EFFECT OF WASTE PLASTER OF PARIS ON PHYSICAL AND MECHANICAL PROPERTIES OF CERAMIC POTTERY BODY

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A thesis submitted in partial fulfilment of the requirement for the award of the Degree of Master of Mechanical Engineering

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MAY 2016

"Special dedicated to my beloved parents and wife who always gave me support and encouragement"

ACKNOWLEDGEMENTS

In the name of ALLAH, Most Gracious, Most Merciful

I would like to thank Almighthy Allah for giving me life and blessing to gain knowledge to produce this thesis. I wish to express my sincere gratitude to my supervisor, Dr. Nur Azam bin Badarulzaman, who built my knowledge base and experience through his encouragement, support, guidance, comments, suggestions and resources througout this work. I would also like to thank Universiti Tun Hussien Onn Malaysia (UTHM) Batu Pahat for giving me the opportunity and facilities to complete such an exciting research project, and supporting me toward my research and other intellectual activities. I wish to express my appreciation to the Faculty of Mechanical and Manufacturing Engineering staffs, who assisted me patiently with management of raw materials and experimental apparatus loans.

I sincerely acknowledge the sacrifices made by my parents for their encouragement and help in all aspects of pursuing higher education and research. I also would like to exspress my appreciation to my beloved wife, Noor Naimah binti Mohamed Nor, for her guidance and support toward my research writing. Special thanks to my colleagues Siti Rudiah Karim, Ainorhayat Hamidon, and Siti Salwa Khamis. Their help is very much appreciated. I wish to thank my relatives and friends for their moral supports and prayers. It would have been very hard for me to complete this study without cooperation and support from all.

ABSTRACT

Over the years, millions tonnes of waste plaster of Paris (POP) were generated and disposed in landfills or most of the time was dumped directly into the environment without any treatments, makes it as one of the environmental issues. Therefore, a new alternative is required to convert the wastes POP into useful materials and marketable to minimize the environmental impact. In the early stage, this study focused on the characterization of the raw material used through particle size analysis, thermal analysis, and identification of its purity. Then, the slip casting technique and standard American Society for Test and Materials (ASTM) was respectively used to fabricate and characterize all of the pottery samples. In the second stage, the ceramic pottery body was fabricated using different composition of waste POP, started from 0 wt.% until 12 wt.%. The samples obtained were analysed through viscosity test and its green body was observed. The results showed that the samples with compositions of 0 to 10 wt.% of waste POP were the only samples that can be used in this study. The analysis on the effects of particle sizes ranging from 25 to 73 µm and sintering temperatures ranging from 950 to 1050 °*C* on the physical and mechanical properties of the fabricated ceramic pottery body, respectively, were then determined in the third and fourth stage of this study. The physical properties were reported in terms of shrinkage, porosity, and density values; whereas, the mechanical properties were reported in terms of the value of modulus of rupture (MOR). The result showed that a dense and a high strength of ceramic pottery can be produced by using a finer size of particle of 25 μm and at a high sintering temperature of 1050 °C, based on the low porosity value, the high density value, MOR and also the controllable value of shrinkage. Therefore, it can be concluded that the waste POP can be successfully used as a filler to enhance the properties of ceramic pottery body.

ABSTRAK

Selama bertahun-tahun, berjuta-juta tan sisa daripada Plaster Paris (POP) dihasilkan dan dilupuskan di tapak pelupusan atau seringkali dibuang terus di persekitaran tanpa sebarang rawatan, menjadikan ia sebagai salah satu isu alam sekitar. Oleh itu, satu alternatif baru diperlukan untuk menukarkan sisa POP kepada bahan yang sesuai untuk digunakan dan juga bernilai bagi mengurangkan kesan alam sekitar. Pada peringkat awal, kajian ini tertumpu kepada pencirian bahan mentah yang digunakan melalui analisa saiz partikel, analisa terma, dan pengenalpastian keasliannya. Kemudian, teknik slip pemutus dan standard American Society for Test and Materials (ASTM) masing-masing digunakan untuk membentuk dan mencirikan semua sampel tembikar. Pada peringkat kedua, tembikar seramik telah dibentuk menggunakan komposisi sisa POP yang berlainan, bermula dari 0 wt.% Sehingga 12 wt.%. Sampel yang diperolehi dianalisis melalui ujian kelikatan dan pemerhatian badan hijau. Keputusan menunjukkan bahawa sampel dengan komposisi 0 hingga 10 wt.% sisa POP adalah satu-satunya sampel yang boleh digunakan dalam kajian ini. Analisis mengenai kesan saiz zarah antara 25 hingga 73 µm dan suhu pembakaran antara 950 hingga 1050 °C terhadap sifat-sifat fizikal dan mekanikal badan tembikar seramik yang dibentuk, masing-masing, kemudiannya ditentukan pada peringkat ketiga dan keempat kajian ini. Ciri-ciri fizikal dilaporkan dari segi nilai-nilai pengecutan, keliangan, dan ketumpatan, manakala, sifat-sifat mekanikal dilaporkan melalui nilai modulus patah (MOR). Keputusan menunjukkan tembikar seramik yang padat dan berkekuatan tinggi boleh dihasilkan menggunakan saiz zarah yang paling halus iaitu 25 µm dan pada suhu pembakaran yang tinggi iaitu 1050 °C, berdasarkan nilai keliangan yang rendah dan nilai ketumpatan, MOR dan juga nilai pengecutan terkawal yang tinggi. Oleh itu, dapat disimpulkan bahawa sisa POP boleh digunakan sebagai pengisi untuk meningkatkan sifat-sifat badan tembikar seramik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

O	-	Oxygen
Al	-	Aluminium
Si	-	Silicon
K	-	Potassium
Na	-	Sodium
Ca	-	Calcium
S	-	Sulfur
Na_2O	-	Sodium Oxide
K_2O	-	Potassium Oxide
Li_2O	-	Lithium Oxide
CaO	-	Calcium Oxide
MgO	-	Magnesium Oxide
SO_3	-	Sulfur Oxide
SiO_2	-	Silicon Oxide
Al_2O_3	-	Aluminium Oxide
POP	-	Plaster of Paris
XRD	-	X-Ray Diffraction
TGA	-	Thermogravimetric Analysis
SEM	-	Scanning Electron Microscopy
MOR	-	Modulus of Rupture
PSA	-	Particle Size Analysis
ASTM	-	American Society for Testing and Materials
JCPDS	-	Joint Committee on Powder Diffraction Standards
SEM-EDS	-	Energy Dispersive Spectroscopy of Scanning Electron

LIST OF SYMBOLS

L_0	-	Length of Ceramic Samples Before Sintering
L_1	-	Length of Ceramic Samples After Sintering
W_0	-	Width of Ceramic Samples Before Sintering
W_1	-	Width of Ceramic Samples After Sintering
t_0	-	Thickness of Ceramic Samples Before Sintering
t_1	-	Thickness of Ceramic Samples After Sintering
W_d	-	Mass of Dry Sample in Air
W_s	-	Mass of Specimen Immersed and Suspended in Liquid
W_w	-	Mass of Specimen Immersed and Suspended in Air
F	-	Force (N)
L	-	Length (cm)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research background

The word ceramics are usually associated with pottery, tiles, plates and mugs, and also related to brittles and hard materials. Ceramics have been used since the earliest civilization. The field of ceramic materials has its roots in more traditional aspects of the subject like clay based ceramics and glasses. However, during the past few decades, new developments in the use of ceramics in most advanced technological applications have attracted considerable amount of attention. Ceramics can be defined as solid compounds that are formed by the application of heat, and sometimes heat and pressure (Callister and Rethwisch, 2011). These kinds of materials are used widely for cookware, electrical insulator and even mobile engine part.

In recent years, it can be witnessed that there is a growth in social concerns about the problem of waste management and industrial waste generally, or particularly, waste from the construction industry. This problem becomes prominent due to the growing quantity of industrial, construction and demolition waste (Juan *et al*., 2010). Ceramic waste is one type of waste which resulted from ceramic industries. One example for ceramic waste is plaster of Paris (POP) mould.

POP is derived from gypsum or sometimes called calcium sulfate dehydrate ($CaSO_4.½H_2O$), a naturally sedimentary rock occurring through the evaporation of sea water, trapped in lagoons. Most of the water is driven off when gypsum is heated to 128 °C, resulting in a powdery substance commonly known as POP (Colditz, 2002). The molecules incorporate each other into the crystalline lattice of calcium sulfate dehydrate when water is added to the dry plaster (Asante-Kyei, 2012). It is worth noting that a great effort is needed in clearing and classifying in order to produce POP.

However, recycled gypsum from waste mould can be used in a variety of applications. Currently, gypsum from natural or synthetic sources was applied into other materials or products such as polypropylene (Jikan, Arshat, and Badarulzaman, 2013), Portland cement (Chandara *et al*., 2009), natural rubber (Ngamsurat *et al*., 2011), and concrete cube (Kanthe, 2013). Besides, there is a recommendation made based on the basis of laboratory research which has indicated that there may be effective and environmentally sound methods of disposing waste gypsum (Gypsum Association, 1992). In the meantime, the gypsum industry itself is also continuing to explore research options which will verify that similar results and would be observed under real world conditions (Gypsum Association, 1992). Thus, from a technical point of view, recycle and reuse are exactly the most convenient and easiest methods in managing the waste gypsum.

1.2 Problem statement

Issues related to the environmental damage caused by various productive sectors that actively discharges their waste materials directly into ecosystems without adequate treatment has recently become prominent among publics and environmentalists, especially. This problem leads to the search for a great solution to recycle the waste materials and reduce the waste disposal problem in order to achieve sustainable development. This is because, sustainable development of various ceramics industries and protection of the environment is very important as the waste materials generated from industries would increase every years.

Based on scheduled waste report issued by Department of Environment (DOE), it can be noted that Malaysia generates a total of 337,770 metric tonnes of waste gypsum per year in 2012 as compared to 80,000 metric tonnes in 2009 as shown in Figure 1.1. This shows that gypsum is one of the main categories of waste produced in this country. Waste gypsum itself is not dangerous. However, a dangerous gas, known as hydrogen sulfide gas can evolve from it when it is mixed with organic waste and exposed to rain in an anaerobic environment. One of the most common waste gypsum is slip casting mould, which is a waste material produced from the hydration of POP in ceramic factory.

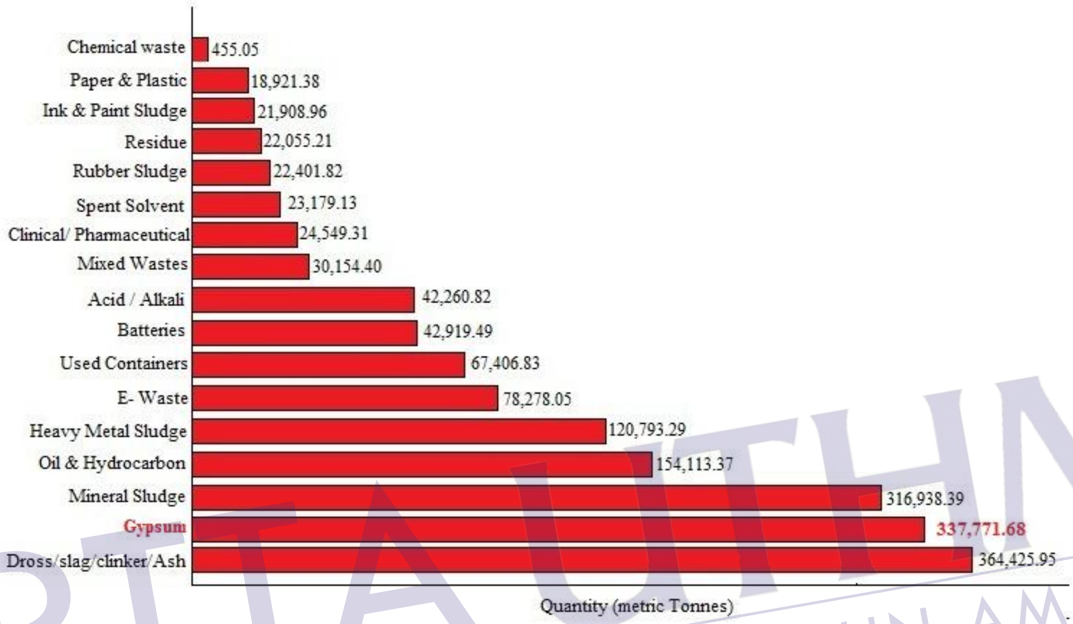

Figure 1.1: Quantity of scheduled waste generation in Malaysia, by category in the year 2012 (Hassan, 2013)

Typically, the POP mould is disposed off in landfills and often dumped directly into the environment after it is being used around 150 to 230 times. To add to that effect, most of the ceramic manufacturing and construction sectors produce lots of waste POP. Consequently, the amount of used POP that has been disposed without recycling becomes one of the environmental issues. Therefore, in order to assist the government in addressing the environmental issue, it is crucial to develop new material which consists of waste POP. In the meantime, another approach needs to be implemented to convert waste POP into materials that are fit for use and hence have commercial value to minimize the environmental impact. Thus, it is aimed in this study to discover new alternative to recycle waste POP and also evaluate the suitability of the waste POP in the fabrication of ceramic pottery after considering their potentials as filler in ceramic processing.

1.3 Objectives of study

Reducing, reusing and recycling are often cited as methods for preserving limited landfill space, and can also reduce landfill toxicity in some cases. In the past, gypsum production and construction waste was considered as acceptable waste material at landfill sites. Nowadays, some landfill operators and municipalities are no longer accepting gypsum wastes of any kind, essentially due to shortage of landfill space. Moreover, most gypsum manufacturing companies many of which, in the past, have been involved in some forms of limited recycling, are now learning how to increase the amount of recycling they are doing and are looking for new uses of waste materials. There are many recent studies on waste gypsum conducted but further work in this area is still required.

The main objectives of this study are:

i. To fabricate pottery ceramic body with waste POP as a filler in the composition of 0 to 12 wt%.
ii. To determine the effect of different particle size distributions of the POP to the pottery ceramic main body in physical and mechanical properties.
iii. To investigate the effects of different sintering temperature on the physical and mechanical properties of pottery ceramic.

1.4 Scopes of study

This study aims to discover and evaluate the suitability of waste POP in fabrication of high performance of ceramic pottery body. To achieve the objectives of this study, these following scopes and limitations are applied:

i. Characterization of waste POP and other raw material used was conducted via X-ray diffraction (XRD) technique, thermogravimetric analysis (TGA) and particle size analyzer.

ii. Combination of the waste POP with ball clay, kaolinite, potash feldspar and silica was prepared according to different quantity of composition. Composition employed was within the range of 0 to 12 wt.%.
iii. The rheological properties of the slurry obtained was characterized through viscosity test.
iv. Slip casting technique was carried out for fabrication of the sample.
v. Scanning electron microscopy (SEM) and optical microscopy were used to observe the microstructure of the pottery.
vi. The sintering temperature and particle size were investigated in the range of 950 °C to 1050 °C and 25 μm to 73 μm, respectively.
vii. The properties of the ceramic structure were characterized based on the following parameters: physical properties (porosity, density and shrinkage) and mechanical properties (modulus of rupture).

1.5 Significance of study

This study is important because there has been no research conducted pertaining to the combination of ceramics with waste POP until today, compared to the research on combination of ceramics with pure POP. Therefore, it is significant to conduct a study about the combination of ceramics with waste POP in order to know its mechanical and physical properties. The results of this research hopefully could assist all the related parties in producing a high quality product using this kind of ceramics with substantial cost savings. Besides that, an effective method of disposal also can be obtained through the reuse of the waste POP as well as reducing the impact of environmental pollution. This is in line with the recommended practices of green technology which have been suggested to the people all around the world and Malaysia especially.

Since the study on combination of ceramics with waste POP has yet been done, the essential characteristics of this kind of ceramics are not known accurately. Therefore, again, it appears that it is crucial to implement this study in order to determine the microstructure, the elements and chemical composition as well as the mechanical and physical properties of the resulting ceramics. Finally, it can also reduce the production costs and harness the waste POP in a much better way.

1.6 Outline of the thesis

There are five chapters in this study. Chapter 1 includes the research background, problem statement, objective and scope and also significance of the research proposed. In order to define this study, literature review was carried out and detailed in Chapter 2. Literature review includes all the information needed for this study. Meanwhile, Chapter 3 discusses and elaborates the methods undertaken throughout the research. Chapter 4 covers the results and discussion on thermal analysis and identification on the purity of material used in this study, the findings and theoretical explanations regarding the effects of three parameters, that are composition of waste POP, sintering temperature and particle size on physical and mechanical properties, and lastly focuses on the observation of morphology using SEM. Finally, conclusions and recommendations are provided in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Ceramics

The term ceramics comes from the Greek word keramos, which means potter's clay. Ceramics can be either crystalline or glass like and have few free electrons at room temperature. This is the reason why ceramics have some of the properties like electrical, non-conducting and exhibit low thermal conductivity. Generally ceramics are hard, brittle, stiff and higher in compressive strength than tensile (Horath, 2001).

Other than that, ceramics are usually associated with mixed bonding which is a combination of covalent, ionic and some metallic. Ceramics also consist of arrays of interconnected atom that is not discrete molecules (Carter and Norton, 2007).

Traditionally, ceramics are made from three basic components which are clay, silica and feldspar. For example, product from traditional ceramics includes high volume items such as bricks and tiles, toilet bowls (whiteware) and pottery. On the other hand, advanced ceramics are pure compounds or nearly pure compounds of primarily oxides, carbides or nitrates (Jacobs and Kilduff, 2004). The product from advanced ceramics is newer material such as laser host materials, piezoelectric ceramics, optical and so on. Figure 2.1 shows comparison between traditional and advanced ceramics from different aspects.

REFERENCES

Abshinova, M. A. and Li, Z. W. (2014). Effect of milling time on dynamic permeability values of reduced carbonyl iron filled composites. *Journal of Magnetism and Magnetic Materials*, 369, 147-154.

Abd Rahman, H. and Yacob, D. H. (2008). Effect of double sintering on the properties of porous ceramic. *Brunei International Conference on Engineering and Technology 3*. Bandar Seri Begawan, Brunei Darussalam: Institute Technology Brunei.

Abd Rahman, H., Rahmat, N. and Shariff, M. (2009). Microwave drying effects on the properties of alumina-zeolite foam. *Green Technology and Engineering*, 521- 525.

Adamis, Z., Fodor, J., & Williams, R. B. (2005). *Bentonite, Kaolin, and Selected Clay Minerals.* Geneva: World Health Organization.

Alias, R. (2012). *The Effects of Sintering Temperature Variations on Microstructure Changes of LTCC Substrate*. Rijake, Croatia: INTECH Open Access Publisher.

Allen, T. (1993). *Particle Size Measurement*. 4th ed. London: Chapman and Hall.

American Society for Testing and Materials (1999). *Standard Test Methods for Flexural Properties of Ceramic Whiteware Materials*. West Conshohocken: ASTM C674.

American Society for Testing and Materials (2006). *Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products, Ceramic Tiles, and Glass Tiles*. West Conshohocken: ASTM C373.

Amoros, J. L., Feliu, C., Gines, F. and Agramunt, J. V. (1996). Mechanical strength and microstructure of green ceramic bodies. *Qualicer 96. IV World*

Congress on Ceramic Tile Quality. General Conferences and Communications Pt. 1. Castellon.10 (13).

Amoros, J. L., Orts, M. J., Garcia-Ten, J., Gozalbo, A. and Sanchez, E. (2007). Effect of the green porous texture on porcelain tile properties. *Journal of the European Ceramic Society*, 27(5), 2295-2301.

Amoros, J. L., Cantavella, V., Jarque, J. C. and Feliu, C. (2008). Green strength testing of pressed compacts: an analysis of the different methods. *Journal of the European Ceramic Society*, *28*(4), 701-710.

Amoros, J. L., Boix, J., Llorens, D., Mallol, G., Fuentes, I. and Feliu, C. (2010). Non-destructive measurement of bulk density distribution in large-sized ceramic tiles. *Journal of the European Ceramic Society*, 30(14), 2927-2936.

An, J. W., You, D. H. and Lim, D. S. (2003). Tribological properties of hot-pressed alumina–CNT composites. *Wear*, *255*(1), 677-681.

Aramide, F. O. (2015). Effects of sintering temperature on the phase developments and mechanical properties ifon clay. *Leonardo Journal of Sciences*, *26*, 67-82.

Arem, J. E. (2011).*Observations on the Occurrence of Plagioclase Feldspars.* New York: Van Nostrand Reinhold.

Ariffin, K.A. (2003). *Feldspathic Minerals*. University Science Malaysia: EBS 425/3 Mineral Preindustrial.

Aroke U. O., El-Nafaty U. A. and Osha O. A. (2013). Properties and characterization of kaolin clay form Alkaleri, North-Eastern Nigeria. *International Journal of Emerging Technology and Advanced Engineering*, 3(11), 387-392.

Asante-Kyei, K. (2012). Manufacturing of local plaster of Paris (pop) from salt residue mined in Sege in the Dangme east district of the greater Accra region of Ghana. *Research Journal of Environmental and Earth Sciences*, 4(11), 953-958.

Atwood, J. D. & Zuckerman, J. J. (1999). *Inorganic Reactions and Methods: Formation of Ceramics.* Weinheim: Wiley –VCH publisher.

Barbosa da Silva, J., Silva A. G., Neves, G. A., Barbosa de Lima, W. C. P., de Farias Neto, S. R., and de Lima, A. G. B. (2012). Heat and mass transfer and volume variations during drying of industrial ceramic bricks: an experimental investigation. *Defect and Diffusion Forum.* 326.

Biernacki, R., Haratym, R., and Kwapisz, J. (2012). Evaluation of synthetic gypsum recovered via wet flue-gas desulfurization from electric power plants for use in foundries. *Archives of Foundry Engineering*, *12*(3), 5-8.

Bortzmeyer, D., Langguth, G. and Orange, G. (1993). Fracture mechanics of green products. *Journal of the European Ceramic Society*, 11(1), 9-16.

Callister, W. D. & Rethwisch, D. G. (2007). *Materials Science and Engineering: An Introduction*. 7th. New York: John Wiley and Sons.

Callister Jr, W. D. (2010). *Materials Science and Engineering, an Introduction 8th Edition Solution Manual*. New York: John Wiley and Sons.

Callister, W. D. & Rethwisch, D. G. (2011). *Materials Science and Engineering: An Introduction*. New York: John Wiley and Sons.

Carter, C. B. & Norton, M. G. (2007). *Ceramic Materials: Science and Engineering*. Berlin: Springer Science & Business Media.

Carty, W. M. and Senapati, U. (1998). Porcelain raw materials, processing, phase evolution, and mechanical behavior. *Journal of the American Ceramic Society*, *81*(1), 3-20.

Chandara, C., Azizli, K. A. M., Ahmad, Z. A. and Sakai, E. (2009). Use of waste gypsum to replace natural gypsum as set retarders in Portland cement. *Waste management*, 29(5), 1675-1679 .

Choi, H., Lee, W. and Kim, S. (2009). Effect of grinding aids on the kinetics of fine grinding energy consumed of calcite powders by a stirred ball mill. *Advanced Powder Technology*, 20(4), 350-354.

Chukwudi, B. C., Ademusuru, P. O. and Okorie, B. A. (2012). Characterization of sintered ceramic tiles produced from steel slag. *Journal Mineral Materials Character Engineering*, *11*, 863-868.

Colditz, J. C. (2002). Plaster of paris: the forgotten hand splinting material. *Journal of Hand Therapy*, 15(2), 144-157.

Correia, S. L., Curto, K. A. S., Hotza, D. and Segadaes, A. M. (2005). Using experiments design to model linear firing shrinkage of triaxial ceramic bodies. *Materials Science Forum*, 498, 430-435.

Das, S. K., Dana, K., Singh, N. and Sarkar, R. (2005). Shrinkage and strength behaviour of quartzitic and kaolinitic clays in wall tile compositions. *Applied Clay Science*, *29*(2), 137-143.

De Jonghe, L. C. & Rahaman, M. N. (2003). *Sintering of Ceramics. Handbook of Advanced Ceramics: Materials, Applications, Processing and Properties.* 2nd. California: Academic Press.

De Bellis, A. C. (2002). *Computer Modeling of Sintering in Ceramics.* University of Pittsburgh: PhD Thesis.

Dhara, S., Pradhan, M., Ghosh, D. and Bhargava, P. (2003). Nature inspired processing routes for ceramic foams. *Journal of American Ceramic Society*, 86, 1645-1657.

Dick, J. S. (2014). *Rubber Technology: Compounding and Testing for Performance*. Munich: Carl Hanser Verlag.

Dinger, D. R. (2005). *Ceramic Processing E-zine: volume 2.* Augusta Rd Clemson: Dinger Ceramic Consulting Service.

Eichler, J., Rodel, J., Eisele, U. and Hoffman, M. (2007). Effect of grain size on mechanical properties of submicrometer 3Y-TZP: fracture strength and hydrothermal degradation. *Journal of the American Ceramic Society*, *90*(9), 2830-2836.

Ergun, Y. (2004). Development and characterization of PMMA based porous materials used for high pressure casting of sanitaryware ceramics. *Key Engineering Materials*, 264-268, 2235-2238.

Escalante-Garcia, J. I., Magallanes-Rivera, R. X., & Gorokhovsky, A. (2009). Waste gypsum–blast furnace slag cement in mortars with granulated slag and silica sand as aggregates. *Construction and building materials*,*23*(8), 2851-2855.

Ferreira, S. B., Domingues, P. C., Soares, S. M., and Camarini, G. (2015). Recycled Plaster and Red Ceramic Waste Based Mortars. *International Journal of Engineering and Technology*, *7*(3), 209.

Friedman H. (1997). *The Mineral kaolinite.* Retrieved from http://www.minerals.net/mineral/kaolinite.aspx

Galmarini, S. (2011). Ceramics: Sintering and microstructure. *Work practices Ceramics Process: TP3 Sintering*, 1-15.

Ganesapillai, M., Regupathi, I. and Murugesan, T. (2008). Characterization and process optimization of microwave drying of plaster of paris. *Drying Technology*, 26(12), 1484-1496.

German, R. M. (1985). *Liquid Phase Sintering*. Berlin: Springer Science & Business Media.

Geotechnical Engineering (2006). *Chapter 5.0: Geotechnical Inputs for Pavement Design.* Federal Highway Administration: US Department of Transportation Publication.

Gibson, L. J. & Ashby, M. F. (1997). *Cellular Solids: Structure and Properties*. Cambridge: Cambridge university press.

Godinho-Castro, A. P., Testolin, R. C., Janke, L., Corrêa, A. X., and Radetski, C. M. (2012). Incorporation of gypsum waste in ceramic block production: Proposal for a minimal battery of tests to evaluate technical and environmental viability of this recycling process. *Waste management*, *32*(1), 153-157.

Gypsum Association (1992). *Treatment and Disposal of Gypsum Board Waste.* Washington, D.C: Construction Dimensions.

Hadi, K. A. A. (2008). The genesis and characteristics of primary kaolinitic clay occurrence at Bukit Lampas, Simpang Pulai, Ipoh. *Bulletin of the Geological Society of Malaysia*, *54*, 9-16.

Handle, F. (2007). *Extrusion in Ceramics*. Berlin: Springer Science & Business Media.

Hansen, T. (1997). *The Physics of Clay Bodies.* Retrieved from http://www.digitalfire.com/4sight/glossary/glossary_clay_shrinkage.html

Hassan, H. (2013). Overview of schedule waste management in Malaysia and the way forward. *Sustainability and Environmental Management Conference and Exhibition*. Malaysia: ENSEARCH.

Hassan, R. (1997). *Teknologi Pembuatan Seramik (Bahan Dan Proses).* Universiti Tun Hussien Onn Malaysia: Degree Thesis.

Hewitt, S. A. and Kibble, K. A. (2009). Effects of ball milling time on the synthesis and consolidation of nanostructured WC–Co composites. *International Journal of Refractory Metals and Hard Materials*, 27(6), 937-948.

Horath, L. D. (2001). *Fundamentals of Materials Science for Technologists: Properties, Testing, and Laboratory Exercises.* 2nd ed. United States of America: Prentice Hall.

Hwang, S. H., Bang, D. S., Yoon, K. H., & Park, Y. B. (2011*). Smart Materials and Structures Based on Carbon Nanotube Composites*. Rijake, Croatia: INTECH Open Access Publisher.

Iloghalu, F. and Nnuka, E. (2014). Evaluation of the fluxing potentials of okene potassium feldspar for silicate ceramics production. *Evaluation*, 1(4).

Industrial Accident Prevention Association (2008). *Silica in the Workplace.* Canada: Centre for Health & Safety Innovation.

Ismail, N. F. (2012). *Consolidation of Single and Double Layers Ceramic Structure*. Universiti Tun Hussein Onn Malaysia: Master Thesis.

Jacobs, J. A. & Kilduff, T. F. (2004). *Engineering Materials Technology: Structures, Processing, Properties, and Selection*. United States of America: Prentice hall.

James, F. S. & Doremus, R. (2008). *Ceramic and Glass Materials: Structure, Properties and Processing*. Berlin: Springer.

Jikan, S. S., Arshat, I. and Badarulzaman, N. A. (2013). Melt flow and mechanical properties of polypropylene/recycled plaster of paris. *Applied Mechanics and Materials*, 315, 905-908.

Jillavenkatesa, A., Dapkunas, S. J., & Lum, L.S. H. (2001). *Particle Size Characterization.*Washington: National Institute of Standards and Technology (NIST).

Juan, A., Medina, C., Morán, J. M., Guerra, M. I., De Rojas, M. I. S., Frías, M., and Aguado, P. J. (2010). *Re-Use of Ceramic Wastes in Construction*. INTECH Open Access Publisher.

Kamarudin, R. A., and Zakaria, M. S. (2007). The utilization of red gypsum waste for glazes. *Malaysian Journal of Analytical Sciences*, *11*(1), 57-64

Kanthe, V. N. (2013). Use of waste plaster of paris in concrete. *International Journal of Innovative Research and Development*, *2*(3), 855-862.

Kasuriya, S. and Atong, D. (2004). Rapid drying of ceramic and efficient food processing with a continuous microwave belt furnace. *National Metal and Material Technology Center*, 27-28.

Kojima, Y., and Yasue, T. (2006). Synthesis of large plate-like gypsum dihydrate from waste gypsum board. *Journal of the European Ceramic Society*, *26*(4), 777-783.

Konta, J. (1982). *Properties of Ceramic Raw Materials Monographs-Handbook of Ceramics*. Freiburg-Alemanha: Verlang Schmid GmbH.

Kumar, A., Agarwala, V. and Singh, D. (2014). Effect of milling on dielectric and microwave absorption properties of SiC based composites. *Ceramics International*, 40(1), 1797-1806.

Lai, M. O., Lu, L. and Laing, W. (2004). Formation of magnesium nanocomposite via mechanical milling. *Composite Structures*, 66(1), 301-304.

Leiser D. B. and Whittemore O. J. (1970). Compaction behavior of ceramic particles. *American Ceramic Society Bulletin, 49,* 714-717.

Limpaiboon, K., & Nualanong, A. (2011). Influence of different additives at various contents on the properties of pottery clay body. *Walailak Journal of Science and Technology*, *7*(2), 155-167.

Liu, J., Lin, L., Li, J., Liu, J., Yuan, Y., Ivanov, M. and Guo, J. (2014). Effects of ball milling time on microstructure evolution and optical transparency of Nd: YAG ceramics. *Ceramics International*, 40(7), 9841-9851.

Lum, L. S., Malghan, S. G. and Schiller, S. B. (1996). Standard reference materials for particle size analysis of ceramic powders by gravity sedimentation. *Powder Technology*, *87*(3), 233-238.

Lunn, R. (2014). *Silica, Crystalline (Respirable Siz*e). Washington D. C: Department of Health and Human Services.

Lyckfeldt, O. (2007). *Slip Casting and Pressure Slip Casting: Forming of Complex Shapes*. Sweden: Swerea IVF.

Martin-Marquez, J., Rincon, J. M. and Romero, M. (2010). Effect of microstructure on mechanical properties of porcelain stoneware. *Journal of the European Ceramic Society*, *30*(15), 3063-3069.

Marzuki, N. M. (2012*). Preparation of Ceramic Membrane Via Gelcasting Technique.* Universiti Tun Hussein Onn Malaysia: Degree Thesis.

Mayco. (2004). *An introductory course on the basics of ceramics*. *Ceramics*, 101.

Mencek, J. (1992). *Strength and Fracture of Glass and Ceramics.* Netherland: Elsevier Science Publishers.

Meng, Z. H., Huang, S. Y. and Yang, M. (2009). Effects of processing parameters on density and electric properties of electric ceramic compacted by low-voltage electromagnetic compaction. *Journal of Materials Processing Technology, 209(2),* 672-678.

Mewis, J. (1979). Thixotropy-a general review. *Journal of Non-Newtonian Fluid Mechanics*, *6*(1), 1-20.

Midwest Research Institute. (1996). *Introduction to Mineral Products Industry: Ceramic Clay Manufacturing*. North Carolina: U.S Environmental Protection Agency.

Miles, W. J. (1990). Mining industry responds to crystalline silica regulations. *Mining Engineering*, *19*, 345-348.

Mobarak, Y., Bassyouni, M. and Almutawa, M. (2013). Materials selection, synthesis, and dialectical properties of PVC nanocomposites. *Advances in Materials Science and Engineering*.

Moreno, R., Salomoni, A., and Stamenkovic, I. (1997). Influence of slip rheology on pressure casting of alumina. *Journal of the European Ceramic Society*, *17*(2), 327-331.

Muller, N. S., Kilikoglou, V., Day, P. M. and Vekinis, G. (2010). The influence of temper shape on the mechanical properties of archaeological ceramics. *Journal of the European Ceramic Society*, *30*(12), 2457-2465.

Muller, N. S., Vekinis, G., Day, P. M. and Kilikoglou, V. (2015). The influence of microstructure and texture on the mechanical properties of rock tempered archaeological ceramics. *Journal of the European Ceramic Society*, *35*(2), 831-843.

Murray, H. H. and Kogel, J. E. (2005). Engineered clay products for the paper industry. *Applied Clay Science*, *29*(3), 199-206.

Neville, A.M. (2002). *Properties of Concrete.* 4th ed. New York: Pearson Education Limited.

Ngamsurat, S., Boonkerd, K., Leela-adisorn, U. and Potiyaraj, P. (2011). Curing characteristics of natural rubber filled with gypsum. *Energy Procedia*, *9*, 452-458.

Nor, M. A. A. M., Akil, H. M. and Ahmad, Z. A. (2009). The effect of polymeric template density and solid loading on the properties of ceramic foam. *Science of Sintering*, *41*(3), 319-327.

Norliza, I. Murthy, V. and Teng, W. D. (2009). Ceramic membrane fabrication from industrial waste: effect of particle size distribution on the porosity. *Journal of Applied Sciences*, *9*, 3136-3140.

Obradovic, V., Brncic, M., and Jezek, D. (2009). Influence of the sieving amplitude on the particle size distribution of corn flour for direct expanded extrudates manufacturing. *Agriculturae Conspectus Scientificus*, *74*(3), 249-252.

Orts, M. J., Escardino, A., Amorós, J. L. and Negre, F. (1993). Microstructural changes during the firing of stoneware floor tiles. *Applied Clay Science*, 8(2), 193-205.

Pan, D. A., Li, L. J., Yang, J., Bu, J. B., Guo, B., Liu, B., and Volinsky, A. A. (2015). Production of glass–ceramics from heavy metal gypsum and pickling sludge. *International Journal of Environmental Science and Technology*, *12*(9), 3047-3052.

Papageorgiou, A., Tzouvalas, G. and Tsimas, S. (2005). Use of inorganic setting retarders in cement industry. *Cement and Concrete Composites*, *27*(2), 183-189.

Petersham, M. (ed.) (1984). *Understanding Clay Recognition and Processing*. Virginia: Volunteers in Technical Assistance (VITA).

Potgieter, J.H., Potgieter, S.S. and McCrindle, R.I. (2004). A comparison of the performance of various synthetic gypsums in plant trials during the manufacturing of OPC clinker. *Cement and Concrete Research*, 34, 2245–2250.

Pye, K. and Blott, S. J. (2004). Particle size analysis of sediments, soils and related particulate materials for forensic purposes using laser granulometry. *Forensic Science International*, *144*(1), 19-27.

Rajamannan, B., Viruthagiri, G. and Jawahar, K. S. (2013). Effect of grog addition on the technological properties of ceramic brick. *International Journal of Latest Research in Science and Technology*, 2(6), 81-84.

Rice, P. M. (2015). *Pottery analysis: a sourcebook*. Chicago: University of Chicago Press.

Richerson, D.W. (1992). *Modern Ceramic Engineering.* 2nd Ed. New York: Marcel Dekker Inc.

Riedel, R., & Chen, I. W. (2008). *Ceramics Science and Technology*. New York: John Wiley & Sons.

Riedel, R., Ionescu, E. and Chen, I. W. (2011). Modern trends in advanced ceramics. *Ceramics Science and Technology*, 1, 3-38

Riley, F. (2009). *Structural Ceramics: Fundamentals and Case Studies*. Cambridge: Cambridge University Press.

Ryan, W. (1999). *The Manufacture of Wall and Floor Tiles.* Malaysia: Ceramic Research Company.

Sacks, M.D. and Tseng, T.Y. (1984). Preparation of SiO2 glass from model powder compacts. Part 2: Sintering. *Journal of the American Ceramic Society*, 67(8), 532–537.

Sae-oui, P., Sirisinha, C. and Thaptong, P. (2009). Utilization of limestone dust waste as filler in natural rubber. *Journal of Material Cycles and Waste Management*, *11*(2), 166-171.

Safaeikatouli, M., Jafariahangari, Y. and Baharlouei, A. (2011). An evaluation on the effects of dietary kaolin and zeolite on broilers blood parameters, T4, TSH and growth hormones. *Pakistan Journal Nutrition*, *10*, 233-237.

Shackelford, J.F. (2009). *Introduction to Materials Science for Engineers*. 7th Ed. New Jersey: Pearson Education Inc.

Sharma, A. K. and Mahanwar, P. A. (2010). Effect of particle size of fly ash on recycled poly (ethylene terephthalate)/fly ash composites. *International Journal of Plastics Technology*, 14(1), 53-64.

Singh, N. B. and Middendorf, B. (2007). Calcium sulphate hemihydrate hydration leading to gypsum crystallization. *Progress in Crystal Growth and Characterizdation of Materials*, *53*(1), 57-77.

Souza, A. E., Teixeira, S. R., Santos, G. T. A. and Longo, E. (2013). Addition of sedimentary rock to kaolinite clays: influence on sintering process. *Ceramica*, 59.

Sperazza, M., Moore, J. N. and Hendrix, M. S. (2004). High-resolution particle size analysis of naturally occurring very fine-grained sediment through laser diffractometry. *Journal of Sedimentary Research*, 74(5), 736-743.

Spiller, M. S. (2012). *Dental Ceramics*. Albany, NY: Academy of Dental Learning and OSHA Training.

Stubna, I., Trnik, A., Sin, P., Sokolar, R. and Medved, I. (2011). Relationship between mechanical strength and modulus young in traditional ceramics. *Material and Technology*, 45(4), 375-378.

Stubna, I., Trník, A., Podoba, R., Ondruska, J. and Vozar, L. (2014). The influence of thermal expansion and mass loss on the young's modulus of ceramics during firing. *International Journal of Thermophysics, 35(9-10)*, 1879-1887.

Sutton, S. (2014). *Materials Handbook: Ceramic Industry*. Troy, Michigan: BNP Media.

Suzuki, H. and Hayashi, K. (1969). The role of particle size and carbon content in high strength WC-10% Co alloys. *Transactions of the Japan Institute of Metals*, *10*(5), 360-364.

Tangsathitkulchai, C. (2002). Acceleration of particle breakage rates in wet batch ball milling. *Powder Technology*, 124(1), 67-75.

Takeuchi, Y., Nanataki, T., Yamamoto, H. and Takeuchi, K. (1998). *Method for Controlling Firing Shrinkage of Ceramic Green Body*. U.S. Patent 5,753,160.

Takeuchi, Y., Nanataki, T., Iwata, K., Takeuchi, K., and Kimura, T. (2010). *Method for Controlling Shrinkage of Formed Ceramic Body*. U.S. Patent 7,655,180.

Ten, J. G., Orts, M. J., Saburit, A. and Silva, G. (2010). Thermal conductivity of traditional ceramics. Part I: influence of bulk density and firing temperature. *Ceramics International*, 36(6), 1951-1959.

Ulusoy, U., Yekeler, M., Bicer, C. and Gulsoy, Z. (2006). Combination of the particle size distributions of some industrial minerals measured by Andresen pipette and sieving techniques. *Particle & Particle Systems Characterization*, *23*(6), 448-456.

US stoneware (1965). *Jar, Ball and Pebble Milling Theory and Practice*. East Palestine, Ohio: Operating Division of ER Advanced Ceramics, Inc.

Valley, H. (2011). *Industrial Minerals: Feldspar*. North America: Industrial Minerals Association.

Vasilyeva, E. A., Morozova, I. V., Lapshin, A. E. and Konakov, V. G. (2002). Ceramic materials with controlled porosity. *Materials Physics and Mechanics*, 5(1), 43-48.

Vauchy, R., Robisson, A. C., Audubert, F. and Hodaj, F. (2014). Ceramic processing of uranium–plutonium mixed oxide fuels (U_1− yPu_y) O_2 with high plutonium content. *Ceramics International*, *40*(7), 10991-10999.

Vekinis, G., Ashby, M. F. and Beaumont, P. W. R. (1993). Plaster of paris as a model material for brittle porous solids. *Journal of Materials Science*, *28*(12), 3221-3227.

Wen, Y., Nan, L. and Bingqiang, H. (2005). High-strength, lightweight spinel refractories. *American Ceramic Society Bulletin*, *84*(4), 1-3.

Worrall, W.E. (1975). *Clays and Ceramic Raw Materials*. London :Applied Science Pub. Ltd.

Yan, W., Li, N., Li, Y., Liu, G., Han, B. and Xu, J. (2011). Effect of particle size on microstructure and strength of porous spinel ceramics prepared by pore-forming in situ technique. *Bulletin of Materials Science*, *34*(5), 1109-1112.

Yan, W. and Lin, N. (2006) Pore-size distribution and strength of porous mullite ceramics. *American Ceramic Society Bulletin, 85, 9401-9406.*

Yang, Y. and Ding, J. (2012). Microwave property of micron and sub-micron Fe 90 Al 10 flakes fabricated via ball milling and jet milling routes. *Journal of Alloys and Compounds*, 528, 58-62.

Zhang, Y., Kong, D. and Feng, X. (2012). Fabrication and properties of porous β-tricalcium phosphate ceramics prepared using a double slip-casting method using slips with different viscosities. *Ceramics International*, *38*(4), 2991-2996.

Zhou, J., Shu, Z., Tiantian, L. I., Dongxue, Y. U., Sheng, Z., and Wang, Y. (2015). Novel fabrication route for non-fired ceramic tiles only using gypsum.*Ceramics International*, *41*(7), 9193-9198.