SHORT REPORT
doi: 10.2306/scienceasia1513-1874.2007.33.239

Dan Kwian Clays for Slip Casting

Sirirat Rattanachan*

School of Ceramic Engineering, Suranaree University of Technology, Nakhon Ratchasima 30000, Thailand.

* Corresponding author, E-mail: sirirat.b@sut.ac.th

Received 16 Dec 2005
Accepted 5 Sep 2006

ABSTRACT: In the present study, Dan Kwian clays was characterized and prepared for slip casting. The very high plastic (HP) and mild plastic (MP) Dan Kwian clay was mixed with Ranong kaolin and quartz for preparation of slip casting in various compositions. The relationship between viscosity and the amount of sodium silicate used was determined for these slips in the presence of various compositions. The cast thickness and casting time of slip samples were determined. The results showed that the suitable composition of Dan Kwian slips consisted of HP clay content less than 60% wt of total slip weight. The casting of Dan Kwian slips was achieved within 1 hour. Thus, it is possible to prepare Dan Kwian clay body for slip casting.

KEYWORDS: Dan Kwian; Slip Casting; Clay slips; Nakhon Ratchasima.

INTRODUCTION

Dan Kwian pottery is famous and unique products of Korat or Nakhon Ratchasima Province in Thailand. Dan Kwian village is located in the south-east of Nakhon Ratchasima, 15 km from Amphur Muang. Dan Kwian pottery has special characteristics in shapes, colors and high toughness. Shapes and designs were copied from the traditional way of the 'Kha' tribe who originally lived there. Dan Kwian clay is commonly found near the banks of the Moon River, where it has been worn away or eroded, creating an area of swamp-like deposit. The clay is also well known for its plasticity for forming. After firing, it is not easily broken or deformed in bending. The most special feature is a natural red color which is believed to be due to iron oxide present in the clay. Dan Kwian pottery became one of the major export goods from Korat. For making Dan Kwian body, two types of clay, which are the very high plastic (HP) clay and the mild plastic (MP) clay, are used. The ratio of the HP clay and the MP clay is 2:1. The clay mixture is aged and formed by hand throwing and then dried in the grass huts. The green body is fired in the 900-1300°C range.

Since the characteristics and mechanical properties of the unfired and fired body have not been understood, scraps and loss of production are present. So, the firing behavior of Dan Kwian clays was characterized[1]. The Dan Kwian pottery production is limited and has a low productivity because the shapes and designs are traditional and formed by hand. Slip casting of ceramics offers the possibility of producing complex shapes[2]. Slip casting is the process by which a porous mold, typically made of plaster of Paris, is filled with a slip consisting of a suspension of fine ceramic powders in liquid. As the liquid penetrates the mold, a cast layer is simultaneously formed on the plaster surface. In order to obtain a suitable cast from the slip, a number of parameters affecting rheological properties must be controlled, including clay and deflocculant concentration. In order to make a new design for mass production, it is of interest to fabricate Dan Kwian products, by slip casting.

The aim of this study is to characterize Dan Kwian clay in terms of chemical and particle size analyses. Dan Kwian clay was mixed with quartz and kaolin to prepare clay slips. Deflocculant demand and casting rate of clay slips were determined. Samples were also biscuit fired at 850°C to determine the clay shrinkage.

MATERIALS AND METHODS

Experimental Procedure

Two types of Dan Kwian Clay, which were the highly plastic (HP) clay and the mild plastic (MP) clay, were collected at the location shown in Fig. 1. At point HP (N 14°5′37.2″, E 102°12′ 40.4″), the clay layer is 1-2 meters thick and approximately 1 foot in depth from the surface ground. The HP clay is dark red-brown and very plastic. At point MP (N 14°50′30.8″, E 102°12′ 44.4″), the clay is light red-brown and contains some silt and sand. The clay was dry ground in a Fritsch jaw crusher and disc milled, then washed in a lab blunger. Clay slurries were screened through a 150-mesh sieve, and then clay particles allowed settling down. The settled clay was dried in a plaster block for 2-3 days. The HP and MP clay was sampled for characterization.

In the present work, raw materials to be mixed for

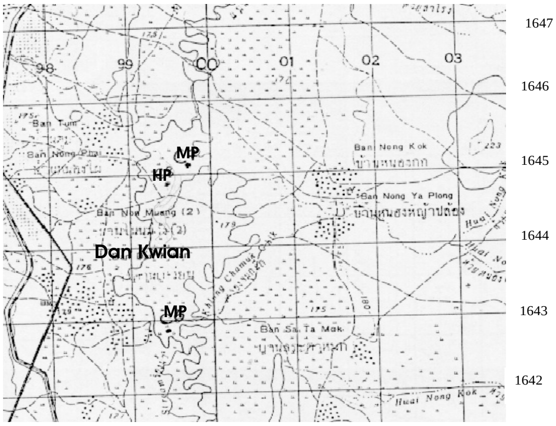


Fig 1. Locality map of HP and MP Dan Kwian samples.

preparing the Dan Kwian clay slip were Ranong kaolin and quartz. Nine Dan Kwian slips, whose compositions are reported in Table 1, were studied. Traditional Dan Kwian slip with 2 parts of HP and 1 part of MP was also prepared for comparison.

Characterization of Dan Kwian clay samples

The particle size analysis was determined using a wet sieve method. The clay slip was prepared and screened through sieves number 120-, 200- and 325-mesh, so giving a plot of the cumulative finer fraction versus the particles diameter. HP and MP Dan Kwian clay was dried at 110°C for 24 h and ground to finer particles for phase and chemical analysis. To identify the phases present in the Dan Kwian clay, an X-ray diffractometer (XRD) with copper radiation and nickel filter was used with a diffractometer D5005 Bruker AXS. Chemical analysis was determined by using X-ray Fluorescence (XRF) Oxford ED 2000. To determine the particle size and shape, HP and MP clay samples were dispersed in water and a small amount of sodium silicate used as a deflocculant. Samples were put in an ultrasonic bath for 30 min to break down the agglomeration of particles. Before observation the clay particles, samples were dropped on the sample holder and coated with gold. Particle size and shape were observed by using scanning electron microscopy (SEM) JSM-6400 JEOL.

Table 1. Composition of Dan Kwian clay slips.

Composition number (DK)	% by wt. HP Dan Kwian Clay	MP Dan Kwian Clay	Ranong Kaolin	Quartz
1	66.6	33.4	-	-
2	70	20	10	-
3	60	30	10	-
4	50	40	10	-
5	50	40	5	5
6	60	30	-	10
7	40	50	10	-
8	30	60	10	-
9	20	70	10	-

Test methods

Raw materials were dispersed in water to obtain slips with gravity of 1.75 g.cm^{-3} and then stirred well. Sodium silicate (Na_2SiO_3) is usually used as a deflocculant[3]. 20 % (w/w) sodium silicate solution was added gradually in this experiment and viscosity of the clay slip was determined by a Brookfield viscometer with spindle no. 3 and speed of 20 rpm after stirring for 15 min. In order to maintain steady the specific gravity of the slip, the clay mixture was added together with the deflocculant.

For casting rate determination, clay slips were poured in plaster molds, and water was sucked out by capillarity leaving a layer of cake on the slip-mold interface. Clay slips were drained from a mold after casting for 5, 10 and 15 min and the casting thickness was measured by a caliper. After casting, the clay was left to dry until it had shrunk sufficiently to enable removal from the mold. The casting time was estimated as a period of time from the draining of excess clay slip to the removal of the casting clay from the mold. The casting samples were dried at 100°C for 24 hours.

The cast samples were fired at 850°C in an electric furnace at a rate of 5 °C/min and soaked at the firing temperature for 30 min. All specimens were cooled to room temperature in the furnace. Shrinkages after drying and firing of the clay samples were estimated as follows:

$$\text{Drying shrinkage} = \frac{(\text{length of sample before drying} - \text{length of sample after drying}) \times 100}{\text{Length of sample before drying}}$$

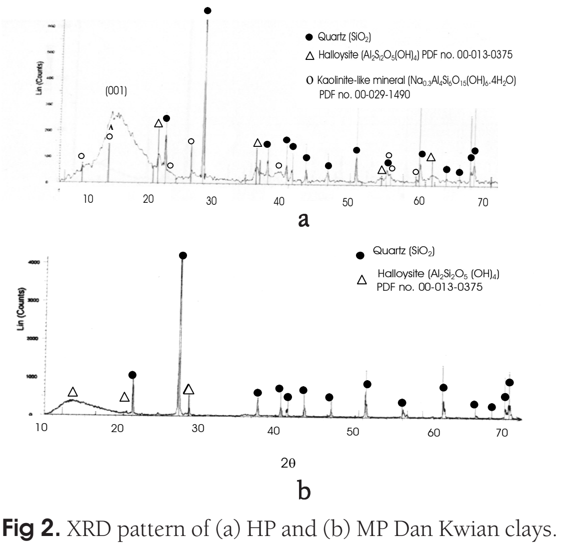


Fig 2. XRD pattern of (a) HP and (b) MP Dan Kwian clays.

Table 2. Chemical compositions of Dan Kwian Clays determined by XRF.

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	MnO	Cr_2O_3	LOI
HP	54.7	21.3	6.63	0.90	0.18	0.21	1.34	0.98	0.05	0.01	0.01	13.8
MP	81.4	7.56	2.91	0.38	0.29	0.80	0.75	0.85	0.04	0.03	0.01	4.72

$$\text{Firing shrinkage} = \frac{(\text{length of sample before firing} - \text{length of sample after firing}) \times 100}{\text{Length of sample before firing}}$$

Results and Discussion

Chemical analysis of the two types of Dan Kwian clay is shown in Table 2. The HP clay has a relatively higher iron oxide (6.63%), a higher aluminum oxide (21.3%) and lower silica (54.7%) content than the MP clay which has 2.91%, 7.56% and 81.4%, respectively. Phase analysis by XRD indicated that Dan Kwian clay consists of mainly quartz plus a kaolinite-like mineral, with a very low structural order, perhaps attributable to halloysite or a very fine-grained and defective kaolinite, as shown in fig. 2. Since a broad X-ray peak is present at around 12° 2θ (001) in the X-ray patterns of the HP and MP clay, it was probable that the HP and MP clay consists of halloysite. Hydrated halloysite ($Al_2O_3.2SiO_2.4H_2O$) structure has random layers shift in both a and b crystallographic directions so that the X-ray pattern is board/diffuse and extremely difficult to interpret. Montmorillonite is characterized by a very pronounced basal peak at around 6° 2θ, that cannot be seen in the XRD patterns.

The particle size distribution of the HP and MP Dan Kwian clays was determined by the wet sieve method, as shown in fig.3. It shows that the particle size of the HP clay is smaller than that of the MP clay. SEM micrographs in fig.4, shows that the HP clay is fine grained and more agglomerated than the MP one. Base on the characterization of the HP and MP clays, phase analysis and particle size distribution, the HP clay is more plastic than the MP one.

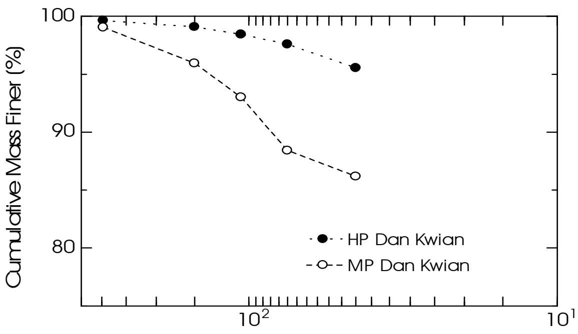
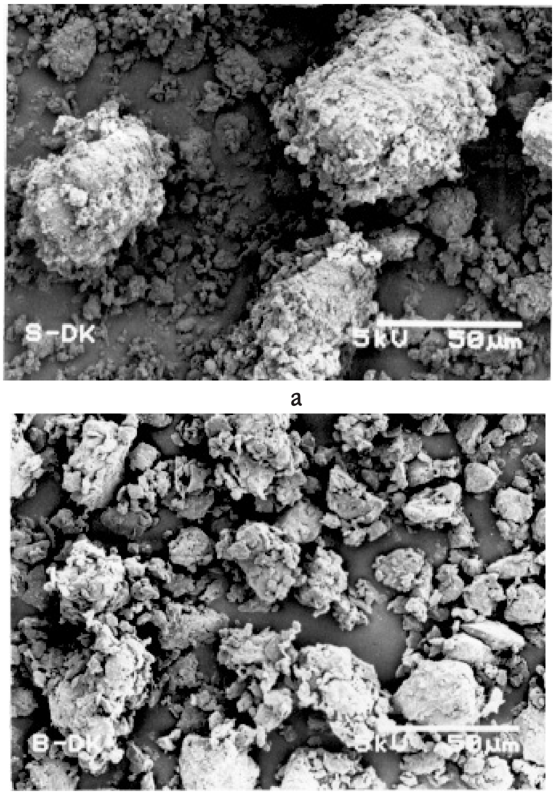


Fig 3. Particle size distribution of HP and MP Dan Kwian clays.



a

b

Fig 4. SEM micrographs of Dan Kwian Clays.
(a) High Plastic Clay (HP), (b) Mild Plastic Clay (MP).

The effect of sodium silicate on viscosity is presented in fig. 5 for the slips with different clay contents. The decrease in viscosity of the slips relates to variations in the particle arrangement caused by the addition of sodium silicate due to the formation of face-to-face contacts. Deflocculant demand was determined by the volume of sodium silicate solution used at the lowest viscosity of a slip sample. After this point, which is known as an over deflocculant point, the viscosity of the clay slip increases again with increasing amount of sodium silicate solution.

As can be seen in fig. 5, a large amount of sodium silicate needs to be added to reach certain viscosity levels for approximately 50% wt. clay concentration loadings. From table 1, slip compositions DK 2, 3, 4, 7,

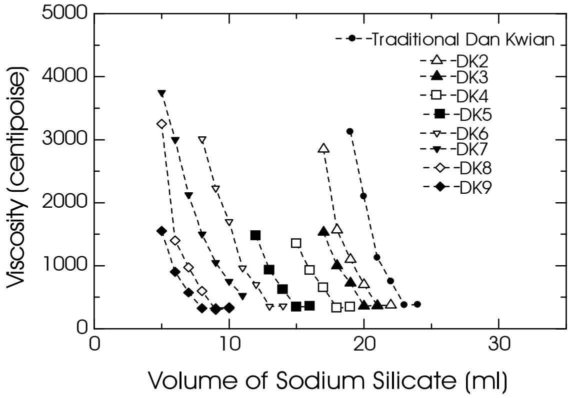


Fig 5. The relationship between viscosity and volume of sodium silicate of various slip compositions.

8 and 9 consist of the same amount of Ranong kaolin content but different amounts of the HP and MP clay. Fine particles clay requires the high deflocculant demand due to high specific surface area of clay particles. As expected in this study, the amount of sodium silicate required to decrease viscosity is much larger in the slips with high HP clay contents than low HP contents, as a result of finer particles and more plasticity of HP clay. DK 3 and DK 6 consist of the same amount of HP and MP clay and 10% by wt of Ranong kaolin and quartz, respectively. The result shows that DK 3 required higher deflocculant demand than DK 6 because of kaolin present in its slip composition. When comparing between DK 4 and DK 5, DK 4 required higher deflocculant demand than DK 5 due to the higher kaolin content (10% wt) in DK 4 composition.

For slip casting, the cast thickness varies with the casting time (table 3). Since the clay platelets tend to align their large plane surfaces with the mould surface, the cast has a low permeability and thus casting is slow with increasing casting time. In addition, the casting rate also depends on the suction pressure generated by the plaster, which depends on the pore size in the plaster mold. In practice, however, the cast product should be removed from the mold within a short time. In this study, the casting time is estimated by a period of time from the draining of excess clay slip to the removal of the cast clay from the mold. By decreasing the HP Dan Kwian content in the clay slips, the cast thickness and casting time decreased with the compositions DK 6, 7, 8 and 9 (Table 3)

Drying and firing shrinkage of slip samples (fig. 6) decrease from compositions DK 6 to DK9. It can indicate that the clay slips with low HP clay contents have low drying and firing shrinkage. On the basic of the deflocculant demand and the viscosity of clay slip, compositions DK 6, 7, 8 and 9 are suitable for preparation of the Dan Kwian slips.

Conclusion

The Dan Kwian clay is famous for the earthenware products of Nakhon Ratchasima. This clay was prepared and mixed with Ranong kaolin and quartz for slip casting. The deflocculant demand of clay slips was in the range of 0.14-0.24 % (w/w) sodium silicate in the clay slip. The cast thickness increased when the amount of the HP Dan Kwian clay increased in the composition. Casting of the Dan Kwian slips was accomplished in shorter times (50-60 min) by decreasing the HP clay content in the slip composition. In this study, the slip compositions DK 6, 7, 8 and 9 were found to be suitable for slip casting.

Acknowledgements

Author would like to thank Associated Professor Charussri Lorprayoon for her advice and discussion and special thank to Suranaree University of Technology, Thailand for raw materials and equipment supports.

Table 3. Slip properties of the clay samples.

Composition	Deflocculant demand (% wt)	Cast thickness (mm)			CastingTime# (min)
		5 min	10 min	15 min	
Traditional	0.42	2.20	2.65	3.10	170
DK 2	0.39	2.10	2.60	2.94	150
DK 3	0.37	2.00	2.35	2.75	120
DK 4	0.33	1.35	1.90	2.45	75
DK 5	0.27	2.05	2.90	3.70	50
DK 6	0.24	1.80	2.20	2.65	60
DK 7	0.24	1.60	2.10	2.50	50
DK 8	0.16	1.90	2.40	2.70	50
DK 9	0.14	1.70	2.50	2.70	41

Casting time = a period of time from the draining of excess clay slip to the removal of cast clay from the mold.

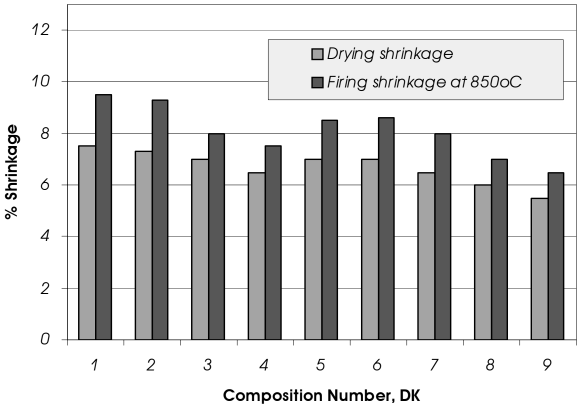


Fig 6. Drying and Firing shrinkage of various slip compositions.

References

1. Rattanachan S. (2002) Characterization of Nakhon-Ratchasima Clays for Ceramic Applications. *Research report*, Suranaree University of Technology, Thailand.
2. Hampton J.H.D., Savage S.B., Drew R.A.L. (1988) Experimental analysis and modeling of slip casting. *J. Am. Ceram. Soc.*, **71(12)**, 1040-5.
3. Ryan W. and Worrall W.E. (1961) Casting experiments with fire clays. *Br. Ceram. Soc. Trans.* **60**, 540-55.