



## INVESTIGATION OF OPTIMAL PARAMETERS FOR LIMESTONE MILLING PROCESS IN MORTAR PRODUCTION

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### บทคัดย่อ

ปูนซีเมนต์มอร์ตาร์ได้รับการพัฒนาเพื่อใช้กันอย่างแพร่หลายในอุตสาหกรรมก่อสร้างวัตถุดิบสำคัญที่ใช้ในการผลิตปูนคือทราย กระบวนการบดเป็นกระบวนการหนึ่งของการผลิตเพื่อลดขนาดของหินปูนเป็นทรายให้ได้ขนาดตามที่ต้องการ (ขนาด 0.1-0.6 มม.) ส่วนที่เหลือจะเป็นผงหรือฝุ่นละเอียดที่มีขนาดเล็กกว่า 0.1 มม. อาจเป็นมลภาวะทางอากาศ ซึ่งจำเป็นต้องมีการจับเก็บและกำจัดต่อไป การศึกษานี้จึงได้ทำการทดลองหาค่าพารามิเตอร์ที่เหมาะสมที่สุดของเครื่องบดแบบลูกกลิ้งแนวตั้งเพื่อปรับปรุงการบดให้สามารถเพิ่มสัดส่วนของทรายที่ได้ขนาดและลดปริมาณผงหรือฝุ่นละเอียดลง จากผลการทดลองได้ค่าที่เหมาะสมของพารามิเตอร์สำหรับการปรับตั้งเครื่องบดแบบลูกกลิ้งเป็นดังนี้ อัตราป้อนวัตถุดิบ 130 ตันต่อชั่วโมง แรงอัดบด 103 บาร์ ความเร็วในการหมุนของโต๊ะ 9.5 รอบต่อนาที และอัตราการดูดผงละเอียด 37,838 ลบ.ม./ชั่วโมง ทำให้สัดส่วนของทรายเพิ่มจาก 62.91% เป็น 77.34% คิดเป็นผลผลิตเพิ่มขึ้น 14% ในขณะที่สัดส่วนของผงละเอียดลดลงจาก 37% เป็น 14.80%

คำสำคัญ: กระบวนการบดหินปูน; อุตสาหกรรมปูนซีเมนต์; การผลิตปูนมอร์ตาร์; เครื่องบดแบบลูกกลิ้งแนวตั้ง

### ABSTRACT

Mortar cement has been developed for widespread use in the construction industry. One of the important raw materials used in the mortar production is sand. Milling process was once used to digest aggregated limestone to produce sand of the desired size (0.1-0.6 mm), with the residue being a significant volume of powder smaller than 0.1 mm. The powder or fine dust can pollute the air, interrupt the milling process, and necessitate storage and removal of the powder. The optimal set parameters of the vertical roller mill were investigated in this study to improve the limestone milling operation, increase the desired sand, and decrease powder. According to the experimental results, the estimated values of parameters reflected that feed rate of raw material at 130 tons per hour, milling pressure 103 bar, table rotating speed 9.5 rpm, and fine dust suction rate at 37,838 m<sup>3</sup>/h could increase the proportion of sand from 62.91% to 77.34%, implying productivity risen by 14% while the proportion of the percentage of fine powder decreased from 37% to 14.80 %.

**KEYWORDS:** Limestone Milling Process; Cement Industry; Mortar Production; Vertical Roller Mill

## 1. Introduction

The cement industry plays a significant role in the country's growth, especially in terms of construction, buildings, and transportation. Thailand has a cement industry that is considered a large heavy industry, with a combined annual production capacity of 60,155 thousand tons [1]. One of the cement products produced to meet the needs of the construction industry is "Mortar."

The milling of limestone with a diameter of 20 mm as a raw material to manufacture a grain of sand with a diameter of 0.1-0.6 mm is the first step in the mortar development process.

Sand is a key component that improves the workability and durability of concrete by increasing the density of the mortar structure [2]. Sand with a diameter of less than 0.1 mm will be viewed as powder residue and will need to be washed. The dust problem is polluting and endangering public health. It is imperative to take responsibility for these issues by enhancing the mortar manufacturing process to reduce powder residue.

In general, the cement production process begins with crushing coarse rocks from limestone mines to smaller limestone, then it goes through a milling process to be smaller sand according to the characteristics of the desired product. In the case study mortar production, a vertical roller mill produces sand (0.1-0.6 mm.) as shown in Figure 1. Figure 2 states those of aggregated limestone, smaller sand, and powder.

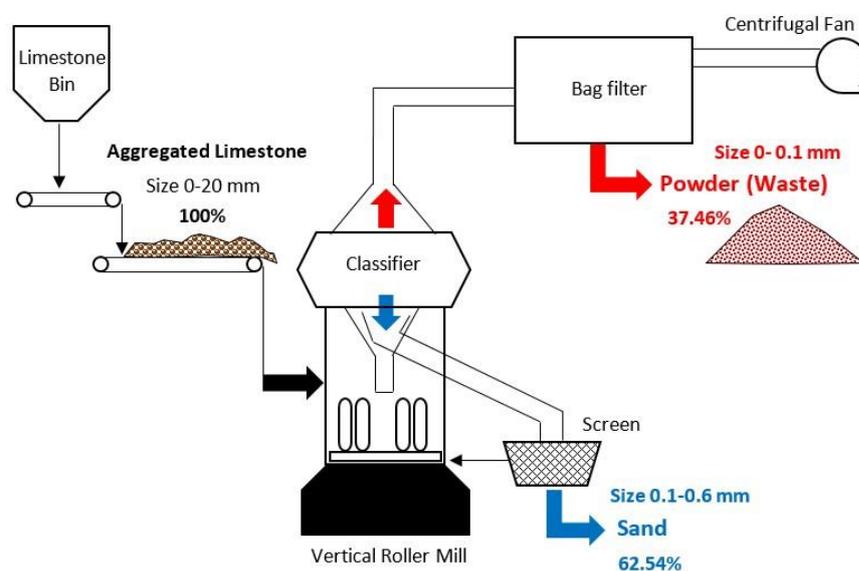
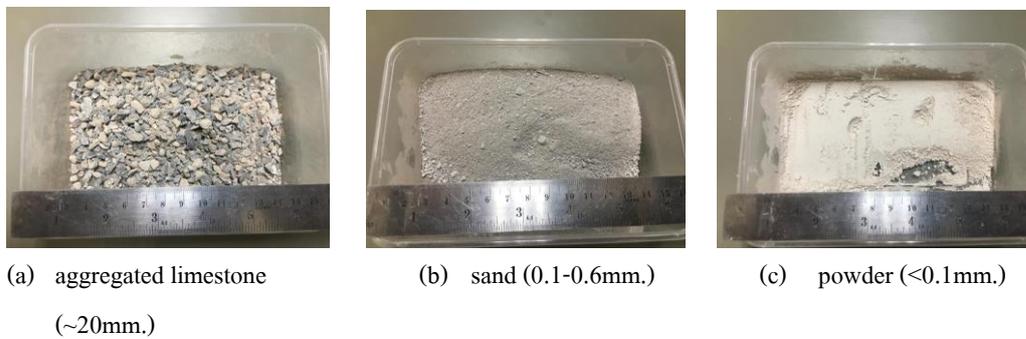


Figure 1 Milling process in mortar production

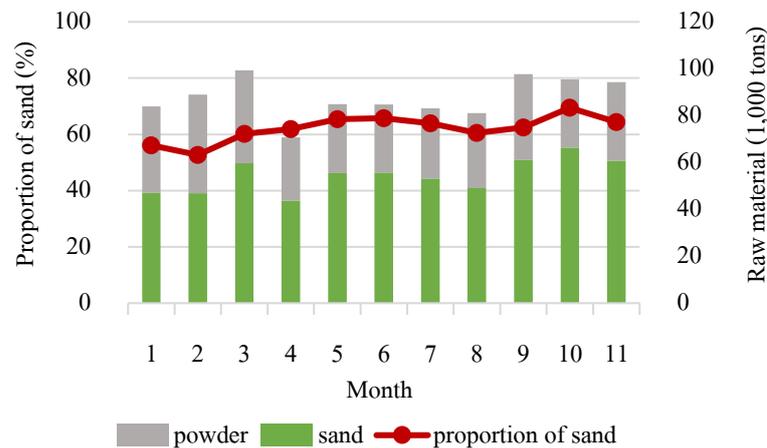
According to statistics of the mortar production, as shown in Figure 3, it was found that the proportion of smaller sand to aggregated limestone was 63%. The remaining was powder residue that disrupted the milling operation and cost to remove the clutter of powder residue from the storage area to other places. Moreover, the environment was affected by the transportation of powder residue. As a result, enhancing the limestone milling process is what that should be pursued. The objective of this

research was to set the parameters of the limestone roller milling process in order to produce more proportion of smaller sand and reduce the proportion of powder residue.



**Figure 2** Aggregated limestone, sand, and powder

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**Figure 3** Statistical data of the proportion of sand and dust in the milling process (2019)

## 2. Vertical roller mill and parameters of the milling process

The vertical roller mill is widely used in mineral reduction processes, especially in the cement industry [3]. Typically, a vertical roller mill consists of 2-4 fixed rollers and rotating table diameters ranging from 1.5-7.5 meters depending on the

suitability of the industry [4]. This research used the roller mill, which consisted of 4 rollers and a rotating table with a diameter of 5.5 m., to reduce the size of limestone in the mortar production. In the milling process, the limestone was reduced by 3 mechanisms: abrasive, shear, and compression [5].

The vertical roller mill is automatically operated as shown in Figure 4. It can be divided into 2 main functions: milling and separating starting from feeding raw material, aggregated limestone with a conveyor system that can control the feed rate, then the raw material falls to the center of the rotating table that can adjust the rotating speed. While milling with a roller on the rotating table, milling pressure comes from the hydraulic system. At the same time, the suction air from the centrifugal fan pulls the milled raw material to the classifier to separate it from powder [6]. As for the vibrating screen (6 mm. sieve hole) and separate it into sand and powder. The parameters of the milling process include feed rate, milling pressure, rotating speed, and fan speed.

As mentioned above, the initial parameters of the milling process in this study consisted of the feed rate of raw material, milling roller, rotating speed, and suction rate.

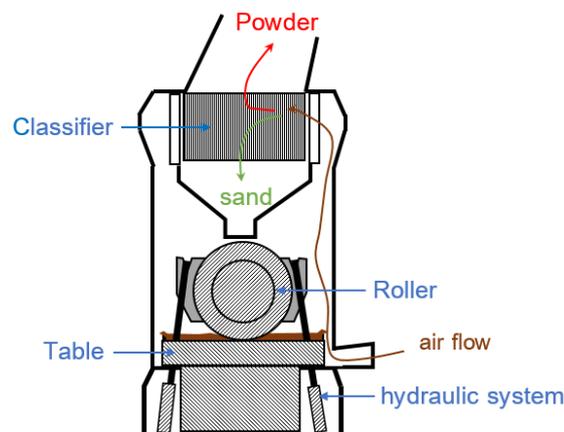


Figure 4 Vertical Roller Mill

The vertical roller mills were also used in the milling process of gold ore [6] and iron ore [7], which found that milling pressure had a significant effect on the production rate and material size. If the milling pressure was too high, it could vibrate and increase the wear of the table liner [8].

Ghalandari, et al. [9], described milling pressure that the compressive force of the roller pressed on the rotating table is an important parameter influencing the grinding performance of a vertical roller mill. Increasing milling pressure would improve the material fineness.

For the case of coal material, the research found that table speeds respond to the grinding when the material was ground under the pressure between the table and the roller for a long period, or a long retention time, the material could be finer [10]. Also, the flow rate in a vertical roller mill had a direct influence on the proportion of raw materials circulating in the sizing

equipment and reverted to the grinding process in a vertical roller mill [11]. The roles and functions of suction flow rate were drying, transporting, and classifying material [8].

### 3. Methodology

The central composite design (CCD) was used for an experimental design in this research to investigate four factors or parameters of the milling process. Each factor had 3 levels: low, medium, and high. The experiment was repeated 3 times. The experimental procedure is shown in Figure 5.

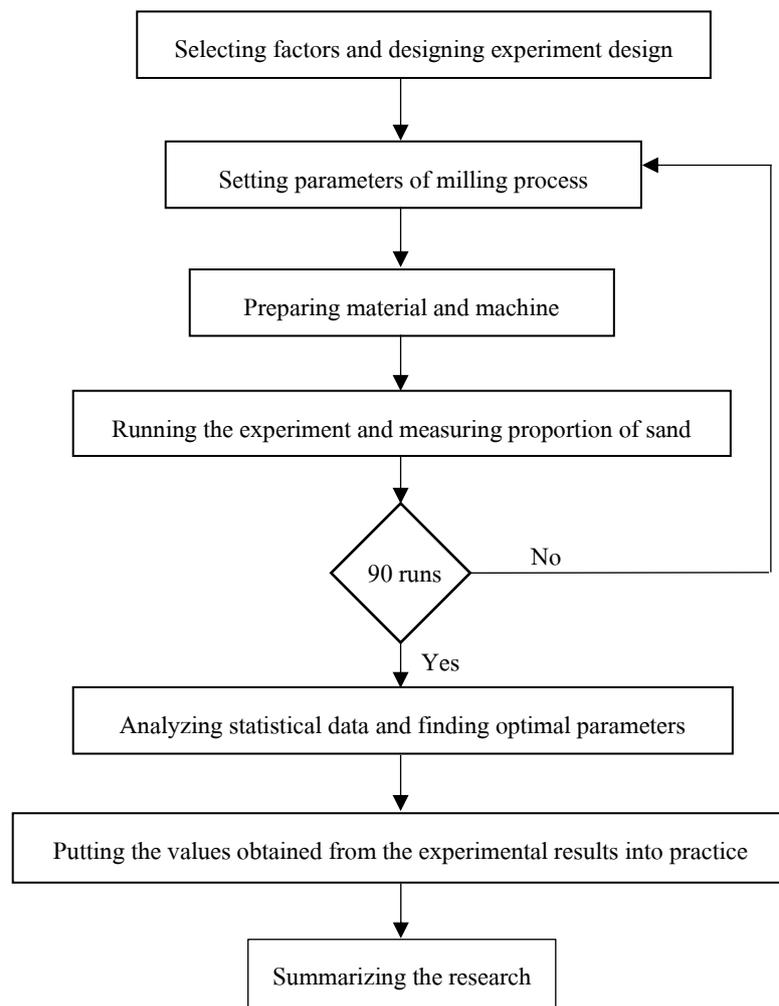


Figure 5 Research flowchart

Therefore, a total of 90 experiments were performed. After the experiments were completed, the proportion of sand was analyzed to determine the relationship of factors and to determine the optimal parameters that resulted in the highest proportion of sand by statistical methods. Finally, the parameters obtained were used for actual production to verify the results and draw a conclusion.

### 3.1 Factors

The factors of the central composite design experiment consisted of the feed rate of raw material (A), milling pressure (B), table rotating speed (C), and suction rate (D)

Feed rate is the amount of mixed stone that is fed to the milling process by the conveyor belt. In the case study, the feed rate could be adjusted with an automated command system from the control room. The feed rate in the production process varied from 130 ton/h to 150 ton/h. Therefore, the mean feed rate to be used in this experiment was 140 ton/h.

Milling pressure is the hydraulic pressure that pulls the roller to press against the raw material on the rotary plate, which can adjust the pressure through the operation of the pressure control valve, the minimum pressure that can be adjusted is 100 bar. The medium and high milling pressures to be used in this experiment were 110 bar and 120 bar, respectively.

Table speed is the speed of the turntable driven by a motor through a gear. In the past, the speed was set at 11.9 rpm. In this study, this parameter was set from 9.5 to 14.3 rpm.

Suction rate is the amount of air flowing inside the mill to convey the crushed material to the size sorting device. The air volume was controlled from 34,000 m<sup>3</sup>/h to 38,000 m<sup>3</sup>/h.

### 3.2 Response variables

The response variables were the proportion of sand produced by the milling process and its quantity by weights. This proportion of sand came from the weight of sand produced (tons per hour) divided by the weight of limestone (tons per hour) fed into the milling process. The sand quantity was measured with a calibrated weighing scale that was equipped at a fixed conveyor speed of 1.33 m/s. The calibration of belt scales is performed using a pendulum standard weight comparison, also known as the simulation measurement method with static load [12], which is normally very effective when used with balances in which belt without change in speed and position of the load point.

## 4. Results

### 4.1 Factors affecting the proportion of small sand

From Table 1, at feed rate 130 ton/h, milling pressure 100 bar, table rotating speed 9.5 rpm, and suction rate 38,000 m<sup>3</sup>/h, the average sand proportion was the most likely of all conditions that were tested, 78.95%, followed by feed rate 130 ton/h, milling pressure 100 bar, table rotating speed 14.3 rpm and suction rate 38,000 m<sup>3</sup>/h, the sand proportion was 71.97%. Overall, it can be seen that increasing the rotation speed would reduce the sand ratio by 5 to 10%.

**Table 1** Results of the experiment

No.	Feed rate [A] (ton/h)	Milling pressure [B] (bar)	Table rotating speed [C] (rpm)	Suction rate [D] (m <sup>3</sup> /h)	Average proportion of sand (%)
1	130	100	9.5	34,000	61.69
2	130	100	9.5	38,000	78.95**
3	130	100	14.3	34,000	59.90
4	130	100	14.3	38,000	71.97
5	130	120	9.5	34,000	66.15
6	130	120	9.5	38,000	66.00
7	130	120	14.3	34,000	68.41
8	130	120	14.3	38,000	63.85
9	150	100	9.5	34,000	53.49
10	150	100	9.5	38,000	65.96
11	150	100	14.3	34,000	58.36
12	150	100	14.3	38,000	58.09
13	150	120	9.5	34,000	51.73
14	150	120	9.5	38,000	60.80
15	150	120	14.3	34,000	53.67
16	150	120	14.3	38,000	61.13
17	130	110	11.9	36,000	68.67
18	150	110	11.9	36,000	62.07
19	140	100	11.9	36,000	66.24
20	140	120	11.9	36,000	59.79
21	140	110	9.5	36,000	69.14
22	140	110	14.3	36,000	66.98
23	140	110	11.9	34,000	60.62
24	140	110	11.9	38,000	65.24
25	140	110	11.9	36,000	68.74
26	140	110	11.9	36,000	68.00
27	140	110	11.9	36,000	67.64
28	140	110	11.9	36,000	68.38
29	140	110	11.9	36,000	68.31
30	140	110	11.9	36,000	67.64

The results of variance analysis using Minitab19 are shown in Figure 6. The feed rate (A), milling pressure (B) and suction rate (D) were found to have p-values below 0.05, thus implying that these three factors had a significant effect on the sand proportion at the 95% confidence level, while the table rotating speed (C) had a p-value of 0.055, so it had no effect on the sand proportion at the 95% confidence level.

Moreover, the interaction between milling pressure and table rotating speed had a significant effect on the sand proportion (p-value = 0.014). This means that the centrifugal force generated by the table rotating speed would lead the limestone moving into the area under the roller, where the table rotating speed would affect the sand proportion under the milling pressure.

The interaction was found between milling pressure and suction rate (p-value less than 0.05), and may affect the proportion of sand. When the suction rate is insufficient to carry some limestone up to classifier, this limestone is crushed again, which may produce more fine powder or less sand.

For the interaction between milling pressure and suction rate, the p-value is less than 0.05, thus affecting the sand ratio at 95% confidence level. Since the table rotating speed and suction rate are the factors that control the direction of motion of the limestone in the milling chamber. The rotating table would cause the limestone to move horizontally, but the suction rate would cause the limestone to move vertically. Both of these factors affect the sand proportion.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	14	2553.26	182.38	31.06	0.000
Linear	4	1746.06	436.52	74.35	0.000
Feed rate	1	1074.70	1074.70	183.04	0.000
Milling pressure	1	89.02	89.02	15.16	0.000
Table speed	1	22.30	22.30	3.80	0.055
Suction rate	1	560.04	560.04	95.38	0.000
Square	4	481.80	120.45	20.51	0.000
Feed rate*Feed rate	1	3.26	3.26	0.55	0.459
Milling pressure*Milling pressure	1	70.05	70.05	11.93	0.001
Table speed*Table speed	1	32.53	32.53	5.54	0.021
Suction rate*Suction rate	1	73.99	73.99	12.60	0.001
2-Way Interaction	6	325.40	54.23	9.24	0.000
Feed rate*Milling pressure	1	0.04	0.04	0.01	0.936
Feed rate*Table speed	1	11.80	11.80	2.01	0.160
Feed rate*Suction rate	1	3.18	3.18	0.54	0.464
Milling pressure*Table speed	1	37.48	37.48	6.38	0.014
Milling pressure*Suction rate	1	165.59	165.59	28.20	0.000
Table speed*Suction rate	1	107.31	107.31	18.28	0.000
Error	75	440.36	5.87		
Lack-of-Fit	11	418.64	38.06	112.16	0.000
Pure Error	64	21.72	0.34		
Total	89	2993.62			

Figure 6 Analysis of variance

Figure 7 states the relation between feed rate and proportion of sand. When the levels of milling pressure, and suction rate were changed, the straight lines showing the proportion of sand were parallel, indicating that there was no interaction between feed rate and other factors to the sand proportion. In addition, at a feed rate of 130 ton/h, milling pressure 110 bar, table rotating speed 9.5 rpm and suction rate 36,000 m<sup>3</sup>/h, the proportion of sand was the highest, as shown in Fig. 7(a), 7(b) and 7(c).

Figure 8 states the relation between milling pressure and proportion of sand as a curve. At milling pressure 100 bar, table rotating speed 9.5 rpm yielded a maximum proportion of sand 69.0% , whereas at milling pressure 120 bar, a maximum proportion of sand was 65.9% at table rotating speed 14.3 rpm (Figure 8(a)). It was also found that at the suction rate of 34,000 m<sup>3</sup>/h, when the milling pressure was changed from 100 bar to 120 bar, the proportion of sand increased. Conversely, when adjusting the milling pressure at suction rates of 36,000 m<sup>3</sup>/h and 38,000 m<sup>3</sup>/h, the proportion of sand decreased as shown in Figure 8(b).

Figure 9 states the relation between table rotating speed and proportion of sand at suction rate 34,000 m<sup>3</sup>/h, and table rotating speed 14.3 rpm yields the highest proportion of sand 63.8%, but at table rotating speed 9.5 rpm, both suction rate 36,000 m<sup>3</sup>/h and 38,000 m<sup>3</sup>/h, the highest proportion of sand was 69.8% and 71.5% respectively.

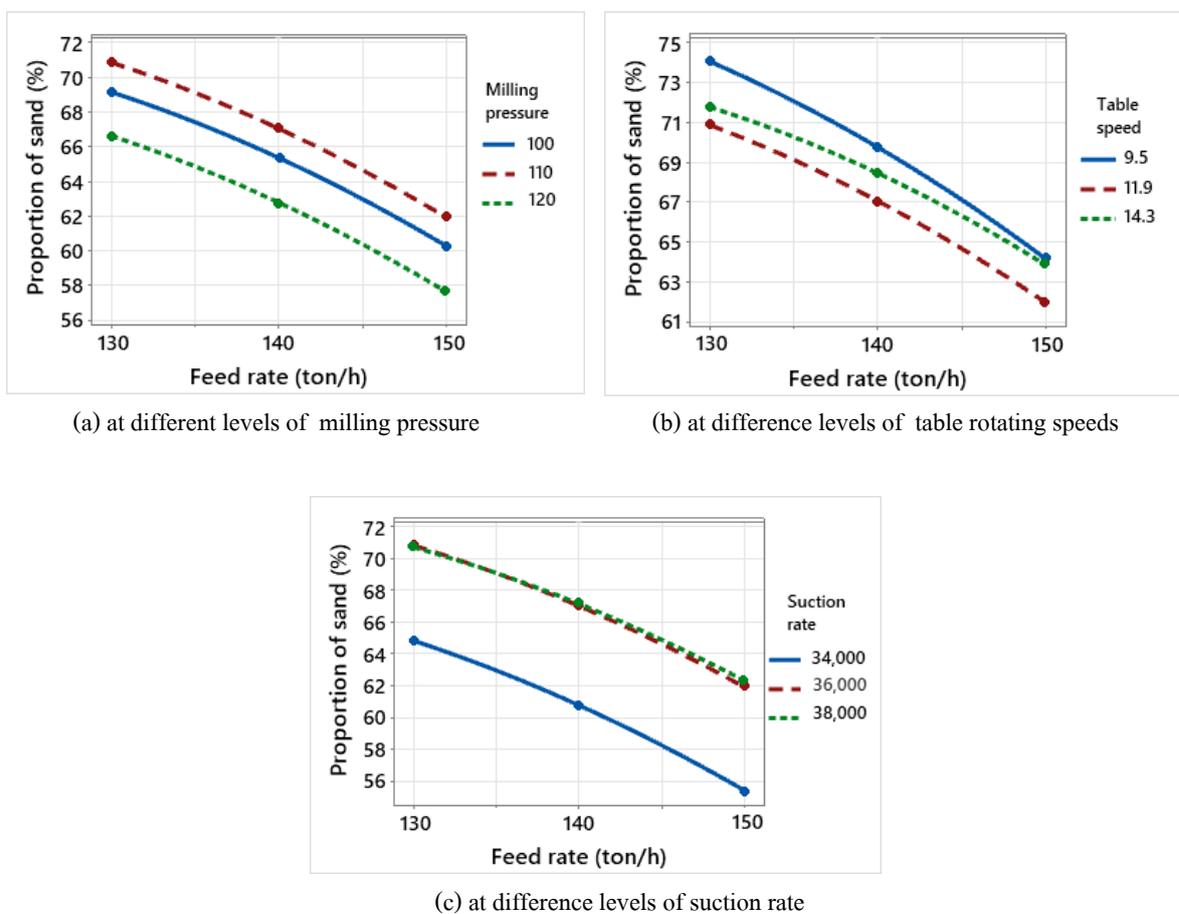


Figure 7 Relationship between feed rate and proportion of sand

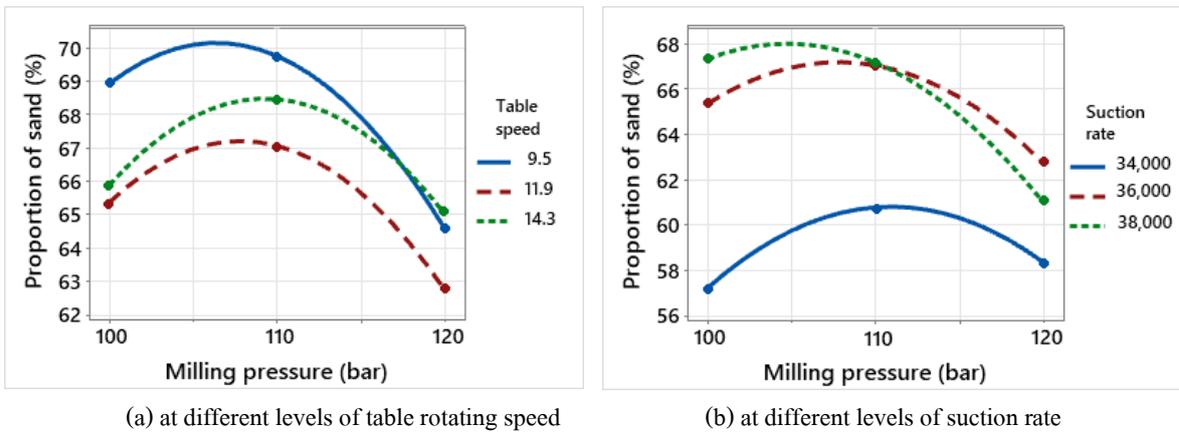


Figure 8 Relationship between milling pressure and proportion of sand

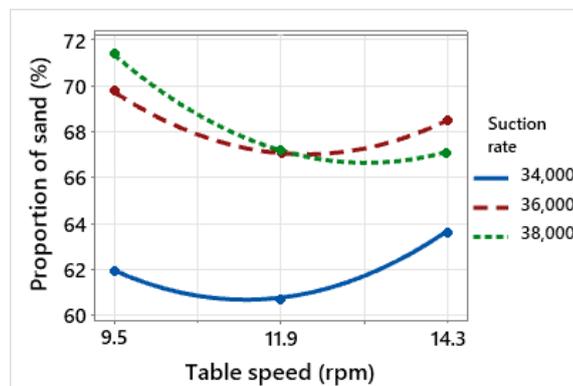


Figure 9 Relationship between table rotating speed and proportion of sand

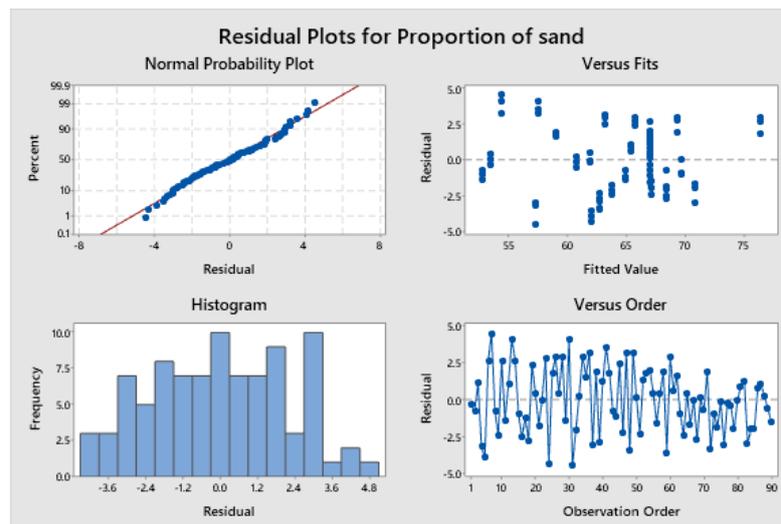
#### 4.2 Predicted equation and optimum value for milling process

The percentage of proportion of sand ( $Y$ ) could be described from the Quadratic equation ( $R^2 = 0.85$ ) as follows:

$$Y = 67.066 - 4.461A - 1.284B - 0.643C + 3.220D - 0.647A^2 - 3.002B^2 + 2.046C^2 - 3.085D^2 - 0.028AB + 0.496AC + 0.257AD + 0.884BC - 1.857BD - 1.495CD \quad (1)$$

Where:  $A$  = Level of feed rate,  $A = [-1 \ 1]$   
 $B$  = Level of milling pressure,  $B = [-1 \ 1]$   
 $C$  = Level of table rotating speed,  $C = [-1 \ 1]$   
 $D$  = Level of suction rate,  $D = [-1 \ 1]$

By examining the reliability sufficiently to accurately predict the sand fraction, it was found that the residual values obtained from the above equation were normally distributed as shown in Figure 10, independent of each other, and the variance was constant value. This is in accordance with the assumptions of the analysis of variance. Therefore, this model can be used to accurately and accurately predict the proportion of sand.



**Figure 10** Residual plots for proportion of sand

Figure 11 states the optimal parameters for highest sand proportion of 76.79% of the raw material. The optimal parameters were feed rate of 130 ton/h, milling pressure of 103 bar, table rotating speed of 9.5 rpm and suction rate of 37,838 m<sup>3</sup>/h. were the parameters resulting in the highest sand proportion. When these values are substituted into equation (1), the result is shown as follows.

$$\begin{aligned}
 Y &= 67.066 - 4.461(-1) - 1.284(-0.6364) - 0.643(-1) + 3.220(0.9192) - 0.647(-1)^2 - 3.002(-0.6364)^2 + 2.046(-1)^2 \\
 &\quad - 3.085(0.9192)^2 - 0.028(-1)(-0.6364) + 0.496(-1)(-1) + 0.257(-1)(0.9192) + 0.884(-0.6364)(-1) \\
 &\quad - 1.857(-0.6364)(0.9192) - 1.495(-1)(0.9192) \\
 &= 76.79
 \end{aligned}$$

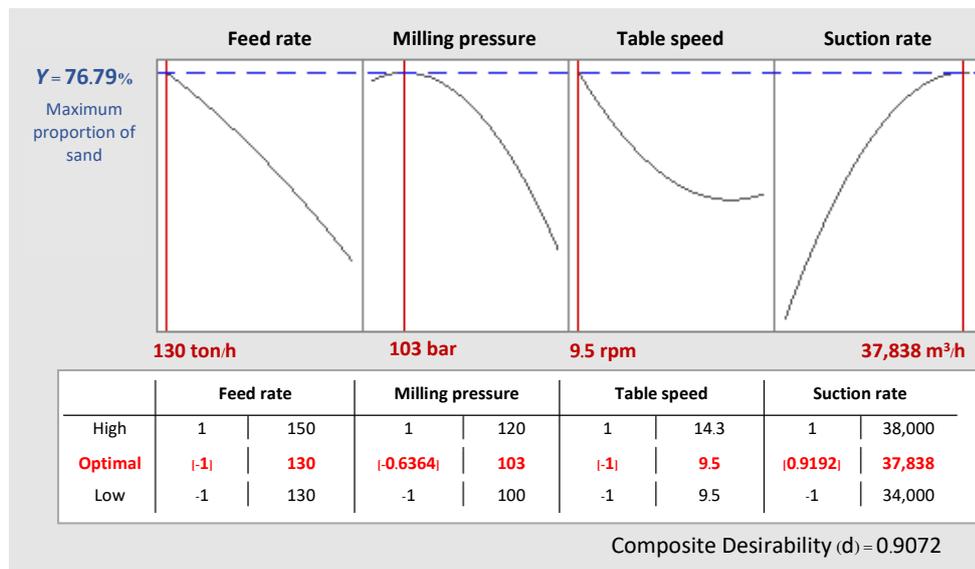


Figure 11 Optimal parameters for proportion of sand

### 4.3 Comparative results between before and after improvement

After obtaining the optimum parameters from the experiments, those parameters were applied to actual situation of mortar production for 40 hours, it was found that the average proportion of sand was increased from 62.91% to 77.34% of the raw materials as shown in Figure 12. The average value of sand proportion was increased by 14.43%. In addition, the variance value of the proportion was decreased from 5.43 to 1.52.



Figure 12 Comparative results of proportion of sand

## 5. Conclusion

From the results of the experiment to determine the optimal parameters in the vertical roller milling process using the Central composite design (CCD) method, it was found that the factors affecting the proportion of the sand were significant feed rate, milling pressure and suction rate. In addition, table rotating speed also had interaction with other factors. From the analysis of the appropriate parameters, it was found that feed rate 130 ton/h, milling pressure 103 bar, table rotating speed 9.5 rpm and suction rate 37,838 m<sup>3</sup>/h resulted in the highest proportion of sand that 76.79%, in other words, reduced to the lowest proportion of fines at 22.06%.

When the above parameters were applied in actual production, it was found that the average sand proportion increased from 62.91% to 77.34%, or up by 14%. As the proportion of sand increases, in other words, the fine powder of the milling process could be reduced, thereby reducing the environmental impact.

## Conflict of interest

The authors declared that this article has no conflict of interest.

## Acknowledgments

The authors would like to thank the management and staffs of TPI Polene (Public) Co., Ltd. that provide convenience for the experiment.

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