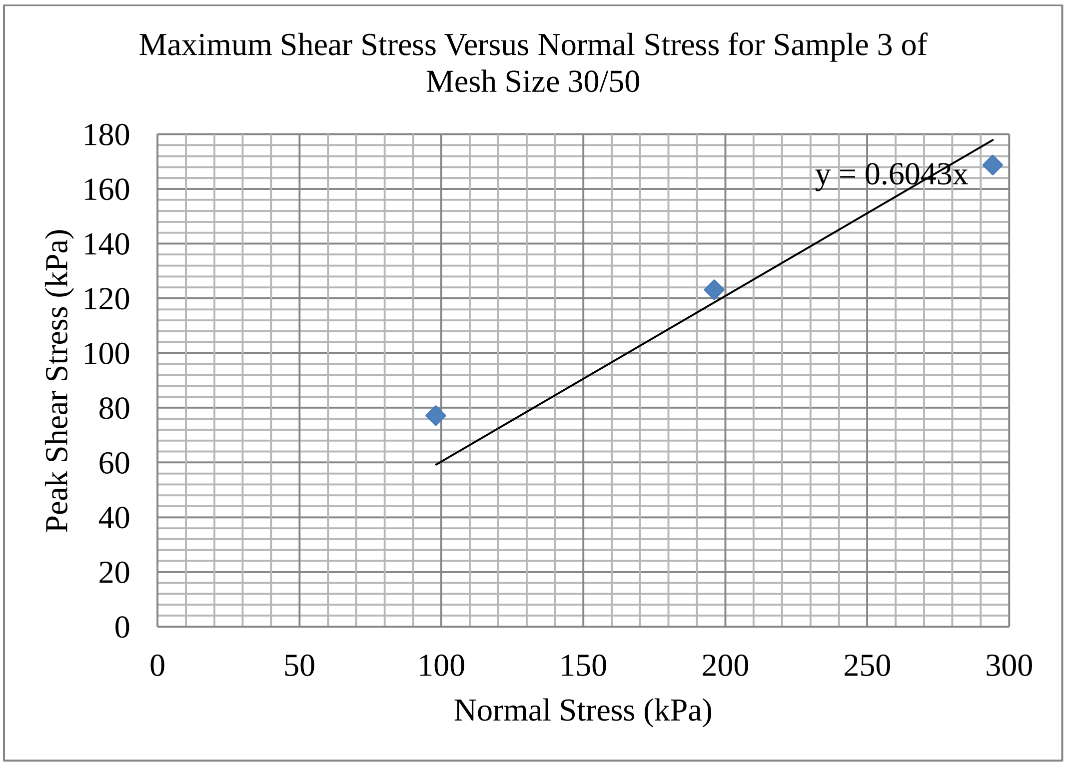

Figure A 8: Maximum shear stress versus normal stress for sample 3 of mesh size 30/50

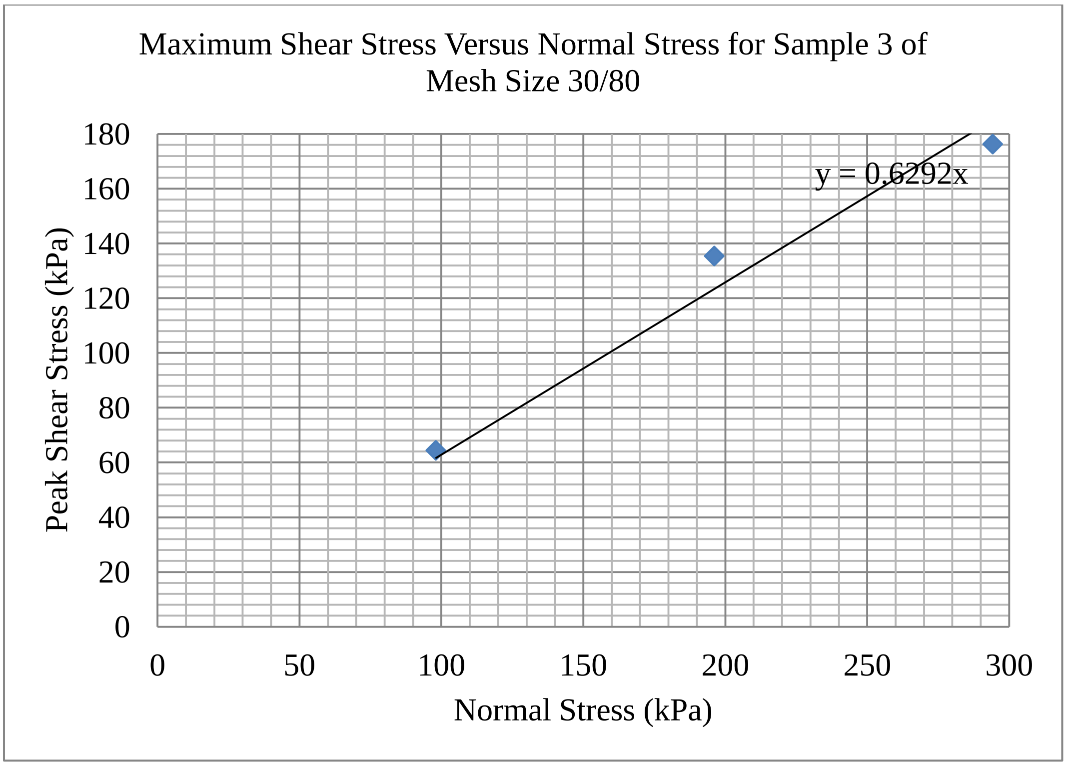

Figure A 9: Maximum shear stress versus normal stress for sample 3 of mesh size 30/80

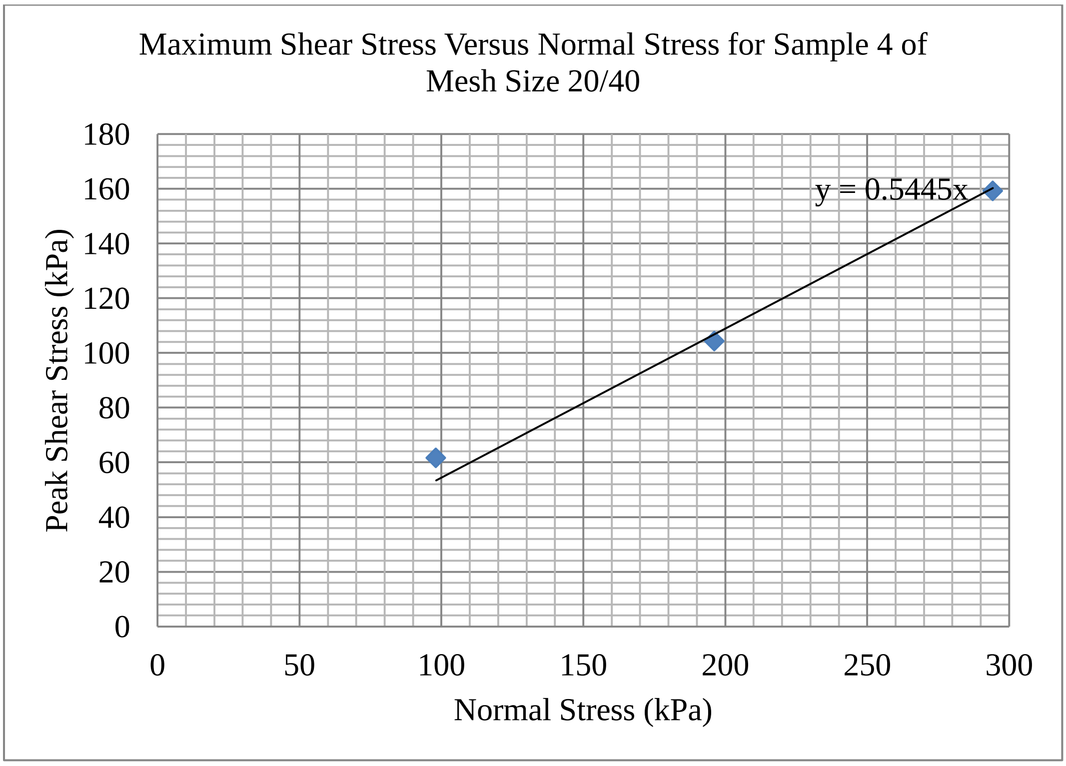

Figure A 10: Maximum shear stress versus normal stress for sample 4 of mesh size 20/40

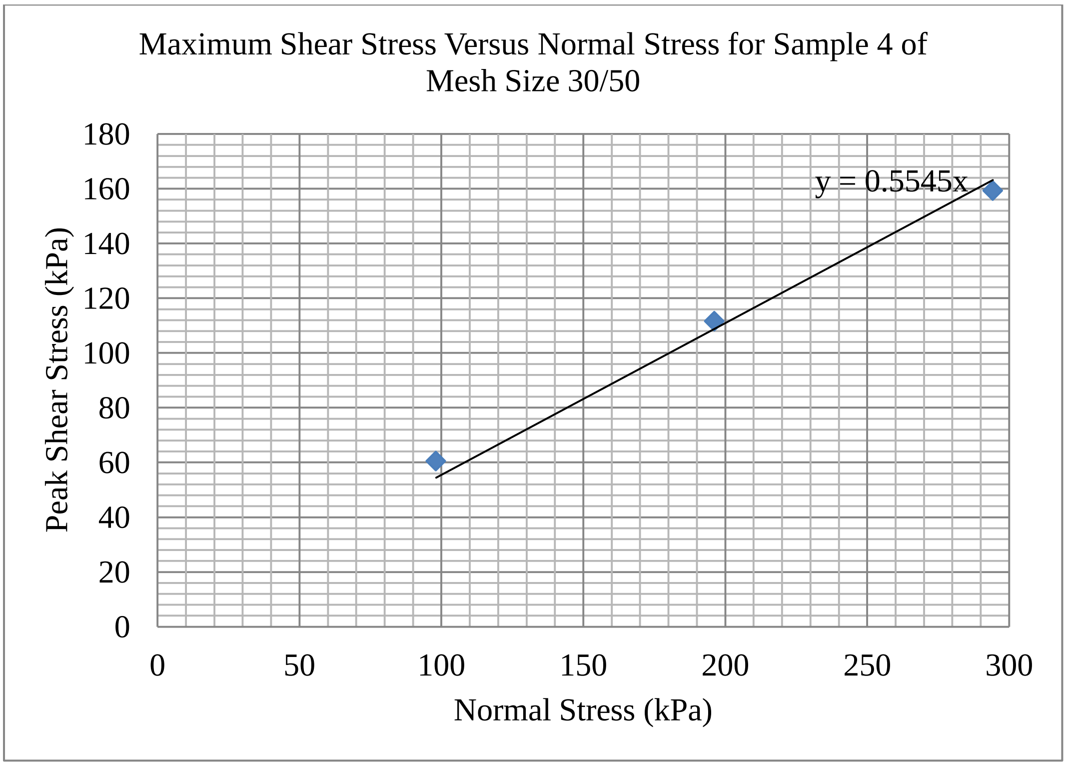

Figure A 11: Maximum shear stress versus normal stress for sample 4 of mesh size 30/50

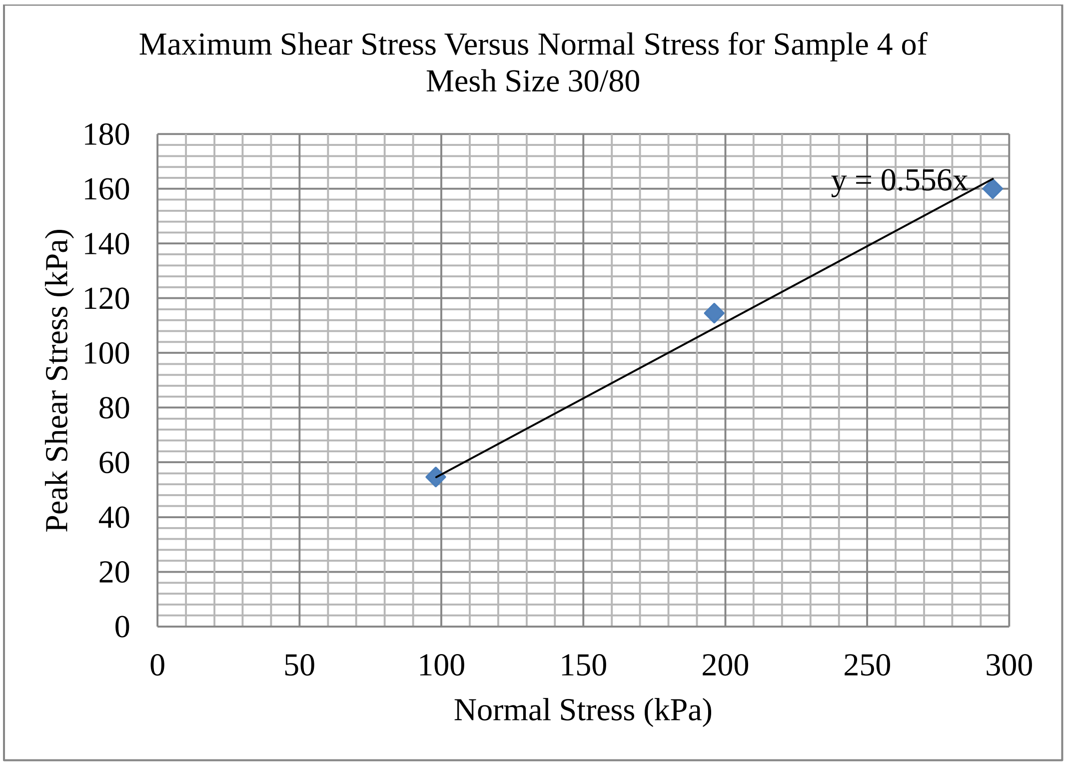

Figure A 12: Maximum shear stress versus normal stress for sample 4 of mesh size 30/80

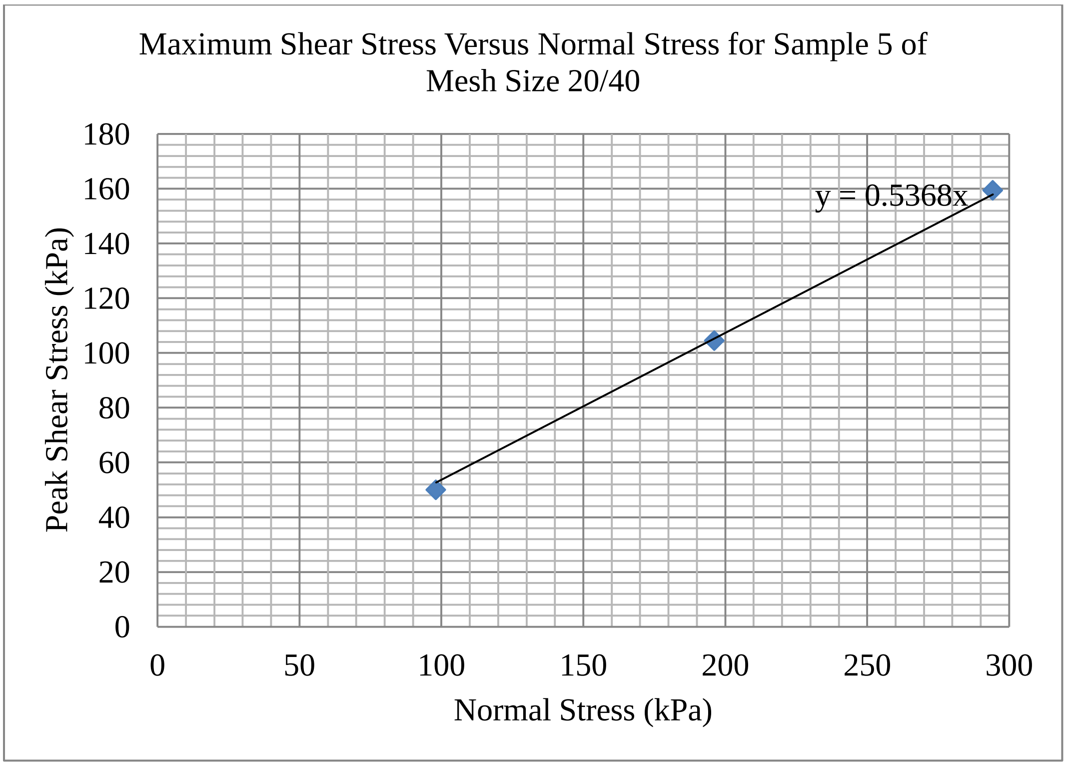

Figure A 13: Maximum shear stress versus normal stress for sample 5 of mesh size 20/40

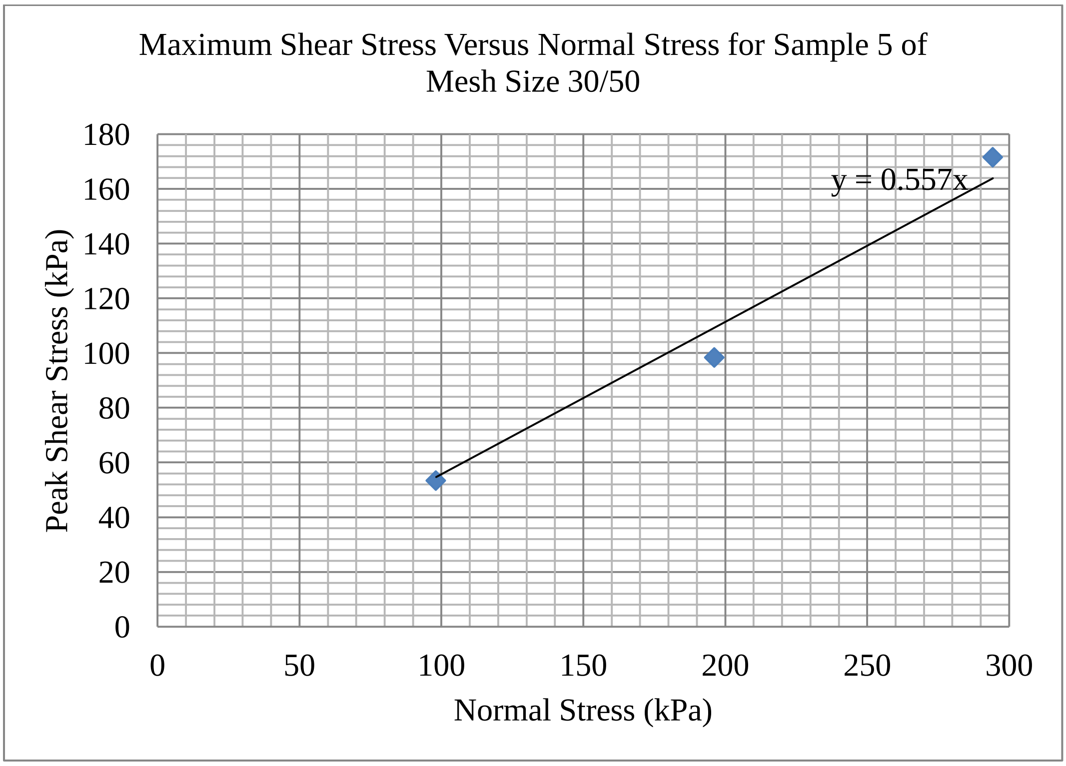

Figure A 14: Maximum shear stress versus normal stress for sample 5 of mesh size 30/50

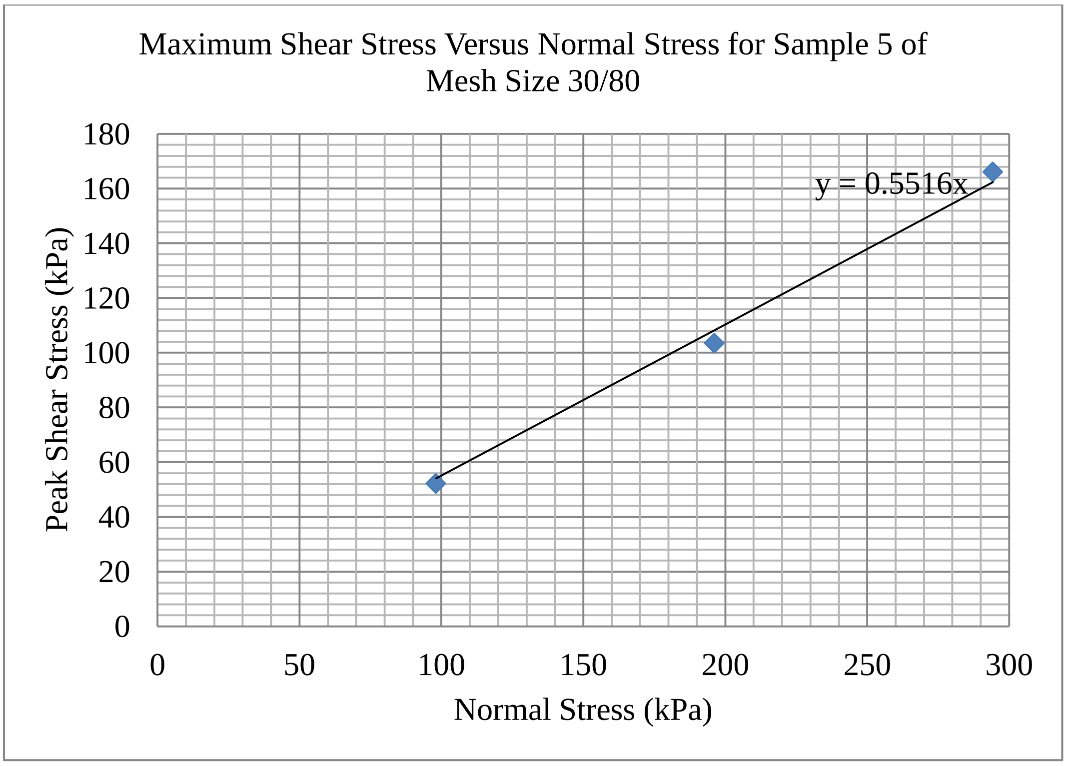

Figure A 15: Maximum shear stress versus normal stress for sample 5 of mesh size 30/80

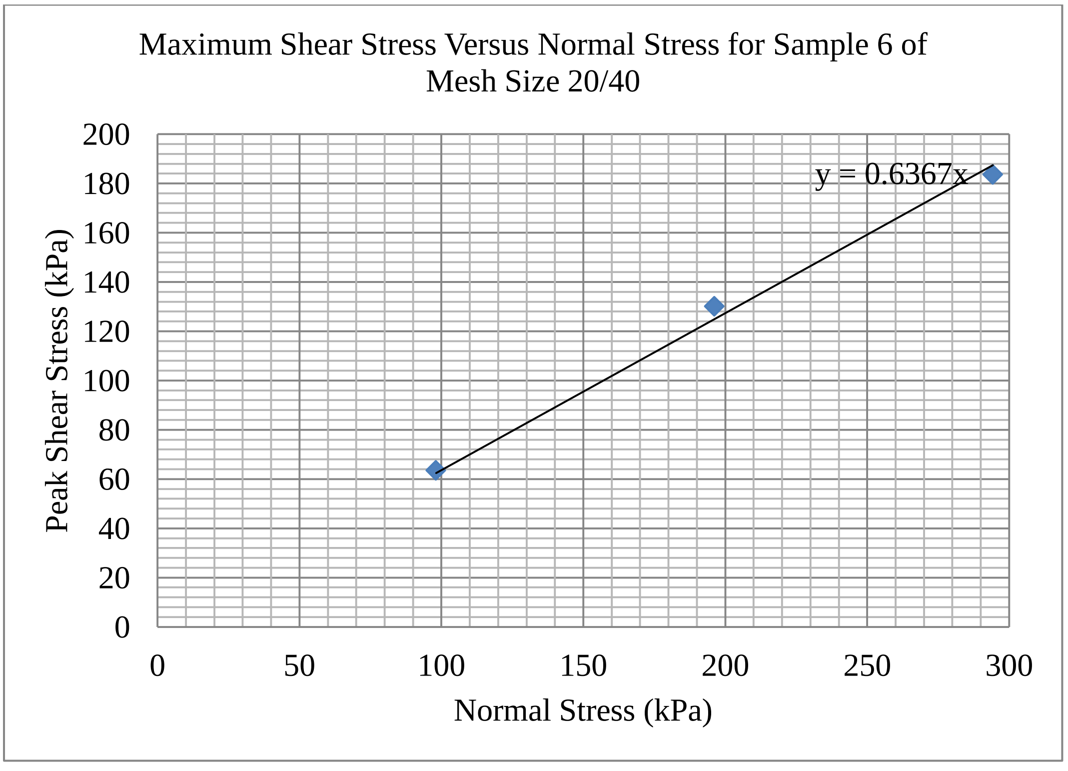

Figure A 16: Maximum shear stress versus normal stress for sample 6 of mesh size 20/40

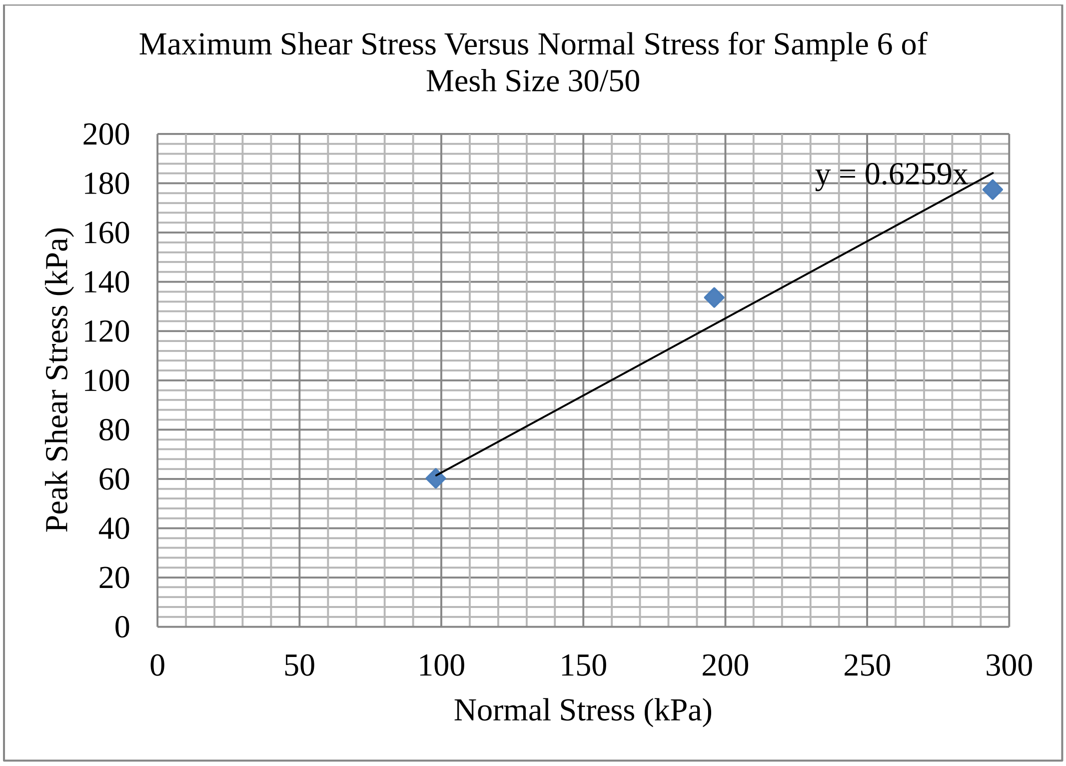

Figure A 17: Maximum shear stress versus normal stress for sample 6 of mesh size 30/50

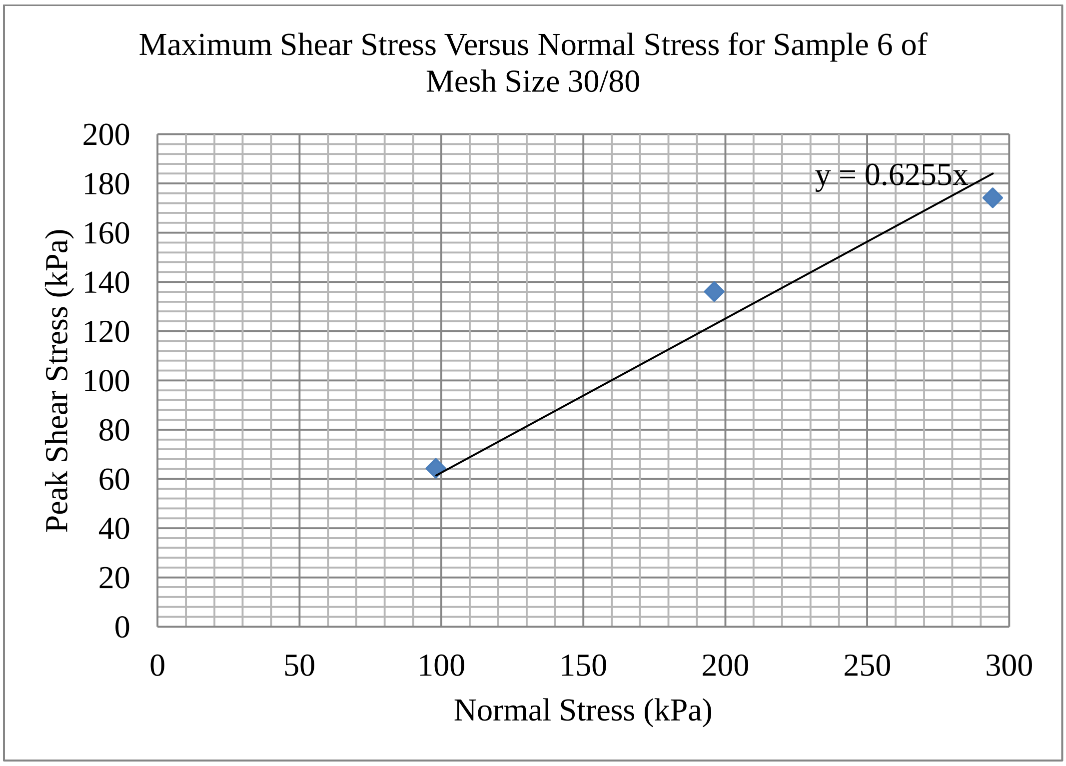

Figure A 18: Maximum shear stress versus normal stress for sample 6 of mesh size 30/80

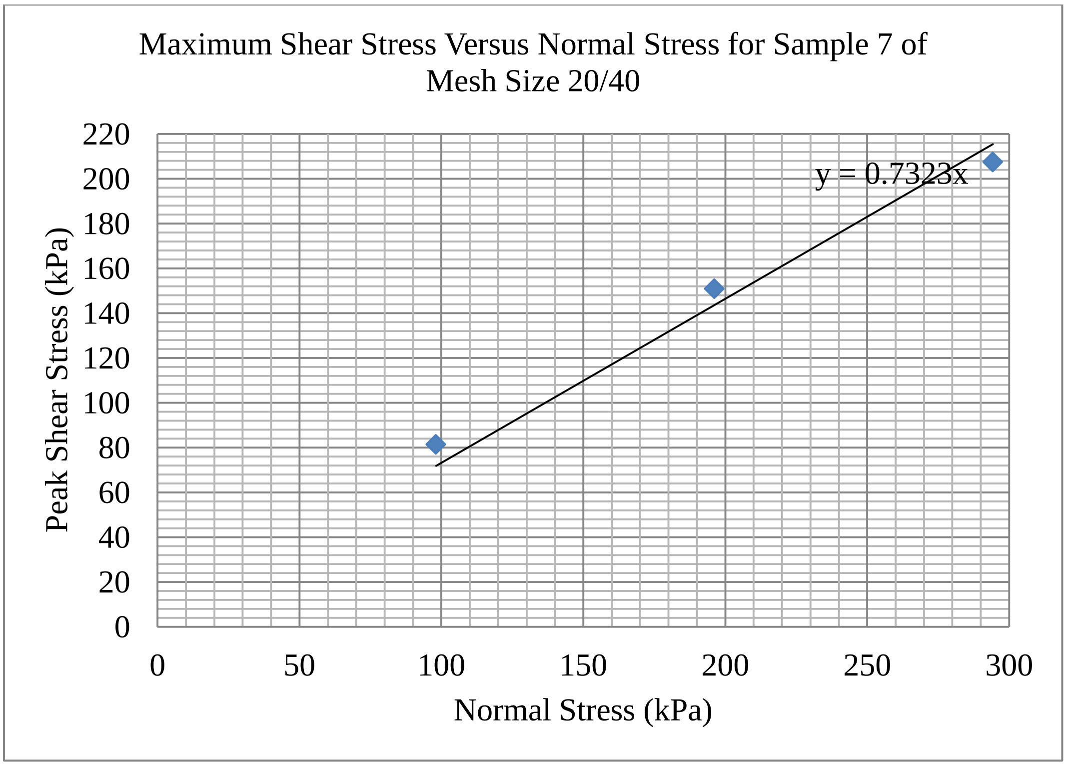

Figure A 19: Maximum shear stress versus normal stress for sample 7 of mesh size 20/40

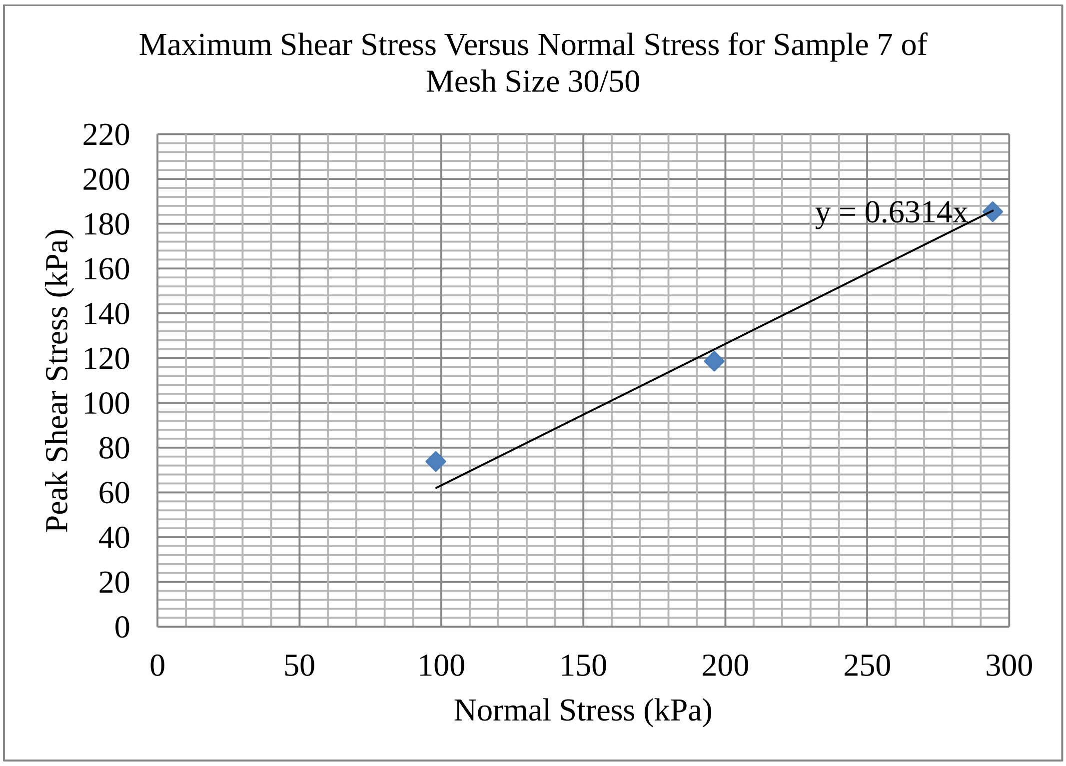

Figure A 20: Maximum shear stress versus normal stress for sample 7 of mesh size 30/50

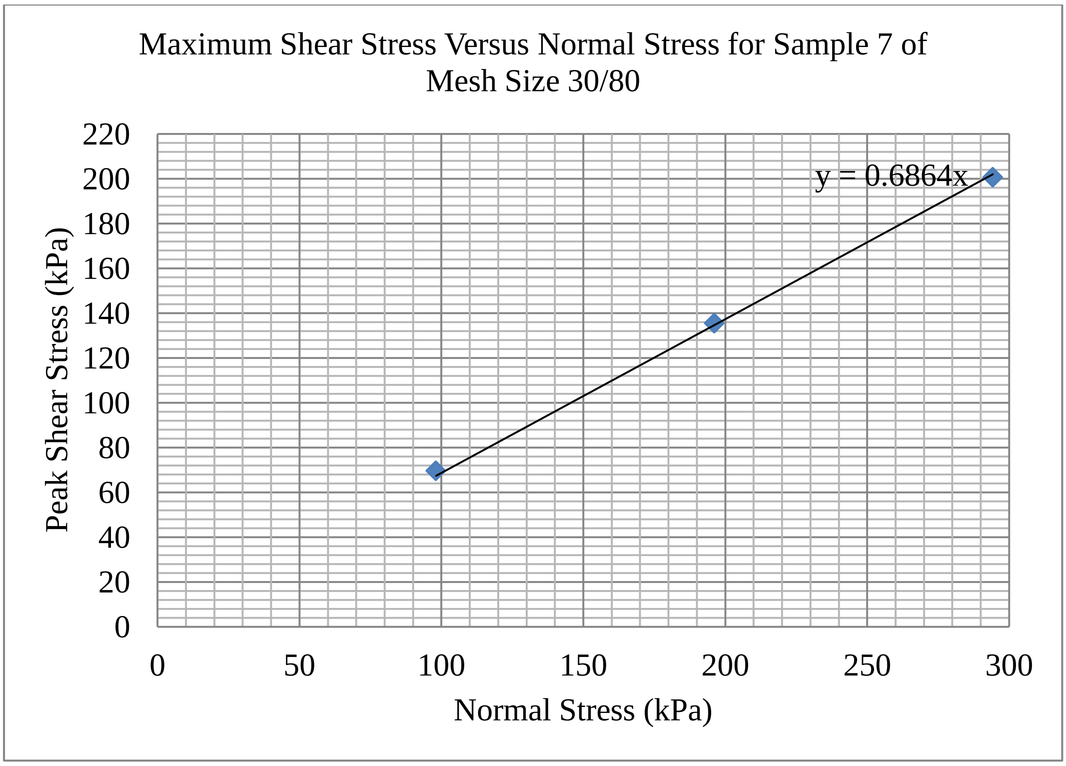

Figure A 21: Maximum shear stress versus normal stress for sample 7 of mesh size 30/80

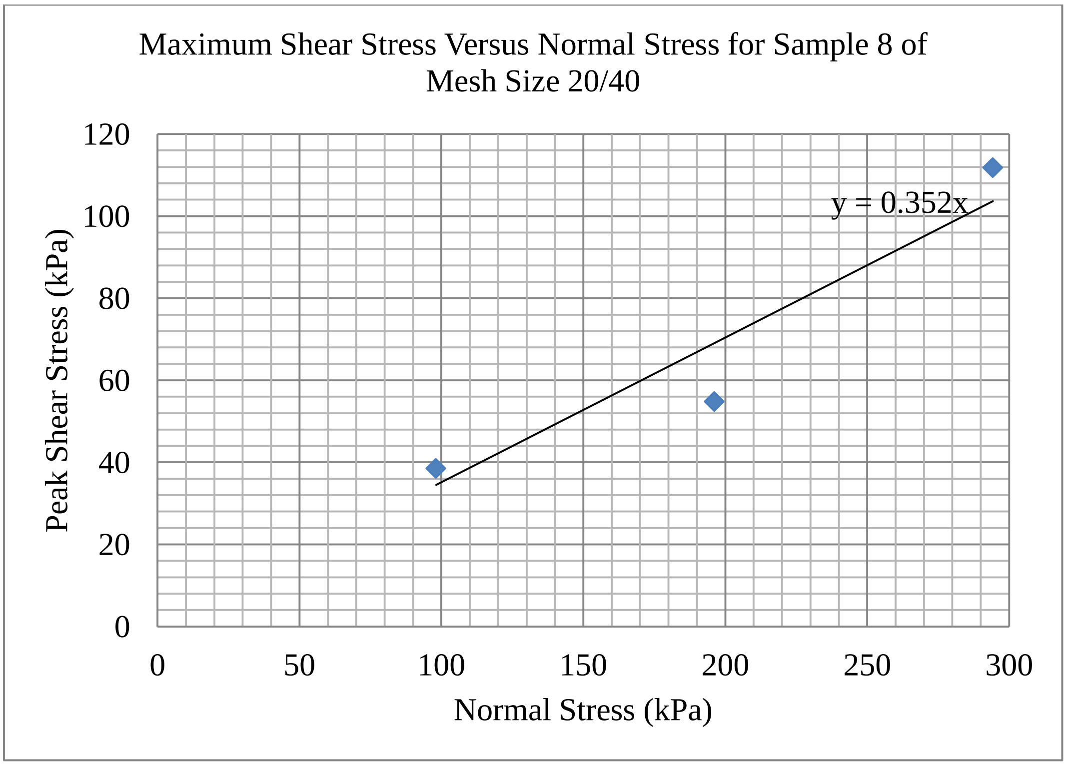

Figure A 22: Maximum shear stress versus normal stress for sample 8 of mesh size 20/40

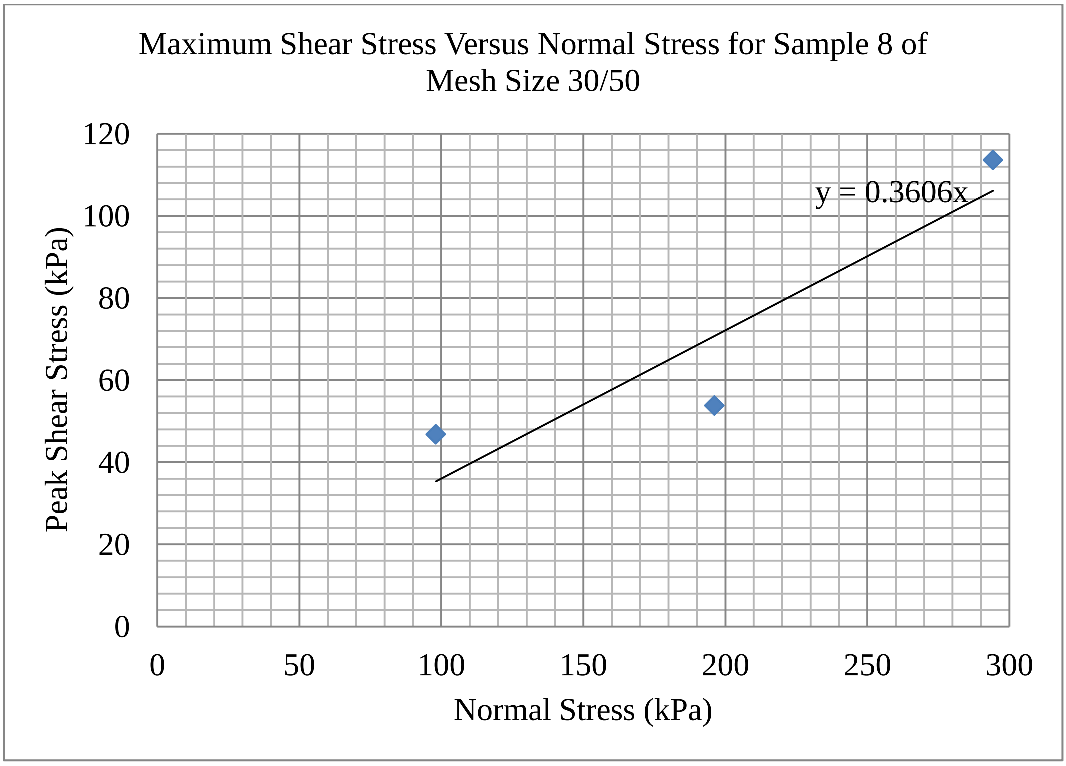

Figure A 23: Maximum shear stress versus normal stress for sample 8 of mesh size 30/50

Appendix B

Carrier Fluid Density calculation, ppg

$$1 \text{ lb/bbl} \approx 1/350 \text{ g/cm}^3$$

$$\text{Specific Gravity} = \frac{\text{Density of the sample at specified condition } \left(\frac{\text{g}}{\text{cm}^3}\right)}{\text{Density of water at same condition } \left(\frac{\text{g}}{\text{cm}^3}\right)}$$

Table B 1: Mass and volume of products

Product	Specific Gravity	Mass of product (gram/s)	Volume (cm^3)
Guar Gum	0.6	3.0	5.0
$H_2 0$	1.0	345.0	345.0
Total		348.0	350.0

$$\text{Density of carrier fluid} \left(\frac{\text{g}}{\text{cm}^3}\right) = \frac{\text{Total mass of products (g)}}{\text{Total volume of products } (350 \text{ cm}^3)}$$

$$= \frac{348 \text{ g}}{350 \text{ cm}^3}$$

$$= 0.9943 \text{ g/cm}^3$$

$$\text{Specific Gravity} = \frac{0.9943 \ \frac{\text{g}}{\text{cm}^3}}{1 \ \frac{\text{g}}{\text{cm}^3}} = 0.9943$$

$$\text{Density of carrier fluid} \left(\frac{\text{lb}}{\text{gal}}\right) = 0.9943 \times 8.345 \text{ lb/gal} = 8.3 \text{ lb/gal}$$