RESEARCH ARTICLE
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Korat Clays as Raw Materials for Lightweight Aggregates

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ABSTRACT: This study assesses the possible use of Korat clays, deposited at Suranaree University of Technology (SUT), for the production of lightweight aggregates. The SUT clays were collected and divided into 2 groups, i.e. white clay and reddish brown clay, to study their heat-treatment behavior. The SUT clay mixtures in various ratios were investigated to find the suitable compositions and heat-treatment (between 1000 and 1250°C) for the production of lightweight aggregates. After firing at 1250°C, the SUT clays expanded 21.05 and 5.70% for the white and reddish brown clays, respectively. Firing expansion was mainly dependent on the amount of SiO_2, fluxing oxides and water of the raw materials. These aggregates are highly impervious to water and exhibit considerable firing expansion, low bulk density (1.29-1.76 g/cm^3) and fair technical properties (unit weight and bending strength) for lightweight concrete. These results encourage the use of these clays for the production of lightweight aggregates.

KEYWORDS: Korat clays, SUT clays, lightweight aggregates, lightweight concrete.

INTRODUCTION

Since steel reinforcement cost influences structure and building costs, the reduction of the structure or building mass is important to reduce steel reinforcement. To reduce the mass or dead weight of a structure, lightweight concrete is used in the construction. The use of lightweight aggregate in concrete can result in a decrease in the cross sections of columns, beams, plates and foundations. Structural lightweight concrete has its obvious advantages of higher strength/weight ratio, higher tensile strain capacity, and a lower coefficient of thermal expansion, as well as heat/sound insulation characteristics due to air voids in the lightweight aggregates[1,2]. Lightweight concrete can easily be produced by utilizing natural lightweight aggregates, i.e. pumice or perlite aggregates.

Lightweight aggregates are defined as materials lighter than water and distinctly more porous than sand, gravel and ground rock, which are commonly referred to as "dense" aggregates[3-5]. An expanded aggregate is formed by quick heating of materials which are able to bloat at high temperature. Sedimentary or very low-grade metamorphic rocks, such as clays or shales, are mostly used for the production of lightweight aggregates[6]. The main constituents of these rocks are mica-illite, kaolinite, smectite and chlorite, along with variable amounts of quartz, feldspars, carbonates, iron oxi-hydroxides and minor amounts of sulfides and organic matter. Iron or calcium compounds are considered to influence the softening and melting temperatures, as well as the bloating, of aggregates[7].

The Korat clay deposits at Suranaree University of Technology (SUT) in Thailand, hereafter denoted as the SUT clays were characterized and studied by monitoring their behavior under heat-treatment[8]. The existing white clay layer and reddish brown clay layer, located about 1-2 feet beneath the surface clay at the SUT deposit, were quite attractive. This deposit is located about 20 km away from the famous Dan Kwian Pottery clay in Chok Chai district, Nakhon Ratchasima, Thailand. The main constituents of these clays are: low quartz, montmorillonite, orthoclase and potassium magnesium silicate. The mixed clays, obtained by randomly mixing the white and reddish brown clays, were shaped into test bars and fired at 600-1200°C. The clays changed their colors to brown after firing at 1200°C due to their iron oxide content (2.63% for the white clay and 5.98% for the reddish brown clay)[8]. They formed hard agglomerates of various sizes. The highest density was reached after heating to 1100°C, due to dehydration and partial melting of the associated minerals. When the temperature was increased to 1200°C, the density and bending strength after firing decreased. The color changed to dark brown with a bloating effect caused by evolution of gases. The fired clay product contained numerous pore sizes. All of these characteristics and behavior of the SUT clays are very promising for the production of lightweight aggregates.

In this study, the white and reddish brown SUT clays were characterized and the heat-treatment behavior of clays mixes in various ratios was studied on a laboratory scale to evaluate their use for the production of lightweight aggregates.

Materials and Methods

Raw Materials

This study was carried on three types of SUT clays selected by visual separation into white, reddish brown and mixtures of the two types in various ratios (reddish brown: white = 90:10, 80:20, 70:30 and randomly mixed). Each clay was ground dry in a jaw crusher, disc milled and washed in a lab blunger. When coarse particles settled down, the fine clay slurry was sieved through 150 mesh, and dried for 24 hours at 100°C. Samples were prepared in cylindrical bars by extrusion for sintering and mechanical testing.

Characterization of the Raw Materials and their Heat-Treatment Behavior

Chemical analysis of these clays was conducted by X-ray fluorescence spectrometry. White and reddish brown clays were fired in an electric furnace at firing temperatures between 1000 and 1250°C with a heating rate of 10°C/min. After firing, 3-point bending strength and % porosity of samples were determined. The mixes of the white and reddish brown clays in various ratios (reddish brown: white = 70:30, 80:20, 90:10) were fired in an electric furnace at the heating rate of 10°C/min. All samples were cooled to room temperature in the furnace. Percent porosity, percent weight loss and percent volume change were evaluated at firing temperatures between 1000 and 1250°C. Porosity was determined by the Archimedes method, ASTM designation C373-72 (reapproved 1982). The volume change was expressed as percent volume change = 100% x $(V_b-V_a)/V_b$, Where V_b is volume of the sample before firing and V_a is its volume after firing.

Preparation of Lightweight Aggregates and Expanded Clay Characterization

The mixed clays were prepared into granules by spraying water onto the mixed clays then sieving. The granules were placed on a refractory plate with an alumina coating and then heated at 1250°C in an electric furnace. The aggregates were screened through 3/4, 1/2, 3/8, 1/4 inch and 4 mesh sieves. The following physical properties were determined on the fired products:

1. Apparent density of aggregates was determined by measuring the weight of the dry aggregate (A), the weight of aggregate suspended in water (C) and the weight of the volumetric flask and water (D). Bulk density of aggregates can be determined from: Bulk density (Apparent) = A / (D+A-C).

2. Percent water absorption of the aggregates was determined by measuring the amount of water which the lightweight aggregate can absorb and was expressed as a percentage of its dry mass. The measurement was carried out after 30 min of total immersion in water at room temperature.

3. Unit weight (loose weight) was carried out by measuring the weight (W) of the loose lightweight aggregates placed in a cylinder of known volume (V). It considered both voids within and between each single grain, and the ratio W/V was expressed in kg/m^3.

Preparation of Lightweight Concrete

The ingredients of lightweight concrete and aggregate size distribution for lightweight concrete are shown in Tables 1 and 2, respectively. Flowability and the compressive strength after 28 days of the lightweight concrete tested were compared to the available lightweight concrete[9].

Table 1. Ingredients for lightweight concrete.

Materials	Volume (%)
Coarse lightweight aggregate	25
Fine aggregate (sand)	46
Cement	22
Water	10-12
Microsilica	7
SMF10*	1

* To adjust flowability.

Table 2. Aggregate size distribution for lightweight concrete.

Size (mm)	% cumulative finer than (by wt.)	
	Coarse lightweight aggregates	Fine aggregates
12.50	100	-
9.50	90	100
4.75	30	85
2.36	10	-
1.18	-	55
0.30	-	10
0.15	-	5

Results and Discussion

Characteristics of the Clays

Chemical analyses of the SUT white and reddish brown clays are shown in Table 3. The difference between the white clay and reddish brown clay is evident

Table 3. Chemical analyses of the SUT clays.

Chemical analysis (%wt)	White SUT clay	Reddish brown SUT clay
SiO_2	71.6	61.2
Al_2O_3	11.6	14.4
Fe_2O_3	2.64	7.48
MgO	1.63	1.90
CaO	0.13	0.21
Na_2O	0.13	0.11
K_2O	4.87	5.60
TiO_2	0.46	0.60
P_2O_5	0.06	0.03
MnO	<0.01	<0.01
Cr_2O_3	<0.01	<0.01
LOI	6.38	9.04
Fluxing *	9.4	15.3
SiO_2/Al_2O_3	6.17	4.25
SiO_2/fluxing	7.62	4.00

*fluxing = Fe_2O_3 +MgO + CaO + Na_2O + K_2O.

considering the chemical composition. White clay has higher silica and lower alumina contents, as compared to the reddish brown clay. However, the white clay has relatively lower iron oxide (2.64%) than the reddish brown clay (7.48%). The iron and calcium components contained in the chemical elements were considered in the so-called fluxing parameter (i.e. the sum of Fe_2O_3+CaO+ MgO +Na_2O+K_2O as in reference 7). Their presence may also influence the softening and melting temperatures, as well as the bloating, of the aggregate. Both samples plotted in the SiO_2/Al_2O_3/fluxing diagram[7,10] fall in the field of bloating materials, as shown in Fig. 1.

Characterization of the Fired SUT Clays

Fig. 2 illustrates the relationship between the apparent porosity and firing temperatures of the SUT clays. When the temperature increased, the apparent porosity of white and reddish brown clays decreased to a minimum at 1200°C. At a firing temperature of

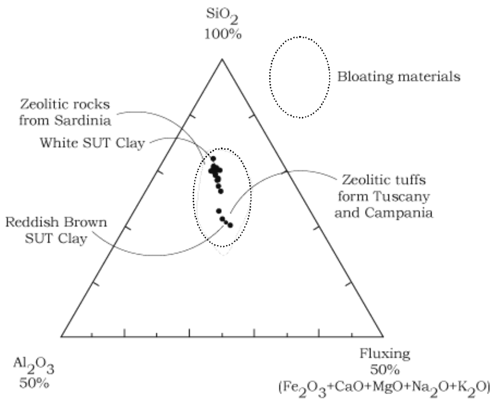

Fig 1. Ternary diagram of bloating materials (dotted field) after Riley, 1969[7]; zeolitic raw materials after de'Gennaro et al., 2004[10].

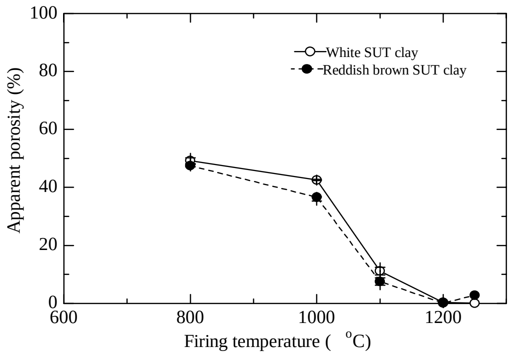

Fig 2. Apparent porosity of the SUT clays after heat-treatment.

1100°C, bending strength increased to 57 and 85 MPa for white and reddish brown clays, respectively, as shown in Fig. 3. With firing above 1100°C, bending strength of both clays decreased. The evolution of gases under heat-treatment above 1100°C was observed by the appearance of increasing porosity for both clays[8].

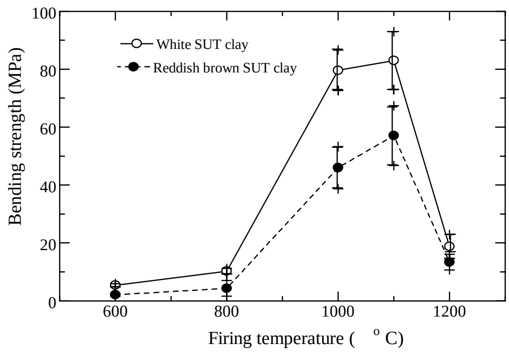

Fig 3. Bending strength of SUT clays after heat-treatment.

The apparent porosity and percent volume expansion of white and reddish brown clays heated at 1250°C are summarized in Table 4. The driving force of volume expansion is essentially the occurrence of thermally unstable or gas-releasing phases[7]. During heating, the evolved gases (e.g. water, carbon dioxide or sulphur dioxide) released from the SUT clays give rise to a porous texture[8]. Beyond 1200°C, the clay expanded by the high temperature phase change,

Table 4. Average physical characteristics of the SUT clays fired at 1250°C.

Clays	% apparent porosity (open pores)	% volume expansion after firing	% weight loss
White clay	0.05	21.05	3.82
Reddish brown clay	2.82	5.70	5.15

including a glassy phase, the presence of which was inferred by XRD analysis. For the SUT clays, this gas is probably represented by water vapor, derived from the dehydration of montmorillonite, and reduction of Fe_2O_3 to liberate oxygen at about 1100°C. The volume expansion was not correlated to the apparent porosity (open pores). This may be because a highly viscous liquid phase at high temperature could entrap the gases and become an external glassy film during cooling, making the outer surface impervious to water. In addition, the correlation between percent volume expansion of the aggregates and the loss of ignition of aggregates (Table 4) has a low significance, suggesting that other factors affect the expansion mechanism. In this phenomenon, the viscosity of the liquid phase formed at high temperature, which basically depends on its chemical composition, played an important role.

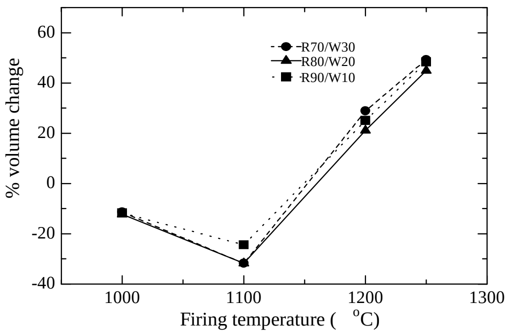

Fig 4. Volume change for the various ratios of mixed SUT clays after heat-treatment.

Characterization of the Mixed SUT Clays

Percent volume change of the SUT clays mixed in various ratios was evaluated at firing temperatures between 1000 and 1250°C. Figure 4 shows that all samples expanded when fired at temperatures up to 1100°C. Percent volume change increased and the water absorption decreased with increasing white SUT clay content, as shown in Figs. 4 and 5. It can be deduced that it is suitable to prepare lightweight aggregates by firing the mixed SUT clays at 1250°C.

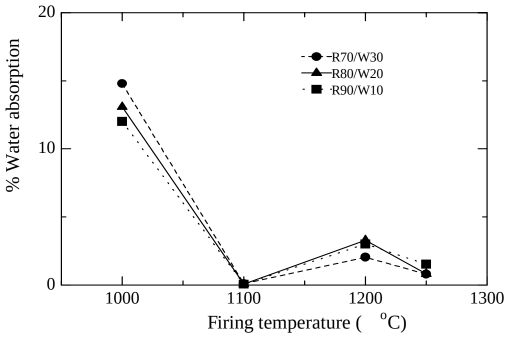

Fig 5. Water absorption for the various ratios of the mixed SUT clays after heat-treatment.

A factor which affected the expansion mechanism is the amount of silica and fluxing elements[10] of clays, which play an important roles in determining the viscosity of the liquid phase formed at high temperature. High silica/fluxing ratios cause a high viscosity of the liquid phase. Consequently, a more viscous body will entrap more gas bubbles, resulting in a more porous and lightweight aggregate. On the other hand, a low SiO_2/fluxing ratio involves a lower melting temperature, which is unable to entrap a significant amount of gas and thus to bloat during firing. This is probably the case of the white SUT clay that has a higher SiO_2/fluxing ratio and more expansion than the reddish brown clay. Bloating depends on the chemical composition and it can be predicted with a reasonable precision on the basis of the loss on ignition, silica/alumina and silica/fluxing ratios of the raw materials.

Physical Properties of the Prepared Lightweight Aggregates and Concrete

Physical properties of the lightweight aggregates which were prepared by firing the various mixed ratios of the SUT clays, were summarized in Table 5. The bulk density of the investigated aggregates is in the 1.29-1.76 g/cm^3 range. By increasing the amount of the white SUT clay, the bulk density of the aggregate is reduced. Any aggregates with dry unit weights of less than 1200 kg/m^3 are defined as lightweight aggregates[9]. In this present study, the aggregates have unit weights in the range of 796 to 1067 kg/m^3. Compressive strength after 28 days of the proposed lightweight concrete was also determined as shown in Table 5. The compressive strengths of the SUT lightweight concretes was higher than that of available lightweight concrete[6].

Conclusion

The SUT clays can actually be used in the production of lightweight aggregates. By increasing the amount of the white SUT clay in the mixture, the volume expansion of aggregates increased and their water absorption decreased. The aggregates prepared at the laboratory scale exhibited bulk density and unit weight values analogous to those of available lightweight aggregates, and the mechanical strength of the lightweight concrete which was made was comparable to the requirements for commercial lightweight aggregates. Bloating depends on the amount of water and silica/fluxing ratio in the SUT clays. The prospect for commercial use is attractive considering both the low cost of raw materials and the simple technology used for the aggregate manufacture.

Table 5. Comparison of physical properties of experimental and available lightweight aggregates. Values for available lightweight aggregates were taken from reference 6.

Aggregates types	Bulk density (g/cm^3)	% water absorption	Unit weight (kg/m^3)	% flowability	Concrete compressive strength (±6 N/mm^2)
R70/W30	1.29	2.11	796	107.14	53.7
R90/W10	1.38	1.83	880	50.00	47.2
Mixed SUT clay (random)	1.76	13.17	1067	128.57	32.7
Foamed slag	-	-	750	-	<40
Leco/Fibo (Expanded clay)	-	-	425	-	<30
Pellite (Blast furnace slag)	-	-	900	-	>40
Liapor (Expanded shale)	-	-	650	-	>40

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