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Ceramics Vitreous China Produced by Utilizing Sediment Soil from Water Supply Treatment Process

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Abstract. Due to generating the abundant of sediment soil, it makes the high burden of disposal cost to the metropolitan waterworks authority. Enhancing the value of sediment soil has been explored. This research aims to utilize the sediment soil, wastes of water supply treatment process for producing ceramics vitreous china. In this experiment, five types of raw materials are exploited, namely, sediment soil, ball clay, kaolin, feldspar and silica sand. The formulas have been divided into two groups. Sediment soil has been used as substituted material in ball clay for the first group, and substituted in kaolin for the second group. The specimens of each formula are formed by uniaxial pressing at 100 bar of size 50×100x7 mm. Then they have been sintered at two different temperatures, 1200°C and 1250°C, with heating rate 400^{o} C/ hr and soaking for 30 minutes. The result reveals that the suitable formula for ceramics vitreous china is No. 2_4 of Group 2 with sintering temperature 1250°C. Its mixture consists of 0% kaolin, 35% ball clay, 30% feldspar, 20% silica sand and 15% sediment soil. The properties of this formula are 9.4% shrinkage, 9.39 MPa of bending strength, 6.34x10^{-6}/K coefficient of thermal expansion, and 0.66% water absorption.

1 Introduction

Metropolitan Waterworks Authority (MWA) is one of an important state enterprises providing water supply for supporting people in the metropolitan area. With the growing population as well as the change in people's living behaviors nowadays, the demand of water consumption is increasing. Therefore, four main plants of water supply have been constructed for serving the increased demand.

These plants are located at Bangkhaen, Mahasawat, Samsen, and Thonburi area with the capacities 3.6, 0.8, 0.7, 0.17 million cubic meter /day. In addition to producing the quality water, sediment Soil has been generated from the water supply treatment process at the clarification station. They have been considered as wastes of the process and generated more than 0.1 million ton/year. Eliminating these sediment soil lead the high disposal costs to the MWA approximately 2x10^{6} THB/ year.

As mentioned above, the problem has been studied and solved by many researchers. Suriyachat et al have reported the application sediment soil from water supply for ceramics products of the SME industry. The research found that ratio of sediment Soil: sand at 70:30 can be used for producing ceramic ware sintered at 800^{o}-900^{o} C [1]. The properties of lighted weight concrete using sediment soil from water supply process as coarse aggregate have been examined by Boonin et al. The results showed that compressive strength of concrete with the ratio 80:20 of plastic clay: sediment soil can achieve the ASTM C338 [2]. Chatsatapattayakul et al have used the chemical sludge from water treatment system with cement in cement mortar and soil cement block. They summarized that soil cement block mixing with 10-30% of chemical sludge met the standards of the Thailand Institute of Scientific and Technological Research (TISTR) for attending a good strength and water resistance [3]. Apart from utilizing sediment soil from water supply treatment process, the similar wastes of the water treatment process from the different sources have been studied. Teixeira et al showed that up to 20% sludge of water treatment plant (silt, sand and clay) can be incorporated into clays used for producing ce ramic bricks [4]. Martínez-García et al have assessed the effect of incorporating waste sludge on the properties and microstructure of clay used for bricks manufacturing. Replacing clay in a ceramic body with different proportions of sludge can reduce the cost due to the utilization of waste. Results have shown that incorporating up to 5 wt% of sludge is beneficial for clay bricks [5]. Investigation utilizing fresh water treatment sludge (WTS) on the physical and mechanical properties, structural parameters as well as mineralogical composition of the ceramic products has been examined by Kizinievic et al. It was found that WTS additive, which is mostly composed from colorific Fe_2O_3, can be utilized as a natural pigment that dyes the ceramic body in darker, more intense red color [6]. Moreover, industrial solid waste generated by a water treatment plant (WTP) at a pulp mill was used for manufacturing construction fired bricks. Wolff et al have proposed that sludge can be used as a substitute for clay in the formulation of clay masses and the mixtures between 50-85% at 850 and 950^{o} C should be tested in the ceramic industry on a pilot scale in order to evaluate their suitability for the production of interior coatings or acoustic bricks [7].

However, the previous researches have not been studied the utilizing of sediment soil for ceramic vitreous china, which can be produced the sanitary ware, table ware, etc. Vitreous china has water absorption less than 1% with coefficient of thermal expansion 4-6x10^{-6}/K [8]. Therefore, this research has focused on studying the effect of sediment soil from water supply treatment process for producing ceramic vitreous china. The benefit of this study can promote the eco-friendly products which utilizing industrial wastes.

Table 1. Chemical analysis of raw materials

% Oxide	Raw Materials				
	Maetan Ball Clay	Ranong Kaolin Clay	Rayong Silica Sand	India Potash Feldspar	Sediment Soil
SiO_2	65.88	45.5	99.16	65.17	58.15
Al_2O_3	20	38	-	18.45	27.84
Fe_2O_3	1.37	0.8	-	0.17	7.17
TiO_2	0.53	0.03	0.03	0.01	0.86
CaO	0.22	0.01	0.03	0.22	0.94
MgO	0.48	0.01	0.02	0.01	1.37
K_2O	1.86	0.9	0.04	12.73	2.76
Na_2O	0.21	0.01	0.09	3.11	0.14
LOI	9.42	13	0.16	0.13	0.77

Table 2. Mixture composition of replacement sediment soil in maetan ball clay and ranong kaolin clay

Raw Materials	% Mixture								
	Group 1.Replacement in Maetan Ball Clay					Group 2. Replacement in Ranong Kaolin Clay			
	No. 1_1	No. 1_2	No. 1_3	No. 1_4	No. 1_5	No. 2_1	No. 2_2	No. 2_3	No. 2_4
Ranong Kaolin Clay	15	15	15	15	15	15	10	5	0
Maetan Ball Clay	35	30	25	20	15	35	35	35	35
India Potash Feldspar	30	30	30	30	30	30	30	30	30
Rayong Silica Sand	20	20	20	20	20	20	20	20	20
Sediment Soil	0	5	10	15	20	0	5	10	15

Note that : No 1_1= No 2_1

2 Materials and methods

2.1 Materials

In this experiment, five types of raw materials are exploited, namely, sediment soil, ball clay, kaolin, feldspar, and silica sand. Wastes material; sediment Soil from water supply treatment process has been utilized for replacement on basic materials. Sediment Soil used in this study has been generated from Mahasawat Plant. The chemical analysis of all materials has been represented in Table 1.

Notice that, all materials are local materials except India Potash Feldspar. The mixture of basic formula has been provided from Ubolrat and Vipa [9]. Considering chemical composition of sediment soil in Table 1, it indicates that main compositions are SiO2 and Al2O3 which similar to Maetan ball clay and Ranong clay. Therefore, the mixture of this experiment has been classified into two groups. Firstly, it is to replace sediment soil in Maetan ball clay. And secondly, sediment soil has been used as replacement material in Ranong kaolin clay. All of formulas have been represented in Table 2. It consists of 8 formulas which No.1_1 is the basic formula.

2.2 Methods

All of materials as mentioned above have been prepared as the procedure illustrated in Fig. 1. It consists of 9 steps. In the 3rd step, formulas of varying the proportion of materials have been constructed which consist of 8 formulas as mentioned in Table 2.

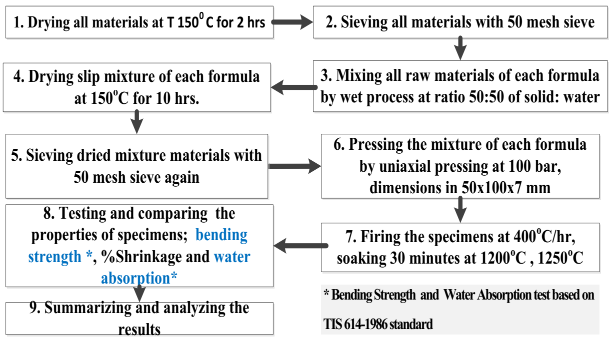

Figure 1. The 9 steps of this experiment.

3 Results and discussion

Specimens of each formula have been tested for analyzing the properties; bending strength, %water absorption, and %shrinkage. They can be described as follows.

3.1 Mechanical and physical properties

Three points bending has been used for testing bending strength of materials. All specimens of two material groups have been represented with their bending strength in Fig. 2 and Fig. 3. Increasing the ratio of sediment soil in the basic formula (No.1_1 or 2_1), the bending strength of them has gradually increased. Similarly, higher sintering temperature also increases the bending strength.

According to Fig. 4 and Fig. 5, both of two material groups have increased shrinkage when adding sediment soil in the basic formula. At the same time, sintering temperature increased also increase %shrinkage of all specimens.

On the contrary, water absorption property is decreased when increasing the ratio of sediment soil in the basic formula (No.1_1 or No.2_1). In addition, increasing sintering temperature also decreases the water absorption of both two formula groups. These have been represented in Fig. 6 and Fig.7.

The results indicated that water absorption can be related to the shrinkage property, with higher shrinkage can provide lower water absorption. Furthermore, lower water absorption can promote the higher bending strength of specimens. These can be summarized that sediment soil has the potential to enhance the beding strength of vitreous china ceramics when comparing with using kaolin clay and ball clay.

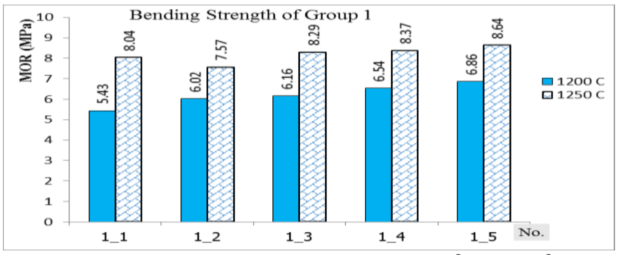

Figure 2. Bending strength of Group 1 at 1200° C, 1250°C

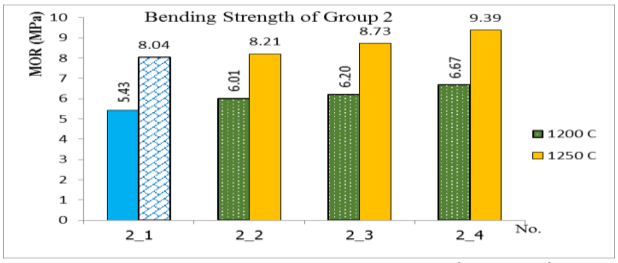

Figure 3. Bending strength of Group 2 at 1200° C, 1250°C

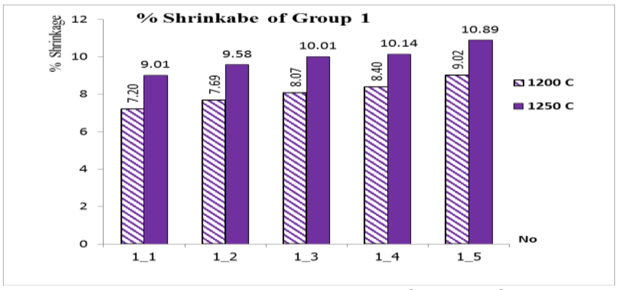

Figure 4. %Shrinkage of Group 1 at 1200° C, 1250°C

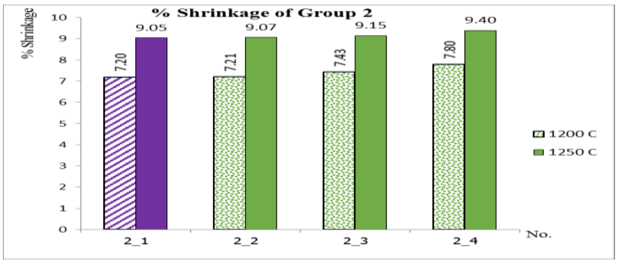

Figure 5 %Shrinkage of Group 2 at 1200° C, 1250°C

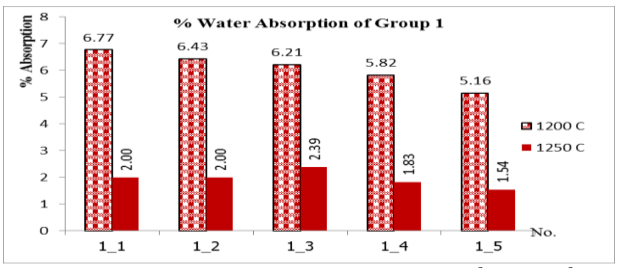

Figure. 6 %Water absorption of Group 1 at 1200° C, 1250°C

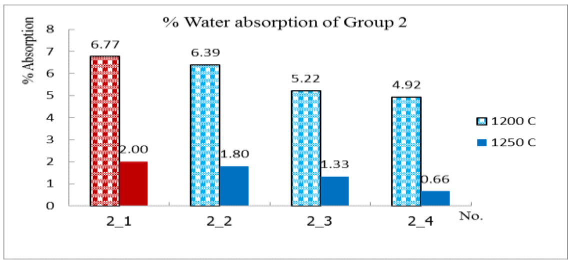

Figure 7. %Water absorption of Group 2 at 1200° C, 1250°C

3.2 Statistical analysis

For approving the results of this study, the experimental design has been conducted [10]. Two way ANOVA has been employed for analyzing the effect of raw material replacement on the properties of each formula. P-values of hypothesis testing with a 0.05 significance level of the experiment are illustrated in Table 3.

As considering Table 3, formula and temperature refer to factors of mixture number and sintering temperature. Their p values are less than 0.05, it means that formula number and temperature have the effects on bending strength, % shrinkage and % water absorption.

Table 3 Two way ANOVA test for 2 factors effect on bending strength, %Shrinkage, and % Water Absorption

P value	Group 1		Group 2	
	Formula	Temp	Formula	Temp
Bending Strength	0.012	0	0.003	0
%Shrinkage	0	0	0.015	0
%Water absorption	0	0	0	0

Two-way ANOVA: MOR versus Formula, Temp

Source	DF	SS	MS	F	P
Formula	4	10.439	2.6097	3.39	0.012
Temp	1	73.803	73.8028	96.00	0.000
Interaction	4	2.713	0.6782	0.88	0.478
Error	90	69.189	0.7688		
Total	99	156.143			

S = 0.8768 R-Sq = 55.69% R-Sq(adj) = 51.26%

Figure 8. Probability plot of bending strength of Group 1

Two-way ANOVA: MOR versus Formula, Temp

Source	DF	SS	MS	F	P
Formula	3	11.237	3.7458	5.06	0.003
Temp	1	97.753	97.7529	132.08	0.000
Interaction	3	8.443	2.8142	3.80	0.014
Error	72	53.288	0.7401		
Total	79	170.721			

S = 0.8603 R-Sq = 68.79% R-Sq(adj) = 65.75%

Figure 9. Probability plot of bending strength of Group 2

Two-way ANOVA: %Sh versus Formula, Temp

Source	DF	SS	MS	F	P
Formula	4	76.790	19.198	49.81	0.000
Temp	1	170.235	170.235	441.68	0.000
Interaction	4	0.226	0.056	0.15	0.964
Error	190	73.231	0.385		
Total	199	320.482			

S = 0.6208 R-Sq = 77.15% R-Sq(adj) = 76.07%

Figure 10. Probability Plot of Shrinkage of Group 1

Details of p value of determined properties for two groups and different temperature have been represented in Fig. 8-9, Fig. 10-11, and Fig. 12-13.

Two-way ANOVA: %Sh versus Formula, Temp

Source	DF	SS	MS	F	P
Formula	3	2.2457	0.7486	3.78	0.015
Temp	1	45.1144	45.1144	227.81	0.000
Interaction	3	1.2993	0.4331	2.19	0.098
Error	64	12.6740	0.1980		
Total	71	61.3334			

S = 0.4450 R-Sq = 79.34% R-Sq(adj) = 77.08%

Figure 11. Probability plot of shrinkage of Group 2

Two-way ANOVA: %Ab versus Formula, Temp

Source	DF	SS	MS	F	P
Formula	4	92.319	23.080	37.66	0.000
Temp	1	277.517	277.517	452.82	0.000
Interaction	4	72.502	18.125	29.57	0.000
Error	90	55.158	0.613		
Total	99	497.496			

S = 0.7829 R-Sq = 88.91% R-Sq(adj) = 87.80%

Figure 12. Probability plot of absorption of Group 1

Two-way ANOVA: %Ab versus Formula,Temp

Source	DF	SS	MS	F	P
Temp	1	383.472	383.472	437.17	0.000
Formula	3	32.327	10.776	12.28	0.000
Interaction	3	2.283	0.761	0.87	0.462
Error	72	63.156	0.877		
Total	79	481.238			

S = 0.9366 R-Sq = 86.88% R-Sq(adj) = 85.60%

Figure 13. Probability plot of absorption of Group 2

4 Conclusion

The chemical composition of sediment soil as shown in Table 1 indicates that its main composition is SiO_2 and Al_2O_3. However, it also contains the fluxing agents, namely, K_2O, CaO, Na_2O which are 2.76%, 0.94%, 0.14%. They take into account for reducing porosity and increasing bending strength of test pieces. Therefore, water absorption and bending strength have showed reducing and increasing of water absorption and bending strength, in Fig. 2,3 and 6,7. Due to reducing porosity, % shrinkage of specimens has been increased when increasing sediment soil, as shown in Fig. 4 and 5.

When recognition on different sintering temperature, it revealed that higher sintering temperature has promoted the higher bending strength, lower water absorption and higher shrinkage of the specimens.

Furthermore, different group of formula materials has given the slightly different properties of test pieces. The effect of replacement sediment soil in Ranong Kaolin clay has promoted the higher bending strength and lower water absorption than replacing in Maethan ball clay. As the effect of Ranong kaolin clay's chemical analysis contains lower fluxing agent than Maethan ball clay and sediment soil.

Because water absorption of vitreous china is less than 1%. The suitable formula of this study is No.2_4 sintering at 1250^{o}C, with less than 1% of water absorption. Its bending strength is higher than the others, which is 9.39 MPa with coefficient of thermal expansion at 6.34x10^{-6} /K at 1000^{o}C. Mixture of this formula is 0% kaolin, 35% ball clay, 30% feldspar, 20% silica sand and 15% sediment soil. It can be concluded that sediment soil can substitue ranong kaolin clay for producing vitreous china ceramics. This means that costs of material producing ceramic products has been decreased (Ranong kaolin clay: 6000 THB/ton) . In addition, the burden of sediment soil diposal of MWA also has been alleviated (20 THB/ton).

However, the future work is to prepare the material for casting the vitreous china and extracting Fe_2O_3 should be performed. If the results of this study can be the commercial products, it may response the customer needs who favors the eco-friendly products.

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