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Application of Metakaolin from Northeast of Thailand Used as Binder in Casting Process of Rice Polishing Cylinder

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Abstract**—**The objective of this research was to apply metakaolin from northeast of Thailand as a binder in the casting process of rice polishing cylinder in replacement of the imported calcined magnesite cement and to reduce the production cost of the cylinder. Metakaolin was obtained from three different regions (Udon Thani, Nakhon Phanom, and Ubon Ratchathani). The design of experiment analysis using the MINITAB Release 14 based on the compressive strength and tensile strength testing was conducted. According to the analysis results, it was found that the optimal proportions were calcined magnesite cement: metakaolin from Udon Thani, Nakhon Phanom and Ubon Ratchathani equal to 63:37, 71:29, and 100:0, respectively. When used this formula to cast the cylinder and test the rice milling, it was found that the average broken rice percent was 32.52 and 38.29 for the cylinder contained the metakaolin from Udon Thani and Nakhon Phanom, respectively, which implied that the cylinder which contained the metakaolin from Udon Thani has higher efficiency than the cylinder which contained the metakaolin from Nakhon Phanom at 0.05 level of statistical significance. Whereas, the average wear rate of cylinder from both resources were 7.27 and 6.53 g/h, respectively.

Keywords**—**Binder, casting, metakaolin, rice polishing cylinder.

I. Introduction

IN the last decades, rice milling machine have been used as the agriculture based machinery for Thai agriculturists. Currently, a small rice milling machine which has capacity as 1-2 ton per day is widely used by agriculturists since a small rice milling machine uses less production time and more convenient to use in household. Normally, a small rice milling machine has two different types: vertical axle and horizontal axle. Generally, the horizontal axle which is driven by electric motors is extensively used because it has low price and it can be easily purchased locally. The quality of peeled rice depends on several factors such as types of paddy, grain shape and size, paddy moisture content, and processes of shelling and polishing [1]. The process of rice polishing is an important step and the percentage of good peeled rice rely on the quality of rice polishing cylinder [2]-[4]. In general, the rice polishing cylinder consists of two composite materials which are abrasive material and binder material [5]. The abrasive material consists of the emery grain stone and silicon carbide. The binder material comprises calcined magnesite cement and magnesium chloride.

Nowadays, calcined magnesite cement was imported from abroad around 5,268 tons per year, that cost an average of 89 million baht per year [6]. In order to minimize the amount of the imported calcined magnesite cement, using the domestic pozzolan material which is an agricultural waste such as rice husk ash, bagasse ash, and metakaolin as a part of binder material can reduce the production cost and improve the desired properties of the rice polishing cylinder [7]-[10]. Boonkang et al. [11] have applied pozzolan material used as binder in the casting process of rice polishing cylinder by using a natural pozzolan materials which were rice husk ash, bagasse ash from the northeast, and metakaolin from the north of Thailand. These pozzolan materials were replaced the imported calcined magnisite cement in the ratio of 40 percent. The experimental results revealed that the suitable proportion was rice husk ash:bagasse ash:metakaolin as 15:25:60. When applied this proportion to cast the rice polishing cylinder, it found that average broken rice percent was 19.88 and average wear rate was 4.43 g/h, while the rice polishing cylinder made from only an imported binder had average broken rice percent as 23.98 and average wear rate as 7.02 g/hr. Therefore, the pozzolan rice polishing cylinder has polishing efficiency better than the imported binder rice polishing cylinder. From this study, it also found that metakaolin from the north of Thailand had the highest replacement ratio of pozzolan material. In addition, Ding and Li [12] studied the effects of metakaolin and silica fume on the properties of concrete. This work found that the concrete mixed with metakaolin has better performance than the concrete mixed with silica fume and had higher hardness. The optimal ratio was concrete: metakaolin equal to 85:15 which yielded the greatest compressive strength. Courard et al. [13] studied the durability of concrete replacement by metakaolin at 5-20 percent in terms of their chemical property and behavior. When immersed the metakaolin-concrete in the chloride and sulfate solution for 100 days, this study found that metakaolin decreased the diffusion rate of chloride and sulfate in the concrete. The suitable proportion replacement ratio was around 10-15 percent. Khater [14] studied the influence of metakaolin resistance to magnesium chloride of concrete mortar. The

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proportion of metakaolin replaced the concrete mortar by 0, 5, 10, 15, 20, 25, and 30%. After heating the mixture at 820 °C for two hours, the testing results showed that the resistance to magnesium chloride increased as the amount of metakaolin increased. The optimal ratio of metakaolin at 25% replacement has maximum compressive strength.

From the literature reviews, it was found that metakaolin can be used as a binder replacement with the original binder materials in many applications. In order to minimize the overall production cost of the rice polishing cylinder [11], all binder materials should be brought from the local production area to reduce the transportation costs and promote the local resources. Therefore, the main objective of this research is to determine the optimal formulas of metakaolin from northeast of Thailand as a binder in the casting process of rice polishing cylinder replacing the imported calcined magnesite cement resulting in the lower production cost and lower the imported value.

II. Experimental Procedures

A. Material Preparation and Equipment

1) Control factors were metakaolin and calcined magnisite cement. Metakaolin was baked at 800 °C around six hours in an electrical furnace. After that, it was mashed and screened by the sieve size 325 following the ASTM C618 standard.
2) Metakaolin was collected from three local sources; Udon Thani, Nakhon Phanom, Ubon Ratchathani.
3) The casted specimen and the casted rice polishing cylinder used the same proportion of abrasive material: binder material as 5:1. The horizontal axle rice milling machine was used to test the rice milling.
4) Rice for testing was Jasmine Rice 105 (Industrial standard 888-2532) and paddy moisture content was controlled not to be exceed 14%, and all scraps were removed. Each testing batch consisted of 20 kilograms of Jasmine Rice.
5) MINITAB Release 14.00 program was used to evaluate the experimental results and design of experiment (DOE) by Mixture Design function. In addition, the response surface method was applied to identify the suitable proportion of metakaolin.

B. Design of Experiments

The experiment was separated into two parts.

1) Determine the suitable proportion of metakaolin material based on the compressive strength and tensile strength. Then, the suitable proportion was used to cast the rice polishing cylinder.
2) Test the rice mill efficiency of each metakaolin cylinders and the imported calcined magnesite cement cylinder based on the broken rice percent and the wear rate values. All cylinders used the proportion of abrasive materials: binder material as 5:1.

According to the mixture design function, five formulas for compressive strength and tensile strength of each metakaolin sources were generated as shown in Table I.

TABLE I
Proportion of Metakaolin From DOE

No	Composite Material		
	Calcined Magnesite Cement (gram)	Metakaolin (gram)	Abrasive Material Constant (gram)
1	50	50	500
2	75	25	500
3	0	100	500
4	25	75	500
5	100	0	500

III. Implementation and Results

B. Results of Suitable Metakaolin Proportion from 3 Sources

MINITAB Release 14.00 program had Response Optimizer function to find the right value of the factors which was the best value of the set of experiment. The researcher had chosen to use desirability function to determine the suitable factor. In this step, the response target must be identified including the lower level, the target and the upper level as well as weight of response and the significance of response. In this research, the weight and significance of response was 1 to focus the response near the target and it must be within certain limits. In addition, the ranges of response in terms of compressive strength and tensile strength were chosen closed to the average compressive strength and tensile strength of original binder [3] which was the average compressive strength at 23 MPa with the lower level at 20 MPa and upper level at 26 MPa, whereas the average tensile strength was at 4 MPa with the lower level at 3 MPa and upper level at 5 MPa.

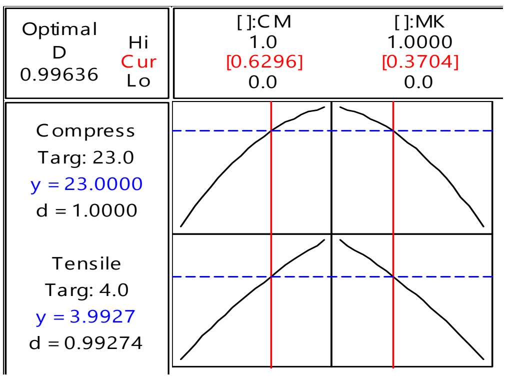

Fig. 1 Optimal proportion of Udon Thani metakaolin

After evaluating all testing data including both compressive strength results and tensile strength results from each metakaolin source, it was found that the optimal formula was calcined magnesite cement: Udon Thani metakaolin was equal to 0.6296:0.3704 as shown in Fig. 1 or roughly around 63:37 percent. This proportion yielded the compressive strength as 23 MPa, the satisfaction as 1, the tensile strength as 3.9927 MPa, and the satisfaction as 0.99274. The overall satisfaction as 0.99636 was near the target value of 1, which implied that this formula was reasonable to cast the rice polishing cylinder. Furthermore, it was also found that the optimal formula was calcined magnesite cement: Nakhon Phanom metakaolin equal to 0.7110: 0.2890 as shown in Fig. 2 or roughly around 71 :29 percent. This proportion yielded the compressive strength as 22.7363 MPa, the satisfaction as 0.91211, the tensile strength as 4.2718 MPa, and the satisfaction as 0.72824. The overall satisfaction as 0.81501 was near the target value of 1, which implied that this formula was reasonable to cast the rice polishing cylinder.

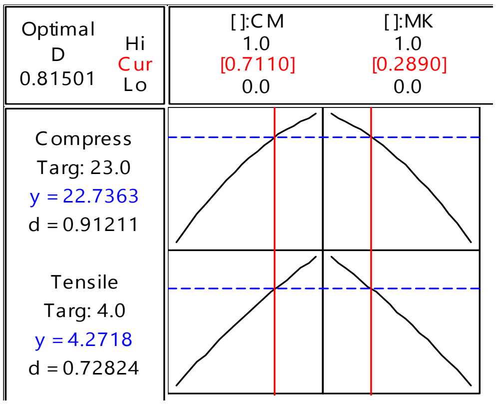

Fig. 2 Optimal proportion of Nakhon Phanom metakaolin

Lastly, it was also found that the optimal formula was calcined magnesite cement: Ubon Ratchathani metakaolin equal to 1.0: 0 as shown in Fig. 3 or roughly around 100:0 percent which implied that Ubon Ratchathani metakaolin cannot completely replaced the calcined magnesite cement. This proportion yielded the compressive strength as 23.6331 MPa, the satisfaction as 0.78895, the tensile strength as 3.9066 MPa, and the satisfaction as 0.90562. The overall satisfaction as 0.84528 was near the target value of 1.

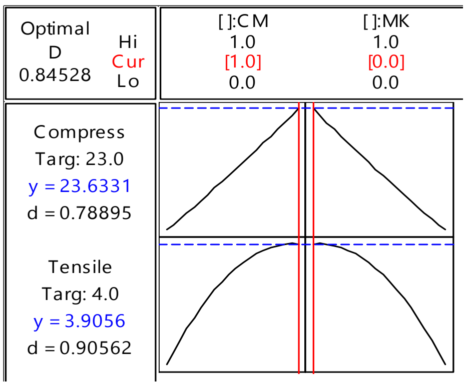

Fig. 3 Optimal proportion of Ubon Rathathani metakaolin

C. Testing Result of Rice Mill Efficiency

The rice mill efficiency of each metakaolin source was compared based on the broken rice percent after rice milling and the wear rate of the cylinder. T-test function was used to analyse and evaluate the efficiency of each cylinder at the significance level of 0.05. Each optimal proportion between the calcined magnesite cement and metakaolin from each source was used to prepare three pieces of the casted rice polishing cylinder. The rice milling testing results revealed that Udon Thani metakaolin cylinder had an average broken rice percent of 32.52 which was lower than that of Nakhon Phanom metakaolin cylinder which had an average broken rice percent of 38.30 as shown in Fig. 4.

Two-sample T-Test for Udon Thani (UD) Cylinder vs Nakhon Phanom (NP) Cylinder

	N	Mean	StDev	SE Mean
UD Cylinder	9	32.52	1.56	0.52
NP Cylinder	9	38.30	2.04	0.68

Estimate for difference: -5.77778
95% CI for difference: (-7.61501, -3.94054)
T-Test of difference = 0 (vs not =): T-Value = -6.74
P-Value = 0.000 DF = 14

Fig. 4 Comparison of average broken rice percentage

When wear rate of the rice polishing cylinder was taken into account, it was found that the average wear rate of Udon Thani metakaolin cylinder was 7.271 g/h which is slightly higher than that of Nakhon Phanom metakaolin cylinder which has average wear rate as 6.526 g/h as shown in Fig. 5.

Two-sample T-Test for UD Cylinder vs NP Cylinder

	N	Mean	StDev	SE Mean
UD Cylinder	9	7.48	1.87	0.62
NP Cylinder	9	6.52	1.54	0.51

Estimate for difference: 0.960000
95% CI for difference: (-0.761171, 2.681171)
T-Test of difference = 0 (vs not =): T-Value = 1.19
P-Value = 0.253 DF = 15

Fig. 5 Comparison of average wear rate

TABLE II
EFFICIENCY EVALUATION OF RICE POLISHING CYLINDER

Detail	Nakhon Phanom Rice Polishing Cylinder	Udon Thani Rice Polishing Cylinder	Imported Binder Rice Polishing Cylinder
Average broken rice percent	38.30	32.52	26.65
Average rice mill time per rice 20 kg	43	36	53
Average wear rate	6.53	7.27	5.26
Average mill rice percent	67.5	68	60.32
Cost of material (baht)	988	984	1,016

Table II represents the rice mill efficiency criteria between rice polishing cylinder made from imported binder and cylinder made from the mixture between the imported binder and metakaolin from Udon Thani and Nakhon Phanom.

IV. CONCLUSIONS

1) When brought metakaolin from three different sources which were Udon Thani, Nakhon Phanom and Ubon Ratchathani for casting the testing specimens and then

mechanical properties testing based on the compressive strength and tensile strength, the optimal formulas of calcined magnesite cement: metakaolin from Udon Thani, Nakhon Phanom and Ubon Ratchathani as 63: 37, 71: 29 and 100: 0, respectively, were obtained.

2) The optimal proportions which were successfully predicted from the response optimizer function were used to cast and test the rill milling, Udon Thani metakaolin cylinder had higher efficiency than Nakhon Phanom metakaolin cylinder, whereas both types of metakaolin cylinder had the average wear rate which was not statistically significant at 0.05.
3) Metakaolin from northeast of Thailand can replace the imported calcined magnesite cement around 30-40 percent resulting in the reduction of overall imported cement cost around 27 - 36 million baht per year.
4) By adding others types of pozzolan materials such as rice husk and ash bagasse could improve the mechanical properties of Ubon Ratchathani metakaolin rice polling specimens.

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