

Potential of using Waste Lime Sludge from Sugar Refinery as Binder in the Production of Earthenware Ceramics

Eufronia M. Magundayao

College of Engineering, Architecture and Fine Arts, Batangas State University, Batangas City Philippines 4200

Abstract: This study focused on the utilization of waste lime sludge from sugar refinery as binder in the production of earthenware ceramics. Four experimental samples were used including the control, one that used the proportion 15:85 for feldspar-clay body formulation as used by the ceramics industry and three formulations that used the waste lime sludge coming from the sugar refinery using the proportion 15:85, 10:90 and 5:95 for waste lime sludge-clay body ratio respectively. These were tested to determine the best formulation. The quality of earthenware ceramics produced were evaluated based from the physical properties such as water of plasticity, drying shrinkage, firing shrinkage, water absorption and compressive strength. Analysis of the result revealed that among the three formulations, 10:90 was considered as the best formulation. Furthermore, variations in the percentage of waste lime sludge-clay body formulations resulted in variations in properties in terms of water of plasticity, drying shrinkage, water absorption and compressive strength. However, there was no variation in terms of firing shrinkage. Based from the findings, the waste lime sludge from sugar refinery has the potential as binder in the production of earthenware ceramics.

Keywords: earthenware ceramics, compressive strength, drying shrinkage, firing shrinkage, waste lime sludge, water of plasticity

I. INTRODUCTION

The turn of the century has brought rapid changes in terms of the country's economy and technology. Many industries have been established and developed but accompanying these developments are the problems concerning waste management particularly solid waste. It has become imperative for business establishments and industries to become aware and to prepare themselves with the recent trends in the field of solid waste management. Solid waste can be generated from industries, suburban and commercial activities in a given area. Irrespective of its origin, content or possible hazards, management of solid waste must be systematically ensured to have environmental best practices. It is therefore imperative for business establishments and industries to become aware and to prepare themselves with recent trends in the field of waste management. [1]. One of the options that can be considered is recycling. It is an important waste management tool where the waste generated are converted into new products. In effect, it decreases the solid waste management problems such as declining landfill capacity, increasing volume of waste to be disposed, emission of greenhouse gases and through recycling, natural resources can be preserved for future usage [2].

Manufacturers of high quality raw and refined sugars produce wastewater which can be treated using the improved secondary wastewater treatment facilities. However, the solid wastes that include lime sludge from the Refinery and mud from the Boiling House are disposed on landfills that becomes an expensive waste since the cost of trucking for the disposal in landfill cost a vast sum of money. There is a need therefore to find alternative ways to utilize these solid wastes to a more useful material by finding a new process to suitably recycle and reuse the waste. This study therefore sought to find an alternative method so that the lime sludge coming from sugar refineries could be a possible additive material in the production of ceramics.

II. OBJECTIVES OF THE STUDY

This study aimed to determine the potential of using waste lime sludge from sugar refinery as binder in the production of earthenware ceramics. Specifically, the study aimed to

- A. Determine if there is a significant difference in the physical properties of the earthenware ceramics produced using 5:95, 10:90 and 15:85 ratios of waste lime sludge-clay body formulation in terms of
 - 1) Water of plasticity
 - 2) Drying shrinkage
 - 3) Firing shrinkage

- 4) Water absorption
- 5) Porosity
- 6) Compressive strength

B. Determine the best ratio of earthenware ceramics produced using waste lime sludge as binder compared to the standard earthenware ceramics in terms of the properties mentioned above.

III. MATERIALS AND METHODS

This study used four experimental samples. These included the control, one that used the proportion 15:85 for feldspar-clay body formulation as used by the ceramics industry[3] and three formulations that used the waste lime sludge coming from the sugar refinery using the proportion 15:85, 10:90 and 5:95 for waste lime sludge –clay body ratio respectively.

A. Preliminary Preparations

The raw materials such as clay, silica and feldspar were purchased from Central Ceramics in Quezon City while the waste lime sludge came from a sugar refinery in Nasugbu, Batangas. The lime sludge-clay body formulation was prepared using different proportions in preparation for physical testing. The Control (15% feldspar, 85% clay body) and Formulation 1(5% sludge, 95% clay body) were mixed with 250mL of water while Formulation 2 (10% sludge, 90% clay body) and Formulation3 (15% sludge, 85% clay body) used 275 mL of water to fully mixed the clay body. Each mixture was allowed to age overnight to increase the plasticity of the clay. [4]. The next day, each formulation was thoroughly kneaded by hand to attain a uniform clay water mixture then it was allowed to age for another 24 hours.

B. Preparation of Test Specimens for Physical Test

Each test specimen was formed in rectangular shape measuring 45 mm x 35 mm x 5 mm by hand pressing into a metal mold. A total of 12 test specimens were produced for each formulation. Six among them were used in the determination of water of plasticity, drying shrinkage, firing shrinkage and compressive strength while the remaining six test specimens were used for the determination of water absorption and porosity. These samples were weighed prior to physical testing.

After weighing, the test specimens were dried at room temperature for seven days followed by drying at 60°C for 20 hours using the laboratory dryer and finally at 110 °C for 10 hours. A laboratory oven was used for firing the test specimen to a temperature of 1100°C for 30 minutes before these were allowed to cool [5]. After cooling, the specimens were subjected to different testing.

IV. RESULTS AND DISCUSSION

A. Comparison of the Physical Properties of the Earthenware Ceramics Produced using Different Formulations

1) *Water of Plasticity:* Table 1 shows the analysis of variance for the comparison of water of plasticity between ceramics produced using different ratios of waste lime sludge-clay body formulations. It could be seen from the table that the computed f-ratio of 23.68 was higher than the tabular f-value of 3.68 at 0.05 level of significance. This indicates significant differences in the water of plasticity among the three body formulations.

TABLE 1
Analysis Of Variance For The Comparison Of Water Of Plasticity

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Groups	60.97821	2	30.48911	23.6853	2.28E - 05	3.682317
Within Groups	19.31277	15	1.287518			
Total	80.29098	17				

Using Multiple Comparison of the Means (Scheffe method) to determine where the significant difference lies among the three formulations, the computed ratio between F1 (5% sludge: 95% clay body) and F2 (10% sludge: 90% clay body) as well as F1 and F3 (15% sludge: 85% clay body) as depicted in Table 2 were 6.28 and 5.47 respectively, indicating significant differences among the said formulations. However, the result of the computed ratio of 0.080 between F2 and F3 was not significant.

TABLE 2

Multiple comparison of the means of water of plasticity between ceramics
Produced using different ratios of waste lime sludge-clay body formulation

Pair	Mean Difference	Tabular Value	Computed Variance	Computed Ratio
F ₁ vs F ₂	3.92	2.71	0.66	6.28
F ₁ vs F ₃	7.91			5.47
F ₂ vs F ₃	3.99			0.80

The results of the analysis of the water of plasticity is due to the amount of lime sludge in the different formulations that affected the overall plasticity of the mixture. The increased amount of water absorbed by the lime sludge generally increased the water of plasticity [6]. Thus, the earthenware ceramics produced using waste lime sludge-clay body formulation proved to be superior over that of the control in terms of this parameter, where formulation 2(10:90) had the highest value.

2) *Drying Shrinkage*: The results presented in Table 3 show that the computed f-ratio of 12.88 is higher than the tabular f-value of 3.68 at 0.05 level of significance. This indicates that there is a significant difference in the drying shrinkage among the three formulations,

TABLE 3

Analysis Of Variance For The Comparison Of Drying Shrinkage

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Groups	10.6603	2	5.33015	12.87953	0.000555	3.682317
Within Groups	6.2077	15	0.413847			
Total	16.868	17				

As seen in Table 4 the computed mean ratio between F₁ and F₂ of 2.59 is not significant; between F₁ and F₃; is not also significant but F₂ and F₃ with a value of 5.11 is significant. This could mean that among the three formulations, F₂ has the greatest drying shrinkage while F₃ has the least drying shrinkage. Wet clay contains a large amount of water. During the drying process, water evaporates and starts shrinking because the particles of clay come closer together [6]. Drying shrinkage is correlated to the plasticity of the clay. The more water that is absorbed by the clay increase the plasticity of the clay and in effect increase the drying shrinkage [7].

TABLE 4

Multiple comparison of the means of drying shrinkage between ceramics
Produced using different ratios of waste lime sludge-clay body formulation

Pair	Mean Difference	Tabular Value	Computed Variance	Computed Ratio
F ₁ vs F ₂	0.96	2.71	0.37	2.59
F ₁ vs F ₃	0.93			2.51
F ₂ vs F ₃	1.88			5.11

3) *Firing Shrinkage*: As shown in Table 5, the computed f-value of 2.36 is below the tabular f-value of 3.68 at 0.5 level of significance which is an indication that there are no significant differences among the three formulations in terms of firing shrinkage.

TABLE 5
Analysis Of Variance For The Comparison Of Firing Shrinkage

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Groups	1.378878	2	0.689439	2.359673	0.128526	3.682317
Within Groups	4.382633	15	0.292176			
Total	5.761511	17				

Furthermore, the computed mean ratio between F1 and F2, F1 and F3 as well as F2 and F3 having a value of 0.16, 1.81 and 1.97 respectively showed no significant differences among the three formulations as seen in Table 6. This could mean that any of the three formulations could be used, but in terms of firing shrinkage, the smaller the shrinkage the better, so formulation 2 (10:90) could be considered as the best formulation in terms of firing shrinkage.

TABLE 6
Multiple comparison of the means of firing shrinkage between ceramics
Produced using different ratios of waste lime sludge-clay body formulation

Pair	Mean Difference	Tabular Value	Computed Variance	Computed Ratio
F ₁ vs F ₂	0.56	2.71	0.31	0.16
F ₁ vs F ₃	0.05			1.81
F ₂ vs F ₃	0.61			1.97

One purpose of drying the ware is to strengthen the body's resistance to strain and stress. Firing rate should be slow due to water smoking, dehydration and other physical and chemical reactions undergone by the body from a dried state to its maturing state. [6]. Also, the raw materials and the firing process have tremendous influence on the quality of ceramics [8]. Ceramics must be fired to attain its permanency. If ceramics will not be fired, it will dissolve back into sludge or mud when it comes in contact with water. [5].

4) *Water Absorption*

TABLE 7
Analysis Of Variance For The Comparison Of Water Absorption

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Groups	187.2349	2	93.61745	240.4743	4.03E-12	3.682317
Within Groups	5.83995	15	0.389303			
Total	193.0745	17				

It can be seen from the table above that the computed f-value of 240.47 revealed significant difference among the three formulations whereas in Table 8 the computed mean ratio of 10.89 between F1 and F2, 21.97 between F1 and F3 and 11.08 between F2 and F3 showed significant differences among the three formulations. Results revealed that water of absorption increases with the amount of sludge added in the formulation mixture that could be attributed to the water absorbing characteristics of the lime sludge. As compared to the standard formulation, F1 could be considered as the best formulation since less liquid penetrated through the material that can cause structural damage to the product.

TABLE 8

Multiple comparison of the means of water absorption between ceramics Produced using different ratios of waste lime sludge-clay body formulation

Pair	Mean Difference	Tabular Value	Computed Variance	Computed Ratio
F ₁ vs F ₂	3.92	2.71	0.36	10.89
F ₁ vs F ₃	7.91			21.97
F ₂ vs F ₃	3.99			11.08

5) *Porosity*: Table 9 presents the significant difference in porosity between ceramics produced using different ratios of waste lime sludge-clay body formulations. It can be seen from the table that the computed f-value of 310.16 was beyond the tabulated f-value of 3.68 at 0.5 level of significance, indicating that there is a significant difference among the different formulations in terms of porosity. Furthermore, Table 10 revealed that the computed mean ratio using Scheffe method between Formulation 1 and Formulation 2 is 12.86; between Formulation 1 and Formulation 3 was 24.65 and between Formulation 2 and Formulation 3 was 11.80. These values were all beyond the tabular value of 2.71 signifying that there were significant differences among the three formulations when paired-wise compare. Porosity refers to the spaces in between fired clay body and it signifies the strength of the ceramics [9]. Also, several factors like the nature of the raw materials, mixing, forming and techniques of firing, to name a few influenced the porosity of the ceramics formed [10].

TABLE 9 Analysis Of Variance For The Comparison Of Porosity

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Groups	438.0636	2	219.0318	310.1614	6.28E-13	3.682317
Within Groups	10.5928	15	0.706187			
Total	448.6564	17				

TABLE 10

Multiple comparison of the means of porosity between ceramics produced Using different ratios of waste lime sludge-clay body formulation

Pair	Mean Difference	Tabular Value	Computed Variance	Computed Ratio
F ₁ vs F ₂	6.3	2.71	0.49	12.86
F ₁ vs F ₃	12.08			24.65
F ₂ vs F ₃	5.78			11.80

6) *Compressive Strength*

As depicted in Table 11, the computed f-value for compressive strength was 4.6495 that was greater than the tabulated f-value of 3.682 indicating significant differences among the three formulations.

TABLE 11

Analysis Of Variance For The Comparison Of Compressive Strength

Source of Variation	SS	df	MS	F	P-value	F-crit
Between Groups	5389.5	2	2694.75	4.64925	0.026843	3.682317
Within Groups	8694.143	15	579.606			
Total	14083.64	17				

Data from Table 12 also revealed that by using Scheffe method, the computed mean value of 0.05 between F1 and F2; of 2.62 between F1 and F3; of 2.68 between F2 and F3 showed that there were no significant differences among the three formulations. This could mean that any of the formulations can be selected but F2 could be considered as the best since it has the highest mean for compressive strength.

Table 12
Multiple comparison of the means of compressive strength between ceramics produced Using different ratios of waste lime sludge-clay body formulation

Pair	Mean Difference	Tabular Value	Computed Variance	Computed Ratio
F ₁ vs F ₂	0.75	2.71	13.90	0.05
F ₁ vs F ₃	36.33			2.62
F ₂ vs F ₃	37.08			2.68

B. Best Ratio of Body Formulation of Produced Ceramics Using Waste Lime Sludge as Binder Compared to the Standard Earthenware Ceramics

TABLE 14
Results of the differene properties of the earthenware ceramics produced Using different ratios of waste lime sludge clay-body formulations As compared to the standard ceramics

Properties	Computed Mean				Results of Statistical Analysis	Remarks (Best Formulation)
	Standard Formulation	F ₁	F ₂	F ₃		
Water of Plasticity	31.57	32.00	36.14	35.61	F ₁ † F ₂ † F ₃	F ₂
Drying Shrinkage	4.70	4.77	5.73	3.34	F ₁ † F ₂ † F ₃	F ₃
Firing Shrinkage	2.72	0.56	0.51	1.12	F ₁ =F ₂ =F ₃	F ₂
Water Absorption	2.056	26.60	30.52	34.50	F ₁ † F ₂ † F ₃	F ₁
Porosity	33.87	43.74	50.04	55.82	F ₁ † F ₂ † F ₃	F ₁
Compressive Strength	152.74	145.65	146.40	109.32	F ₁ † F ₂ † F ₃	F ₂

F₁: Formulation 1 (5% sludge: 95% clay body)

F₂: Formulation 2 (10% sludge: 90% clay body)

F₃: Formulation 3 (15% sludge: 85% clay body)

The summary results of the different properties of the earthenware ceramics produced using different ratios of waste lime sludge-clay body formulations as compared to the standard ceramics is shown in Table 14.

It can be gleaned from the table that based on the statistical analysis conducted there were significant differences among formulation 1, formulation 2 and formulation 3 in terms of water plasticity. However, further analysis of the values revealed that formulation 2 (10:90) is the best formulation.

For drying shrinkage, statistical analysis revealed that there were significant differences among formulation1, formulation 2 and formulation 3. However, further analysis of the results showed that formulation 3(15:85) is desirable for earthenware ceramics.

Table 14 also shows that there were no significant differences among formulation 1, formulation 2 and formulation 3 when firing shrinkage was considered, but further analysis indicates that formulation 2(10:90) is the best for this parameter.



For water of absorption and porosity, it could be noted that there were significant differences among formulation 1 formulation 2 and formulation 3. However, a thorough analysis of the values suggested that formulation 1(5:95) is the best both for water absorption and porosity. This indicates that the said formulation absorbed less water and thus less porous.

The table also revealed that based on statistical analysis conducted, there were significant differences among formulation 1, formulation 2 and formulation 3 in terms of compressive strength. However, formulation 2(10:90) had the ability to bear crushing loads of up to 146.40 kg/cm² as seen from its computed mean, therefore, this formulation is the best among the three formulations.

V. CONCLUSIONS

Variations in the percentage of waste lime sludge-clay body resulted in variations in properties in terms of water of plasticity, drying shrinkage, water absorption, porosity and compressive strength. However, there was no variation in terms of firing shrinkage. Based on the result of the different test and the statistical analysis, Formulation 2 with 10% waste lime sludge and 90% clay body formulations is the best ratio as compared to the standard earthenware ceramics

Waste lime sludge has the potential as binder in the production of earthenware ceramics.

VI. ACKNOWLEDGMENT

The author would like to express her sincere gratitude and appreciation to the Department of Science and Technology (DOST), Industrial Technology and Information Division (ITDI) for the assistance provided during the analysis and testing of the samples.

REFERENCES

- [1] R. Leblanc. (2018). "An Introduction to Solid Waste Management" [Online]. Available: <https://www.thebalancesmb.com/an-introduction-to-solid-waste-management-2878102>
- [2] "What is Waste Management?" [Online]. Available: <https://www.conserve-energy-future.com/waste-management-and-waste-disposal-methods.php>
- [3] J. Bender, J.G. Hardley, J. P. Hellerstein, and C. M. Hohma. (n.d.) "Glass Ceramics and Industrial Materials" [Online]. Available:
- [4] "Plasticity" [Online]. Available: https://digitalfire.com/4sight/glossary/glossary_plasticity.html
- [5] M. Gorea and M. Beneai. "Characterization of Some Clays Used for Whiteware Ceramics II. Technological Characterization" *Studia Universitatis Babe – Bolyai, Geologia*, XLVII,1, 2002, 77-84
- [6] J. Zamek. (2003), "Clay's Plasticity" [Online]. Available :
- [7] P. Mckee (n.d.) "Clay and Pottery" [Online]. Available:
- [8] Goleano, A. 2005)." Synthesizing Cordierite in Ceramic Bodies" [Online]. Available <http://www.hard-tones.com/apulum.porcelain.html>
- [9] M. S. Mukherjee & H. V. Bhaskar Rao. "Factors Affecting Porosity and their Control in Refractory Manufacture" *Transactions of the Indian Ceramic Society* Volume 32, 2014, Issue 5, 17N-23
- [10] T. Hansen. (2015). "Porosity" [Online]. Available: https://digitalfire.com/4sight/glossary/glossary_porosity.html