CERTIFICATION OF APPROVAL

Analysis of Compaction and Sintering of Compacted Silica Sand and Clay Mixture

By

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
July 2010

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.

AHMAD FIRDAUS BIN SUHARDI

ABSTRACT

This paper presents the effect of clay addition on the compacted and sintered sand. The study aims to develop clay – silica sand composite through powder processing and to study the density, porosity and hardness of the composite. Addition up to 20% weight percentage of clay in silica sand were developed through powder metallurgy method and sintered at 1300^{o} C in 1 hour. Green density and porosity in decreasing trend however an improvement in sintered density was observed. Also the addition of clay up to 20% of weight percentage increases the hardness to 8.906 GPa.

ACKNOWLEDGEMENT

First and foremost, heartfelt appreciation outstretch to parents, Mr. Suhardi bin Sanrawi and Mrs. Haslia bte Ahmad for always being there when in need. Their guidance, love and emotional support are highly appreciated.

Uncountable appreciation extended to Ir. Dr. Masri Baharom for being a gratifying supervisor with kind guidance, practical criticism and valuable advice throughout the project duration of 28 weeks.

Great big thanks also extended to other family members and fellow friends who had in one way or another contributed to the success of this report.

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CHAPTER 1

INTRODUCTION

1.0 CHAPTER OVERVIEW

This report describes a project called Analysis of Compaction and Sintering of Compacted Silica Sand and Clay Mixture. This project focuses on the study of density and mechanical properties of compacted and sintered silica sand and clay mixture. This chapter describes an overview concept of study and analysis for this project. Then, the problem statement which leads to this project to be proposed is described. This is followed by the project objectives and project scope of work.

1.1 PROJECT BACKGROUND

Sand consists of small grains or particles of mineral and rock fragments. Although these grains may be of any mineral composition, the dominant component of sand is the mineral quartz, which is composed of silica (silicon dioxide). Other components may include aluminum, feldspar and iron-bearing minerals. Sand with particularly high silica levels that is used for purposes other than construction is referred to as silica sand or industrial sand. Sand can be considered as a mineral soil that has particle sizes from 0.063mm to 2.0mm (British Standard EN ISO 14688-1:2002 [1]).

Clay has always played a major role in human life. Clay raw materials are used and their value recognized in many economic branches, agriculture, civil engineering and environmental studies. This is largely because of their wide-ranging properties, high resistance to atmospheric conditions, geochemical purity, and easy access to their deposits near the earth’s surface and low price (Jiti Konta, 1995 [2]). Clay is mineral soil that has particle size of less than 0.002 mm (British Standard EN ISO 14688-1:2002 [1]).

The chemical compound silicon dioxide, also known as silica (from the Latin *silex*), is an oxide of silicon with a chemical formula of SiO_2 and has been known for its hardness since antiquity. Silica is most commonly found in nature as sand or quartz, as well as in the cell walls of diatoms (Iler, R.K., 1979 [3]).

Figure 1: Silica sand and clay

Ceramic – ceramic composite had been widely used nowadays, particularly in high temperature application. Some examples of ceramic – ceramic composites are alumina – zirconia and zirconia – titania. Ceramic composites products are applied in various fields such as aerospace, electronic, and biomedical.

1.2 PROBLEM STATEMENT.

Extensive study of mechanical properties of the mixture of silica sand around UTP with the available clay in this country is yet to be done. Therefore, experiment can be done on these ceramic – ceramic composite and the experiment results can be compared and beneficial usages of this mixture might be used for further application.

1.3 OBJECTIVE

The main objective for this project is to study the effect of clay addition on the compacted and sintered silica sand in term of density, porosity and hardness.

1.4 SCOPE OF STUDY

The project starts by studying the mechanical properties of silica sand and clay. Then, the method used to compact the mixture of sand and clay will be studied. The project will provide a detail description on the process to compact the silica sand and clay mixture together and produce a green compacted pallet. Then, thorough studies will be done on the green density and porosity of the compacted mixture.

Later, the project will move to the next step in processing the compacted mixture which is sintering process. In sintering process, the compacted mixture will be heated up to certain degree of temperature. Then, the sintered density, porosity and hardness of the samples will be analyzed. All the processes for this project will be done through an experiment-based methodology.

1.5 RELEVANCY OF THE PROJECT

The project will be done extensively to study the effect of compaction and sintering effect on the mechanical properties of silica sand around UTP with addition of clay available in this country. The result of this project will determine the effect of clay addition on the density, porosity and hardness of compacted and sintered silica sand. If the result of this project shows that the mechanical properties of the mixture can be beneficial, further experiment can be done and application of the composite can be implemented.

CHAPTER 2

LITERATURE REVIEW

2.0 CHAPTER OVERVIEW

This chapter will review the projects and researches that had been done before that has relations and can be used as references for this project. The author will also describe some of the theory related to this project.

2.1 RESEARCHES ON CLAY – SAND COMPACTION

There are many researches and projects regarding the sand – clay mixtures that had been done previously. For example, the study of predicting the relationship between compaction stress and dry density, referred to herein as the compaction curve, of composite mixtures based on the micromechanics for bentonite–sand mixtures with different sand fractions (by weight) were performed (Y.M. Tiena, et al, 2004 [4]). Compaction pressure from 0.13MPa up to 100MPa had been used for this research with the water contain for each mixture is 9.69%.

Bentonite clay – sand mixtures compaction also had been tested to produce Bentonite Based Material buffer (BBM buffer) that can be used in High-level Radioactive waste repositories (Atomic Energy of Canada, 1994 [5]). Based on these researches, it shows that the compaction of sand – clay mixtures can be done and eventually the mechanical properties of the composite mixtures can be determined.

2.2 RESEARCHES ON SAND AND CLAY SINTERING

Sintering of various types of sand and clay had been done previously in some projects. For example, special kaolin used in the industrial ceramic Raschig rings manufacturing process was shaped by an extrusion method and sintered at 1200 and 1250 ^{O}C using different soaking times, ranging from 30 to 180 minutes. The physico-chemical properties of specimens such as shrinkage, water absorption, bulk density, porosity, microstructure and mineralogical composition, were studied (M. Salehi et al, 2008 [6]).

Reaction sintering of beach sand sillimanite and alumina is an innovative as well as inexpensive method of mullite formation. Beach sand sillimanite and calcined alumina were used as starting materials and were mixed in appropriate proportion and sintered in compacted form at 1500 - 1575 ^{0}C. The study reveals that the use of submicron size powder enhances the sintering process (H.S. Tripathi, G. Banerjee, 1997 [7]).

In addition, a study on the complexity of the densification of Brazilian kaolinitic clay sintered in air at various temperatures also had been done. The samples were dry pressed in a cylindrical die and sintered at temperatures ranging from 750 ^{O}C to 1150 ^{O}C. Cylindrical ceramic pellets (f = 10 mm) were obtained by uniaxial pressing at 25 MPa. After pressing, the green bodies were dried for 24 h at 110 ^{O}C. The sintering step was carried out at soaking temperatures varying from 750 ^{O}C to 1150 ^{O}C for 1 hour (F.A.C. Milheiro et al. 2004 [8]).

Another sintering process that had been done on clay is the sintering of bentonitic clay being used in the ceramic bodies. The clay was milled, being added with 5% of water and being compressed by 29.5MPa compressive pressure. The compacted clay then being sintered in the temperature range from 1173K up to 1323K between 20 to 40 minutes (A. García R et al. 2009 [10]). Based on these researches, it is proven that the sintering process can be done on the sand, clay and mixture of ceramics.

CHAPTER 3

RESEARCH METHODOLOGY

3.0 CHAPTER OVERVIEW

This chapter focuses on the approach method in developing the project work. Basically, it will be based on lab-based experiments and testing for the study and analysis. The purpose of this chapter is to meet the objectives which are mentioned in the first chapter.

3.1 PROJECT METHODOLOGY

The methodology that will be adopted through this project is lab-based experiment by which the analysis of the compaction and sintering of the silica sand and clay mixture will be tested in the lab. This lab-based experiment methodology had been chosen as the desired result and analysis can only be determined from the experiments. The major processes including the identification of the problems, establish aim and objectives, literature review, material processing, data collection and sampling, data analysis, result interpretation and conclusion as shown in Figure 2.

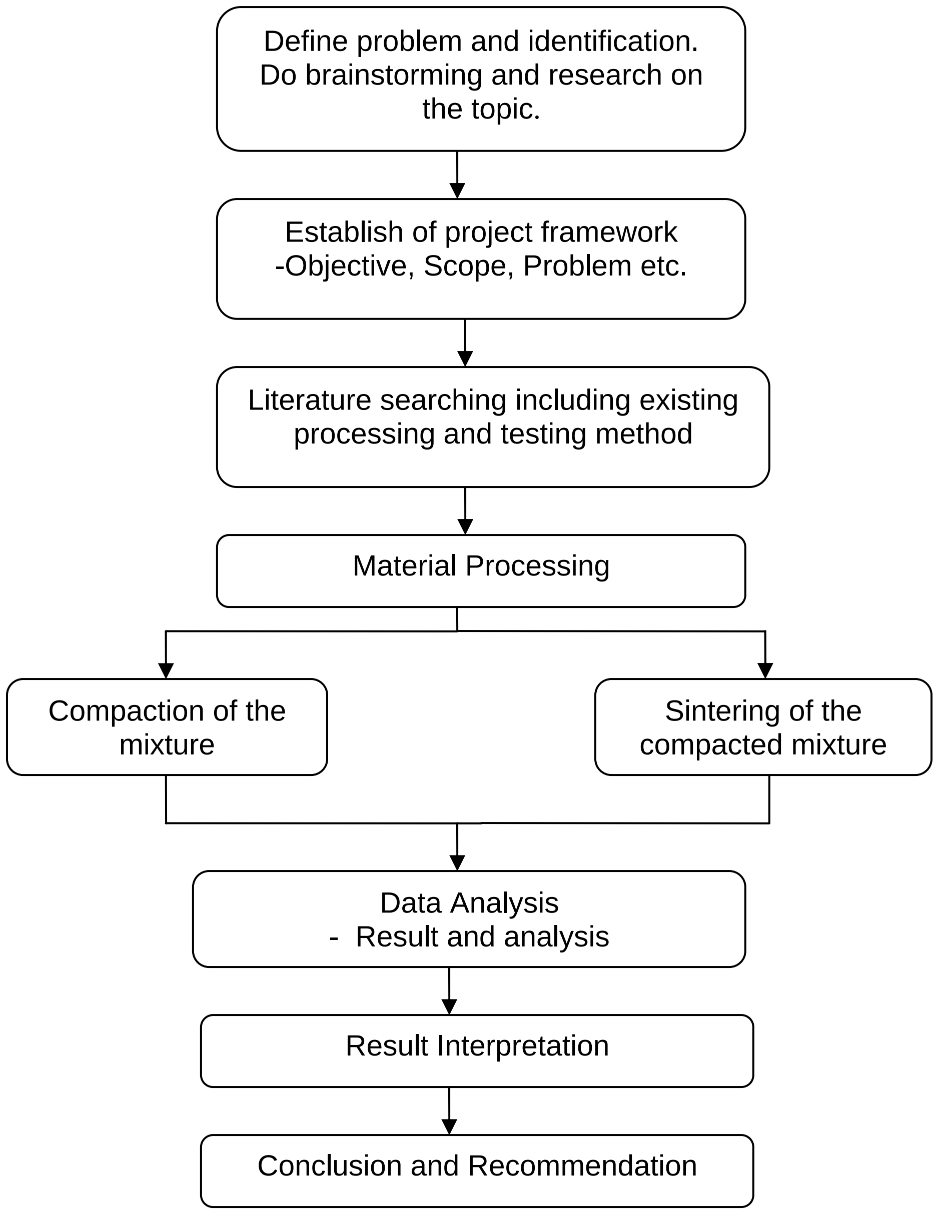

Figure 2: Flow Chart of Methodology

3.2 MATERIAL PROCESSING

The silica sand for this project had been taken in UTP area as we look to make use of the sand around UTP. Impurities in the sand such as gravels and wood had been eliminated to ensure the sand is purely sand. The X-Ray Fluorescence (XRF) result of the sand acquired:

Table 1: Compound percentage of sand

Compound	O	Al_2O_3	**SiO_2**	P_2O_5	K_2O	CaO	TiO_2	Fe_2O_3	ZrO_2
Weight Percentage (%)	53	10.2	**86.56**	1.01	0.422	0.194	0.840	0.5493	0.2284

Based on the XRF result, silica is the major compound is the sand which is 86.56% of the sand.

The clay that will be used for this project had been acquired from the clay that will be used to make clay brick. The clay had been chosen for this project as it is one of the available clay in Malaysia market and will not contain any impurities thus will be suitable to be tested. The compound percentage of the clay based on XRF test is:

Table 2: Compound percentage of clay

Compound	ZnO	Al_2O_3	SiO_2	K_2O	MgO	MnO	Fe_2O_3	P_2O_5	CaO	TiO_2
Weight Percentage (%)	0.0163	**21.02**	**62.01**	4.382	0.754	0.0917	6.984	2.00	0.703	0.885

Based on the XRF result, the major compound of the clay are silica and alumina, which is based on Erickson et al. 1973 [9], the percentage compound of the clay shows that the clay is closed to the standard of bentonite clay.

Table 3: General composition for bentonite binder (Erickson et al. 1973 [9])

Composition	% by weight
Fe	2.9 - 5.5
Al_2O_3	**17.0 – 21.5**
SiO_2	**57.0 – 67.0**
Na_2O	1.8 – 2.7
CaO	1.7 – 2.6
MgO	1.5 – 2.8
H_2O	25.0 – 30.0

The particle size of sand and clay had been reduced to 125µm using ball milling for 1 hour. Sieve machine had been used to ensure only sand and clay with at most 125µm particle size will be used for this experiment. The powder size of the particles will ensure the homogeneity of the compacted mixture. In addition, the smaller size of particle will enhance the sintering process of the mixture as the smaller particles will be easier to create uniformity and control the porosity (H.S. Tripathi, G. Banerjee, 1997 [7]).

3.3 COMPACTION OF THE SILICA SAND AND CLAY MIXTURE

In order to compact the mixture of silica sand and clay together, binder need to be used. This is due to the very high compressive strength of silica sand and clay (1100MPa) and the available machine in the lab does not have the capability to compress up to the required force. For this project, the type of binder that will be used is water. The water will be used to hold the particles of silica sand and clay together during the compaction before the pallet is transferred for sintering process (A. García R et al. 2009 [10]).

The machine that will be used to compress the mixture is Autopalletizer machine. Metallic mould of diameter 13mm will be used for the compaction process. The area of the sample that will be produced is:

$$\text{Area of Pallet} = \pi j^2 = \pi\,(6.5\text{mm})^2 = 1.327\text{cm}^2$$

The first step in the compacting process is to find the suitable percentage of water and the required compaction force to be used for the sample in order to produce a sample pallet that is enough to be held and tested. Unsuitable percentage of water and force might produce a pallet that will break or crack easily after the compaction process. For the first step, the parameters that will be used are:

- Force: 5000 lb, 10000 lb and 15000 lb
- Water percentage: 5%, 10%, 15%
- Percentage of silica sand: 100%, 90%, 80%

For each compaction, 5 samples will be used for repetition purpose.

After the suitable water percentage and compaction force had been determined, the compaction process will go further by varying the percentages of clay addition into silica sand. For this experiment, the percentage of clay addition will be from 0% to 20%. 5 samples will be made for each parameter for repetition purpose. The force and water percentage that will be used are based on the previous testing. For each compacted mixture, green density and porosity will be calculated and analyzed. The parameters used for this step:

- Force: 15000 lb
- Water percentage: 10%
- Percentage of silica sand: 100%, 95%, 90%, 85%, 80%

3.4 GREEN DENSITY

Green density is the density of compacted pallet before it undergoes sintering process. For each compacted silica sand and clay mixture, the green density of the produced pallet will be calculated. The green density of the samples will be measured using Archimedes method. Based on the Archimedes method, the buoyant force on a submerged object is equal to the weight of the fluid displaced. This principle is useful for determining the volume and therefore the density of an irregularly shaped object by measuring its mass in air and its effective mass when submerged in water (density = 1 gram per cubic centimeter).The green density of the pallet can be measured by:

$$\text{Density: } \frac{\text{weight (g)}}{\text{volume}(\text{cm}^3)}$$

3.5 POROSITY

Porosity is the fraction of volume of voids over the total volume. Void is porous space between particles in a material or sample that might contain air or water. Less compacted material or a material that has less bonding between the particles will have higher percentage of porosity. The porosity can be calculated by measuring the theoretical volume and actual volume of the sample. The theoretical volume of the sample will be measured by calculating the sample volume, assuming that the sample does not have any porous space and voids. The actual volume of the sample will be measured using Archimedes method. The porosity can be measured by:

Porosity = $(V_T - V_a) / V_a * 100$

Where:

V_T = Theoretical Volume

V_a = Actual Volume

3.6 SINTERING PROCESS

Sintering is the process of heating the material usually between 60% - 80% of its melting temperature under a certain required time. The sintering process will cause densification of the particles within the material. The densification process will cause adherence and bonding between the particles. This will improve the material properties particularly in term of the density, porosity and hardness. For the sintering process of the samples, the temperature that will be used is 1300 ºC and sintering time will be 1 hour. The heating rate and cooling rate used is 5ºc/min based on the available furnace capability. 1300 ºC will be used as sintering temperature as the melting temperature of silica will be as high as 1800 ºC and based on previous journals, the densification of silica will start at approximately 1250 ºC and one hour of sintering time will be enough to get expected results.

3.7 SINTERED DENSITY AND HARDNESS TEST

After sintering process, sintered density and porosity of each sample will be examined and hardness test will be done on the samples using micro Vickers hardness tester. Hardness test is frequently being used to measure hardness of material through the penetration of indenter on the test piece. The hardness was measured in accordance with ASTM C 1327-99[25]. The indentation load was 10kgf (98.1N) with dwell time of fifteen seconds. The diagonal length will be measured using Scanning Electron Microscope (SEM). Vickers hardness (GPa) were calculated, by the equation:

$$H_v = 0.0018544\,(P/d^2)$$ (Maria Cecilia, Carlos Elias [12])

Where:

H_v = Vickers hardness (GPa)

P = applied (N)

d = arithmetic mean of the two diagonal length (mm).

3.8 GANTT CHART / MILESTONES

		July	August				September				October				Nov	
No	Detail / week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project planning	■														
2	Material Preparation		■													
3	Compaction of Mixture			■	■											
4	Sintering of Samples								■							
5	Hardness testing									■						
6	Microstructure Examination										■					
7	Analysis on Results															
8	Submission of Progress Report 1				▲											
9	Submission of Progress Report 2								▲							
10	Seminar									▲						
11	Poster Exhibition											▲				
12	Submission of Dissertation Final Draft														▲	
13	Oral presentation													During Study Week		
14	Submission of Dissertation (hard bound)												1 week after presentation			

LEGENDS

▲ Milestone

■ Process

[dashed box] Progress of the project

Figure 3: Gantt chart / Milestone of Project

CHAPTER 4

RESULTS AND DISCUSSION

4.0 CHAPTER OVERVIEW

This chapter concluded all the experiments, results and analysis that have been done for this project. All the results have been gathered with the same methodology as explained in the previous chapter. It also included the current development for the project and the result from the portion that has been done.

4.1 COMPACTION OF SILICA SAND AND CLAY MIXTURE

The first step of this project which is the compaction of silica sand and clay mixture had been completed. Based on the compaction test to confirm the suitable compaction force and water percentage, the result showed that the 15000lb force is suitable to be used for the compaction while the suitable water weight percentage is 10%. Based on the testing, low compaction force will not be able to hold the sand and clay particle together thus the sample will break. Suitable water percentage needs to be used to hold the clay and sand particle perfectly during the compaction. If the water percentage is more than enough, the pallet might be easily broken or cracked on the surface after the compaction. If the water percentage is not enough, debris might exist after the compaction and this is undesired as the debris will affect the further test result.

Figure 4: Broken Sample

Figure 5: Sample with Suitable Compaction Force and Water Percentage

After the suitable compaction force and water percentage had been decided, the compaction process of the sand – clay mixture had been done. The compaction had been varied from 0 – 20 % of clay addition into the silica sand with 5 samples for each batch. Based on the force that had been used, the calculated pressure for the compaction process is:

Pressure = Force / Area

= 15000lb /1.327cm^2

= 66723.32423 N / 0.0001327 m^2

= 502.8 MPa

Higher pressure had been used for this experiment if being compared to the previous researches. This is due to minimize the porosity as higher compaction force will cause the particles to stick closer to each other during the compaction.

After the compaction process had been completed, the green density of each sample had been measured using Archimedes method. The theoretical density after the compaction also had been calculated. The average density for each batch had been calculated and the result is as followed:

Table 4: Green Density and Theoretical Density of Compacted Samples

Sand Percentage	sample	sample mass	Volume (cm3)	Green Density (g/cm3)	Average green density (g/cm3)	Theoretical Green Density (g/cm3)	Average theoretical density (g/cm3)
100%	1	0.909	0.44332	2.050437607	2.054856996	1.550929875	1.544787579
	2	0.905	0.44332	2.041414779		1.544105102	
	3	0.906	0.4301	2.106486864		1.545811295	
	4	0.903	0.446	2.024663677		1.540692715	
	5	0.904	0.4407	2.051282051		1.542398908	
95%	1	0.892	0.4486	1.988408382	2.014432482	1.516387869	1.519107847
	2	0.896	0.4407	2.033129113		1.523187814	
	3	0.893	0.4433	2.014437176		1.518087855	
	4	0.89	0.4401	2.022267666		1.512987896	
	5	0.897	0.4454	2.013920072		1.524887801	
90%	1	0.8937	0.4566	1.957293035	1.987987055	1.505549154	1.508876288
	2	0.899	0.446	2.015695067		1.514477665	
	3	0.898	0.4566	1.966710469		1.51279304	
	4	0.894	0.446	2.004484305		1.506054541	
	5	0.897	0.4433	2.023460411		1.511108416	
85%	1	0.884	0.4486	1.970575123	1.949884399	1.480340277	1.483354545
	2	0.887	0.4433	2.000902323		1.485364057	
	3	0.884	0.4539	1.947565543		1.480340277	
	4	0.889	0.4566	1.946999562		1.488713243	
	5	0.885	0.4699	1.883379442		1.48201487	
80%	1	0.891	0.4699	1.896148117	1.905252836	1.448434277	1.452986034
	2	0.888	0.4778	1.858518208		1.443557394	
	3	0.896	0.4699	1.906788678		1.456562415	
	4	0.91	0.4613	1.972685888		1.479321203	
	5	0.884	0.4672	1.892123288		1.437054883	

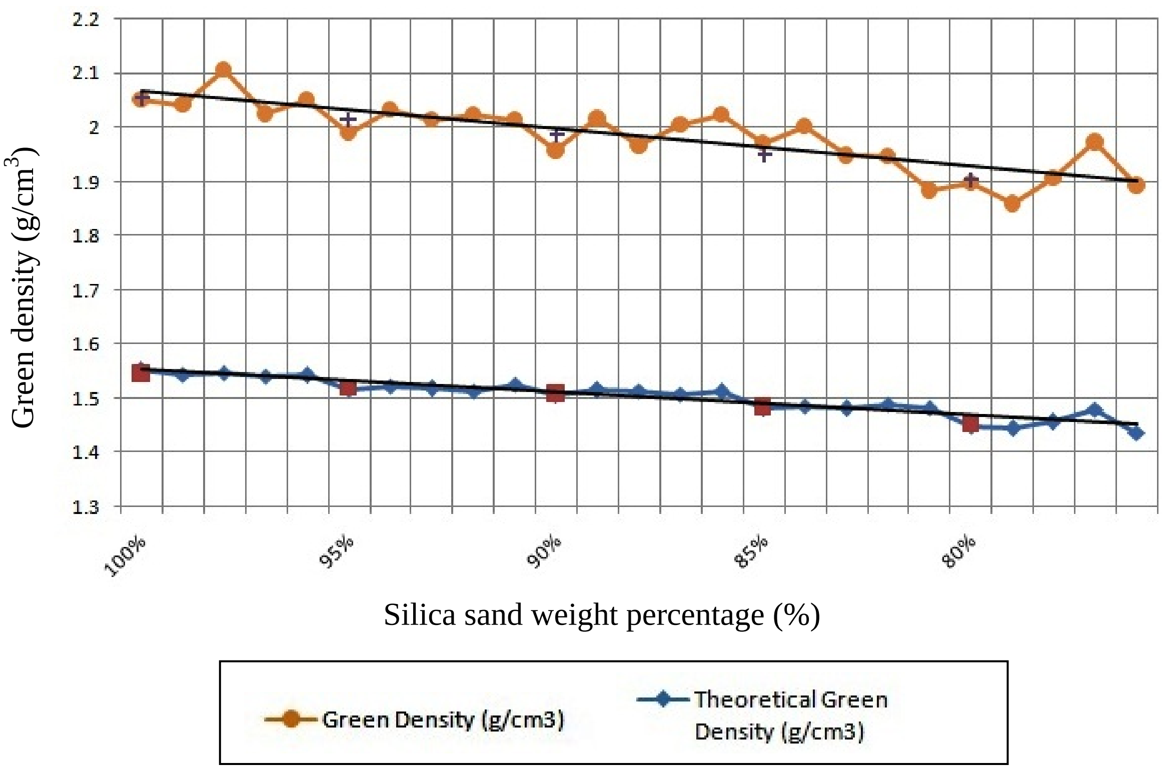

Figure 6: Green Density vs Silica Sand Percentage

A decrease in green density was initially observed as shown in the Figure 6 with increasing amount of clay from 0% to 20%. The initial green density of 2.055 g/cm^3 has decreased to 1.905 g/cm^3. The clay that has lower density (1.73 g/cm^3) than the silica sand (2.055 g/cm^3) has caused the compacted mixture to have decrement in the green density trend with the addition of clay. Based on the linear regression, the green density of the compacted samples will drop by 0.0067 g/cm^3 by additional of 1% clay in the mixture. Thus, for the addition of 20% weight percentage of clay, the green density has decrease about 7.29% from the initial green density.

4.2 SINTERING PROCESS

After the compaction process had been completed and the green density of the samples had been calculated, the samples had been sintered in 1300 ^{O}C with heating and cooling rate of 5 ^{O}C/min and 1 hour of dwell time. The visual inspection on the samples after sintering process:

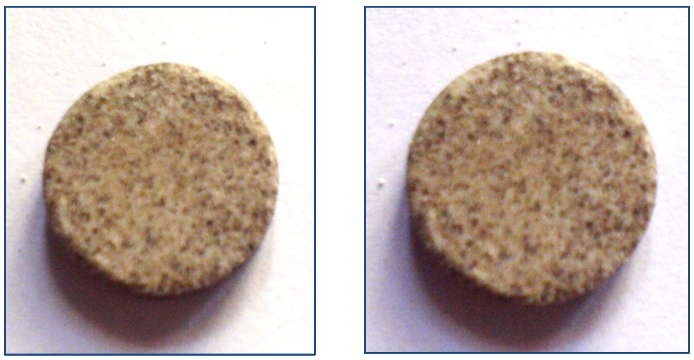

Figure 7: Sintered Samples

After sintering process, the sintered density had been measured using Archimedes method while theoretical density after sintering also had been calculated. In addition, the porosity of the samples before sintering and after sintering process also had been measured. The results are showed in the table:

Table 5: Sintered Density and Sintered Theoretical Density

Sand Percentage	sample	sample mass (g)	Volume (cm3)	Density (g/cm3)	Average sintered density (g/cm3)	Theoretical Density (g/cm3)	Average theoretical density (g/cm3)
100%	1	0.8900	0.3776	2.3570	2.3674	1.8576	1.8679
	2	0.8920	0.3794	2.3510		1.8771	
	3	0.8930	0.3771	2.3680		1.8808	
	4	0.8860	0.3732	2.3740		1.8387	
	5	0.8900	0.3729	2.3870		1.8854	
95%	1	0.9010	0.3842	2.3450	2.3342	1.8427	1.8481
	2	0.8940	0.3924	2.2780		1.8767	
	3	0.8710	0.3541	2.4600		1.7649	
	4	0.8710	0.3741	2.3280		1.8998	
	5	0.8710	0.3854	2.2600		1.8564	
90%	1	0.8760	0.4084	2.1450	2.3045	1.8352	1.8171
	2	0.8750	0.3773	2.3190		1.8148	
	3	0.8740	0.3718	2.3510		1.8003	
	4	0.8780	0.3743	2.3460		1.7831	
	5	0.8730	0.3674	2.3760		1.8499	
85%	1	0.8720	0.3803	2.2930	2.2882	1.7953	1.8009
	2	0.8590	0.3756	2.2870		1.7894	
	3	0.8720	0.3831	2.2760		1.8110	
	4	0.8740	0.3800	2.3000		1.8096	
	5	0.8640	0.3781	2.2850		1.7991	
80%	1	0.8720	0.3833	2.2750	2.2762	1.8000	1.7855
	2	0.8680	0.3853	2.2530		1.7566	
	3	0.8780	0.3846	2.2830		1.8015	
	4	0.8750	0.3838	2.2800		1.7953	
	5	0.8700	0.3799	2.2900		1.7743	

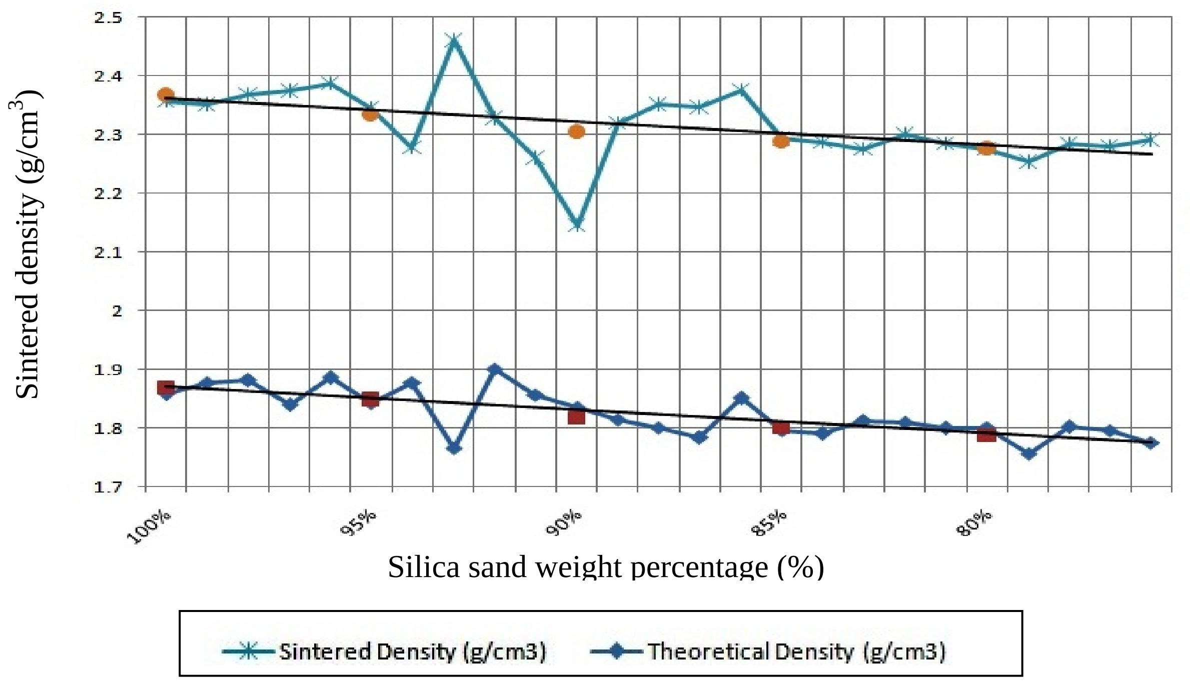

Figure 8: Sintered Density vs Silica Sand Percentage

Figure 9: Green Porosity and Sintered Porosity vs Silica Sand Percentage

A decrease trend can be seen on the sintered density from 2.367 g/cm^3 to 2.276 g/cm^3 with the addition of clay up to 20% of weight percentage as shown in Figure 8. The addition of clay up to 20% of weight percentage has decrease the sintered density by 3.84 %. Based on the linear regression, the sintered density of the compacted samples will drop by 0.00456 g/cm^3 by additional of 1% clay in the mixture. The porosity of the samples has decreased from (33% - 31%) to (27.8% - 26%) as shown in Figure 9 after the sintering which indicated that the bonding and densification of silica sand and clay particles had happened during the sintering process. Moreover, the porosity of the sintered samples has decreased with the addition of clay from 27.8% to 26 %. The presence of clay is seen improves the densification process during the sintering and provides better adhesion and bonding within the particles.

4.3 HARDNESS TEST

The hardness test was performed based on ASTM standard (C 1327-99[25] standard which is Standard Test Method for Vickers Indentation Hardness of Advanced Ceramics). The samples had been mounted, grinded and polished to ensure the indentation on the samples can be seen on the SEM. The indentation had been done using micro Vickers hardness tester. The indentations are then measured using SEM as shown in Figure 10.

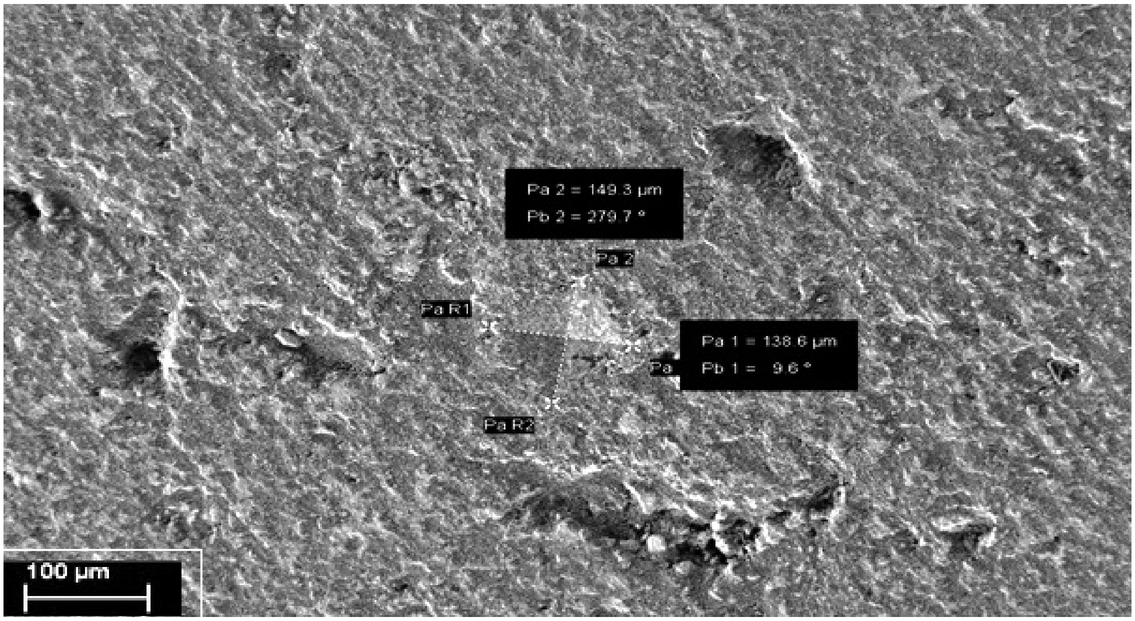

Figure 10: Micrograph of Sample on SEM

Based on the micrographs, the hardness of the samples can be calculated:

d= (d1+d2)/2

= (149.3 µm + 138.6 µm)/2

D= 143.95 µm

$H_v = 0.0018544 (P/d^2)$

$= 0.0018544 (100N/0.14395^2 \text{ mm})$

= 8.949 GPa

This procedure was repeated for all samples. The result of the hardness testing:

Table 6: Hardness of Sintered Samples

Sand Percentage	Indentation	Hardness (Gpa)	Average Hardness (Gpa)
100%	1	8.6300	8.6160
	2	8.6700	
	3	8.7000	
	4	8.5300	
	5	8.5500	
95%	1	8.6700	8.6774
	2	8.6940	
	3	8.6830	
	4	8.6710	
	5	8.6690	
90%	1	8.7430	8.7428
	2	8.7610	
	3	8.7720	
	4	8.7310	
	5	8.7250	
85%	1	8.8200	8.8146
	2	8.8100	
	3	8.7930	
	4	8.8200	
	5	8.8300	
80%	1	8.9300	8.9058
	2	8.9490	
	3	8.8900	
	4	8.8500	
	5	8.9100	

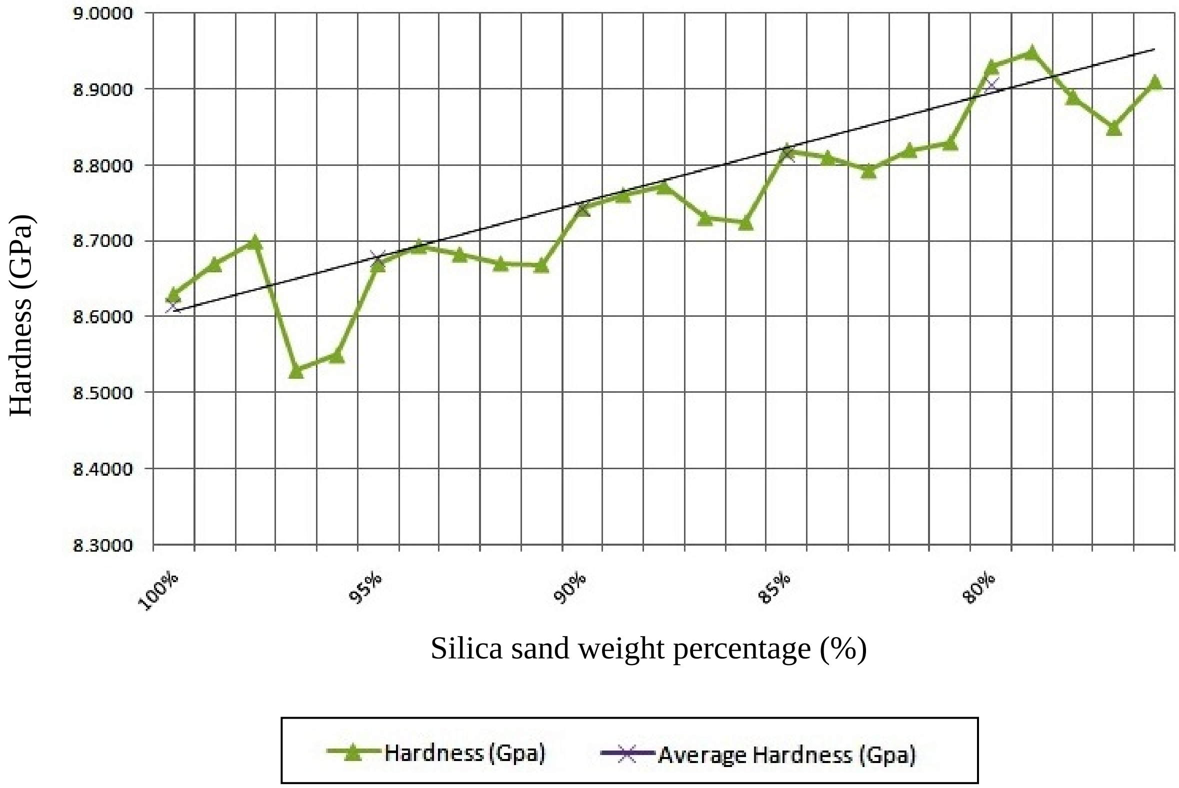

Figure 11: Graph of Hardness vs Silica Sand Percentage

Based on the Figure 11 and Table 6, increase trend of hardness from 8.616 GPa to 8.906 GPa can be observed with the increase of 20% clay weight percentage in the samples. The increment of hardness is about 3.37%. The increase in hardness of the composite is due to the presence of reinforcement particulates that cause higher constraint to localized matrix deformation of the composite. As both the matrix and reinforcement are ceramic materials, therefore this assist in obstructing localized plastic deformation of the matrix during hardness test. Furthermore, the difference in coefficient of thermal expansion between the matrix and reinforcement particulates leads to higher dislocation density in the matrix and this resulted in the hardening of the matrix

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As for the conclusion, with increasing weight percentage of clay up to 20% in the silica sand, the green density has decreased from 2.055 g/cm^3 to 1.905 g/cm^3 which show decrement of 7.29%. A decrease trend also can be seen on the sintered density from 2.367 g/cm^3 to 2.276 g/cm^3 with the addition of clay up to 20% of weight percentage which is a decrease of 3.84%. The decrease trend in the green density and sintered density of the composite is due to the addition of less dense material (clay). The clay is originally has lower density (1.73 g/cm^3) than the silica sand (2.055 g/cm^3). Thus, as clay weight percentage increase within the composite, the density of the composite will decrease.

In term of the porosity, the sintering process has decrease the porosity from (33% - 31%) to (27.8% - 26%). This shows that sintering process has caused densification of the particles and creates bonding within the composite. In addition, the clay addition up to 20% weight percentage has decrease the sintered porosity from 27.8% to 26 %. This proves that the presence of clay is seen improves the densification process during the sintering and provides better adhesion and bonding within the particles.

For the hardness, increase trend of hardness from 8.616 GPa to 8.906 GPa can be observed with the increase of 20% clay weight percentage in the samples. The increment of hardness is about 3.37%. The increase in hardness of the composite is due to the presence of reinforcement particulates that cause higher constraint to localized matrix deformation of the composite. As both the matrix and reinforcement are ceramic materials, therefore this assist in obstructing localized plastic deformation of the matrix during hardness test. Furthermore, the difference in coefficient of thermal expansion between the matrix and reinforcement particulates leads to higher dislocation density in the matrix and this resulted in the hardening of the matrix.

With all the observations produced during the project, it can be concluded that the addition of clay up to 20% weight percentage has decreased the density and porosity of silica sand based – clay composite. The addition of clay also has increase the hardness of the composite. It is proven that the addition of clay up to 20% of weight percentage into silica sand will improve the density, porosity and hardness of the composite.

5.2 RECOMMENDATION

Since the main part of this project will be based on the experiment result, it is highly recommend that the experiments will be done focusing on certain specification of the composite so that the experiment can be done extensively on the focused specification and the result obtained will be more reliable and comparable.

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