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# THE EFFECT OF FGD GYPSUM ADDITION IN THE MIXTURE OF SHOTCRETE USED BOTTOM ASH AS FINE AGGREGATE

Pisut Rodvinij[1], * Pitiwat Wattanachai[1] and Sattaya Chaiwithee[1]

[1]Faculty of Engineering, Chiang Mai University, Thailand

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**ABSTRACT:** Shotcrete used for temporary or permanent protection of slope in Mae Moh mine that may deteriorate when exposed to the weather change. In order to improve the efficiency and reduced cost of shotcrete, by-product materials from Mae Moh power plant area good alternative to use in the mixture. This study investigated the influence of flue gas desulphurization (FGD) gypsum on the properties of shotcrete used bottom ash as fine aggregate. The mixture of shotcrete was a combination of Portland cement type 1 and bottom ash in a ratio of 1:3. The addition of FGD gypsum in the mixture was 4%, 8% and 12% by weight of cement. Water to cement ratio was 0.6. The results demonstrated the slump flow of shotcrete decreased withFGD gypsum increment. However, the setting time of shotcrete was longer with FGD gypsum increment. The addition of FGD gypsum in the mixture at 12% can be reduced the shrinkage approximately 100 microstrains. The addition of FGD gypsum at 4% in the mixture can be developed the compressive strength approximately 8-20% of shotcrete without FGD gypsum. Moreover, the compressive strength and durability of shotcrete mixed with FGD gypsum at 4% could be able to give the highest strength. Nevertheless, the compressive strength and durability of shotcrete tend to decrease with FGD gypsum increment when the mixture containing FGD gypsum exceeds 4%. In conclusion, the addition of FGD gypsum at 4% in the mixture was the most efficient to develop the properties of shotcrete.

*Keywords: Shotcrete, FGD gypsum, Bottom ash, Compressive strength, Durability*

## 1. INTRODUCTION

Mae Moh mine is the largest surface mine in Southeast Asia. The area of Mae Moh mine is approximately 38 square kilometer as shown in Fig.1. Its annual production the lignite is approximately 15 million tons [1]. The overburden consists of claystone layer. Beneath claystone layer was lignite layer. To excavate lignite for generated the electricity, claystone must be mined out. The surface of claystone slopes might be exposed to weather change after excavation. The deterioration and erosion occur on the surface of the slope and induced the reduction in slope stability.

Rodvinij and Wattanachai [2] suggested that claystone deteriorated when it has been exposed to weather change. This can lead to slope stability problems. The failure of slope can be induced many problems with mining activities. However, the protection of claystone from weather change can maintain the physical characteristics and the strength of claystone.

Therefore, shotcrete becomes the suitable stabilization method to stabilize the stability of slopes in Mae Moh mine. Shotcrete is often used for temporary protection of exposed rock surfaces that will deteriorate when exposed to the air. Moreover, shotcrete also used to permanently cover slopes or cut that may erode in time or otherwise deteriorate [3]. Application of shotcrete to the surface of landfills and other waste area is beneficial to prevent the surface from water infiltration [4]. Shotcrete offers high work performance in large areas. However, the large amount of shotcrete might spray on the face of the slope. This induced a high cost for the slope stabilization.

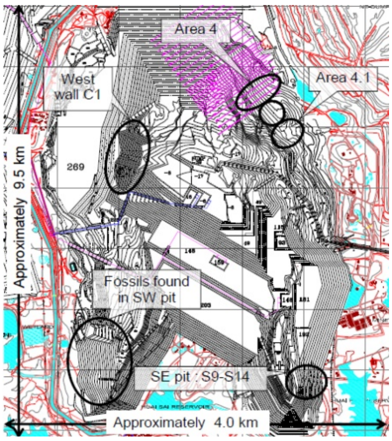


Fig.1 Top-view plan of the open pit.

Therefore, by-product materials from Mae Moh power plant are a good alternative to be used in the mixture of shotcrete to reduce the cost. By-product materials consist of fly ash, bottom ash, and FGD gypsum. Literature review demonstrated by-product materials from Mae Moh power plant are pozzolanic materials. The pozzolanic reaction can increase the strength of mortar in a long term. Moreover, by-product materials can be increased the efficiency of the fresh mortar [5].

This study focused on bottom ash used as fine aggregate and FGD gypsum used as an admixture in the mixture of shotcrete. Fig.2 demonstrated landfill of bottom ash in Mae Moh mine. The bottom ash particles were relatively large and very irregular, showing agglomeration of some spherical particles and other fragments with observable pores [6]. The replacement of sand by bottom ash in the mixture mortar can be reduced the unit weight by approximately 20% due to the unit weight of bottom ash particles is less than sand [7,8]. However, bottom ash used as fine aggregates of mortar can only reach 60%-70% the compressive strength of natural fine aggregates mortar [9].

Fig.2 Landfill of bottom ash in Mae Moh mine.

$SO_2$ is one of the major environmental contaminations generated from coal-burning power stations. It is very important to develop flue gas desulphurization (FGD) technologies to remove $SO_2$ for FGD clean coal combustion. Although FGD technology is successful in reducing $SO_2$ discharge, it generates a large quantity of FGD gypsum at the same time. Normally, FGD gypsum contains in the mixture of mortar can be increased the flexural strength and compressive strength. Although, setting time was prolonged for the composition of FGD gypsum [10]. Moreover, FGD gypsum can be increased the durability of concrete from the sulfate attack [11]. However, the suitable amount of FGD gypsum contains in the mixture should be determined. This is due to the excessive amount of FGD gypsum in the mixture can decrease workability and the strength of the mortar.

Therefore, the effect of FGD gypsum on the properties of shotcrete used bottom ash as a fine aggregate is an important determinant. The properties of shotcrete containing FGD gypsum should be passed the requirement of shotcrete for the slope stabilization. The test results obtained from the experimental in this study can suggest the optimum content of FGD gypsum mixed in the shotcrete mixture. The optimum content of FGD gypsum is the most efficient to develop the properties of shotcrete.

## 2. MATERIALS PREPARATION AND MIX PROPORTION OF SHOTCRETE

This study focused on the wet mix shotcrete. Wet mix shotcrete is predominantly used because of its homogeneity in quality and high work efficiency [12]. The mixture of normal shotcrete consists of sand used as fine aggregate, cement, and water. Shotcrete mixed with by-product materials; the mixture proportion consists of bottom ash used as fine aggregate, cement, water, and FGD gypsum used as an admixture. Fine aggregate should comply with the quality requirements of ASTM C 33 [4]. Particle size distribution of fine aggregate in this experiment was according to Fig.3. Ordinary Portland cement type 1 is used throughout the experiments. Bottom ash and FGD gypsum obtained from a Mae Moh power plant in Lampang province of Thailand. Mixture proportion of shotcrete used in the experiment shows in Table 1.

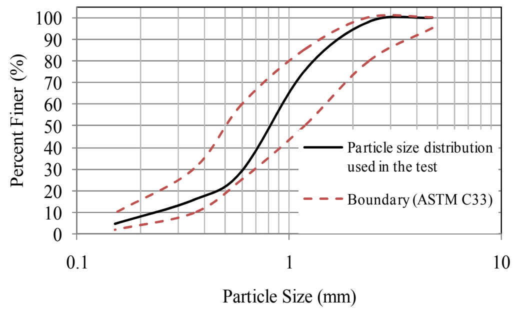


Fig.3 Particle size distribution of fine aggregate.

Table 1 Mixture proportion of shotcrete

| Mixture code | Cement | Sand | Bottom Ash | Water | FGD Gypsum (%) |
|---|---|---|---|---|---|
| M01 | 1 | 3 | - | 0.6 | - |
| MB01 | 1 | - | 3 | 0.6 | - |
| MB01G4 | 1 | - | 3 | 0.6 | 4 |
| MB01G8 | 1 | - | 3 | 0.6 | 8 |
| MB01G12 | 1 | - | 3 | 0.6 | 12 |

Note: The amount of FGD gypsum in the mixture is the percent by weight of cement.

The mixture of normal shotcrete was a combination of Portland cement type 1 and natural sand is in a ratio of 1:3 by weight. However, the mixture of shotcrete mixed with by-product materials was a combination of Portland cement type 1 and bottom ash is in a ratio of 1:3 by weight. FGD gypsum adds in the mixture 0-12% by weight of cement. Water to cement ratio for normal shotcrete and shotcrete mixed with by-product materials was 0.6.

## 3. EXPERIMENTAL PROGRAM

Shotcrete samples mixed according to Table 1 were used in the test. Fresh properties and hardened properties of shotcrete were conducted on each experiment to measure the influence of FGD gypsum on the properties of shotcrete.

The fresh properties evaluation consists of the slump flow and setting time. The slump flow test is intended to be used to determine the flows of mortar, according to ASTM C1437 [13]. The setting time is intended to be used to determine the initial setting time of mortar according to ASTM C191 [14]. The hardened properties evaluation consists of the compressive strength, drying shrinkage and durability. The compressive strength test is intended to be used to determine the compressive strength of shotcrete according to ASTM C109 [15]. The specimen for each mixture cast in the mold of mortar at 5×5×5 cm cube. The specimens were cured in the water for 3, 7, 14, 28 and 56 days. Drying shrinkage test is intended to be used to demine shrinkage of mortar according to ASTM 596 [16]. This test method determines the change in length on drying of mortar bars. Mold for test specimens shall provide for 25×25×285 mm prisms having an effective gage length of 250 mm. Four specimens shall be prepared for each mix proportion to measure the length. Take comparator reading of each specimen after periods of air storage after curing of 3, 7, 14, 28 and 56 days. The shrinkage value is an average of four specimens.

Shotcrete will be used as the surface protection of slopes from the weather change or water infiltration. Therefore, the durability of shotcrete is an important property to consider. The durability test was conducted on the cube specimens at 5×5×5 cm after curing in the water at 28 days. The wet-dry process was used to accelerate the deterioration of the samples. The samples were immersed in the water for 24 hr and heating in an oven at 100±5 °C for 24 hr. This represents one cycle [17]. Unconfined compression tests conducted on the samples which through the wet-dry process in 0-6 cycles to determine the compressive strength of deteriorated samples. The results represented the alteration in compressive strength of shotcrete during the deterioration.

The results obtained from the experiment represented the influence of FGD gypsum on the properties of shotcrete. Moreover, the properties of shotcrete for each mixture have compared with the required properties of shotcrete in Table 2. In order to determine the optimum content of FGD gypsum in the mixture of shotcrete for stabilizing the slope in Mae Moh mine.

Table 2 The requirement for the properties of shotcrete

| Test | Target |
|---|---|
| Initial setting time (min) | ≥ 180 |
| Slump flow (mm) | 203-248 |
| Drying shrinkage (Microstrain) @ 56 days | < 800 |
| Compressive strength (ksc) @ 28 days | >100 |
| Durability (ksc) 6 cycles | > 100 |

## 4. FRESH PROPERTIES OF SHOTCRETE

Slump flow tests and setting time tests were conducted on the fresh shotcrete to determine the fresh properties. The trial mixes according to Table 1 were used in the test.

### 4.1 Slump Flow

The requirement of the slump flow of shotcrete should be between 203-248 mm. The results of slump flow for each mixture shown in Fig.4.

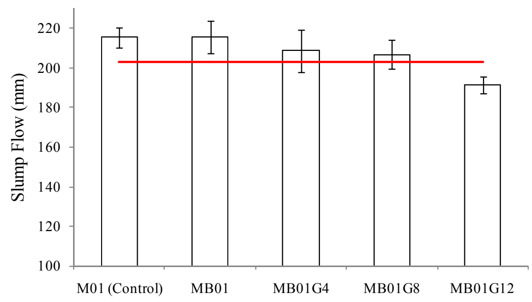


Fig.4 Slump flow of shotcrete for each mixture.

The results demonstrated that the slump flow of normal shotcrete (M01) and shotcrete used bottom ash as a fine aggregate (MB01) were similar. The slump flow was approximately 215 mm. The slump flow was in the range of the recommendation between 203-248 mm.

However, the slump flow of shotcrete tends to decrease with an increase in the amount of FGD gypsum contains in the mixture. The slump flow of shotcrete contains FGD gypsum at 4%, 8%, and

12% was 209 mm, 207 mm and 191 mm, respectively. The slump flow of the mixture contains FGD gypsum exceed 8% was lower than the requirement. Therefore, the amount of FGD gypsum adds in the mixture should not exceed 8% by the weight of cement.

### 4.2 Setting Time

The setting time of shotcrete for each mixture shows in Fig.5. The results demonstrated that the initial setting time and the final setting time of shotcrete used bottom ash as a fine aggregate was shorter than the normal shotcrete. The initial and final setting time of M01 was 183 minutes and 250 minutes, respectively. However, the initial and final setting times of MB01 was 165 minutes and 238 minutes. The requirement for the initial setting time of shotcrete should be longer than 180 minutes. Therefore, the initial setting time of shotcrete used bottom ash as a fine aggregate was shorter than the requirement.

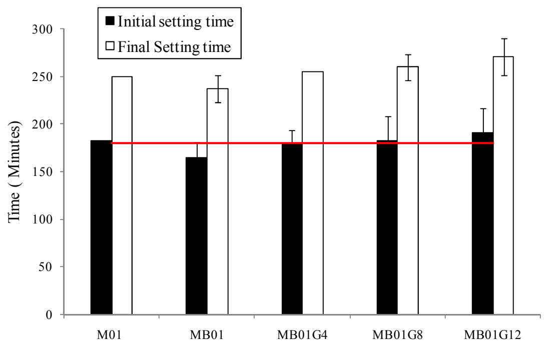


Fig.5 Setting time of shotcrete for each mixture.

Although the initial setting time of MB01 was shorter than the requirement, the addition of FGD gypsum in the mixture can be prolonged the setting times of shotcrete. This phenomenon caused by the absorbability of FGD gypsum. The soluble gypsum provides a range of available sulfate ions during cement hydration. When gypsum exists, the sulfates react with tricalcium aluminates to from ettringite immediately. It is assumed that ettringite forms initially on the reacting $C_3A$ surface, a more or less impermeable coating that impends diffusion of the ion needed to form hydrates that cause setting. Consequently, the solubility of gypsum becomes lower than ever and therefore cannot form ettringite to retard setting time until gypsum is released [10].

The results demonstrated the initial and final setting time tend to increase with an increase in the amount of FGD gypsum contains in the mixture. The initial setting time of MB01G4, MB01G8, and MB01G12 was 180 minutes, 183minutes and 191 minutes, respectively. The final setting time of MB01G4, MB01G8, and MB01G12 was 255minutes, 260minutes and 271 minutes, respectively. Thus, the mixture contains FGD gypsum exceeds 4% can be prolonged the initial setting time of shotcrete longer than the requirement. Moreover, the results demonstrated the initial setting time and the final setting time of MB01G4 was near M01.

## 5. HARDENED PROPERTIES

Compressive strength test, drying shrinkage test and durability test were conducted on shotcrete samples for each mixture to determine the hardened properties.

### 5.1 Compressive Strength

The trial mixes according to Table 1 and curing in the water at 3, 7, 14, 28 and 56 days were conducted on the compression machine to determine the compressive strength of shotcrete. The minimum requirement for the compressive strength of shotcrete is 100 ksc at the curing time 28 days. The results of the compressive strength of shotcrete for each mixture shown in Fig.6.

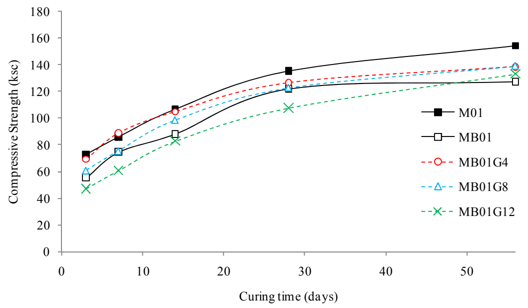


Fig.6 Compressive strength of shotcrete for each mixture.

The results showed the compressive strength of the normal shotcrete was higher than the shotcrete used bottom ash as fine aggregate. This is because the particle strength of bottom ash was less than the particle strength of sand. The bottom ash particles were with the much pores cause of low strength in the particles [6]. Fig.7 shows the failure plane of the samples used bottom ash as fine aggregate. The samples demonstrated the failure plane was shear pass bottom ash particles.

Shotcrete used bottom ash as fine aggregates can only reach 75-85% the compressive strength of normal shotcrete. However, the pores in the particle of bottom ash can be reduced the unit weight of shotcrete mortar. The unit weight of MB01 was approximately 1.8 T/$m^3$ which is lower than M01 approximately 0.2-0.3 T/$m^3$. Therefore, the reduction in the unit weight of MB01 was approximately 10-15% of M01.

Fig.7 Failure plane of shotcrete used bottom ash as fine aggregate.

However, the compressive strength of shotcrete used bottom ash as an aggregate can be increased when adds FGD gypsum in the mixture. The results showed the mixture containing FGD gypsum at 4% by weight of cement can be increased the compressive strength nearly the normal mortar in 3-14 days. However, the compressive strength of MB01G4 can only reach 90% of normal shotcrete at 28 and 56 days. The influence of FGD gypsum on the compressive strength of shotcrete used bottom ash as fine aggregate represented in Fig.8. The relationship between the amount of FGD gypsum in the mixture and compressive strength was presented.

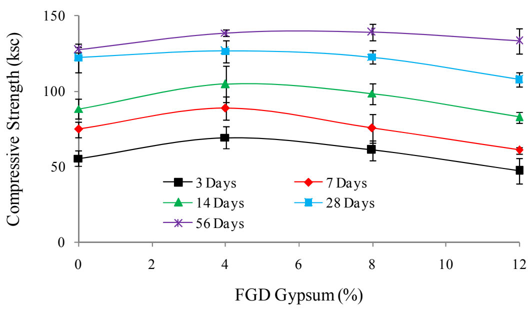


Fig.8 The influence of FGD gypsum on the compressive strength of shotcrete.

The result demonstrated FGD gypsum at 4% add in the mixture was the most efficient to develop the compressive strength of shotcrete. The compressive strength of MB01G4 was higher than the samples without FGD gypsum approximately 8-20%. This is because FGD gypsum obtained from Mae Moh power plant consist of $SO_3$ approximately 49.54%. Therefore, the strength increased when the content ratio of $SO_3$ was the optimum percentage [10]. $SO_3$ seems to be responsible for the higher early compressive strength [18].

The early strength of the samples contains FGD gypsum exceed 4% tend to decrease with FGD gypsum increment. The compressive strength of MB01G8 and MB01G12 can be reached 90% and 70% of MB01G4 in 3-14 days. However, the compressive strength of MB01G8 and MB01G12 was near MB01G4 at 56 days. This is due to the later age strength of the mixture is controlled mainly by calcium silicate hydrate [17]. Consideration of the minimum required strength at 28 days was 100 ksc, the strength of MB01, MB01G4, MB01G8 and MB01G12 passed the requirement. The compressive strength of MB01, MB01G4, MB01G8 and MB01G12 at 28 days was 122 ksc, 126 ksc, 123 ksc, and 108 ksc, respectively.

### 5.2 Drying Shrinkage

The drying shrinkage of shotcrete for each mixture demonstrated in Fig.9. The results showed the shrinkage of normal shotcrete was less than shotcrete used bottom ash fine aggregate. Drying shrinkage of MB01 at 56 days was 282 microstrains and drying shrinkage of M01 at 56 days was 163 microstrains. The results demonstrated that the drying shrinkage of MB01 was more than M01 approximately 119 microstrains. This is because a particle of bottom ash has a high void and high water absorption. Therefore, the moisture in MB01 was high evaporating to the air. This induced shrinkage in shotcrete used bottom ash as fine aggregate.

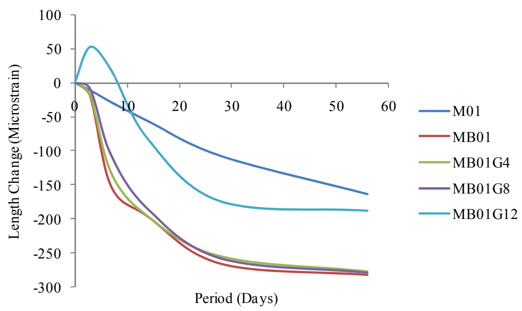


Fig.9 Drying shrinkage of shotcrete for each mixture.

The addition of FGD gypsum in the mixture was reduced drying shrinkage of shotcrete. Drying shrinkage of shotcrete mixed with FGD gypsum at 4% and 8% was slightly different with MB01. The reduction of shrinkage clearly shown in the results of shotcrete mixed with FGD gypsum at 12%.

The results demonstrated FGD gypsum at 12% add in the mixture can expand the samples in 3 days. However, the development of shrinkage occurs in the samples after 3 days. The shrinkage of MB01G12 was discontinued after 28 days as shown the similar of samples length at 28days and 56 days. At 56 days, the shrinkage of MB01G12 was slightly different with the normal shotcrete. Drying shrinkage of MB01G12 was more than the normal shotcrete only 24 microstrains. However, the development of shrinkage in the normal shotcrete tends to continue after 56 days.

### 5.3 Durability of Shotcrete

The results of the durability of shotcrete through the wet-dry process for each cycle is shown in Fig.10. The results demonstrated the compressive strength of shotcrete tends to decrease with an increase in the number of wet-dry cycles. This is due to the deterioration of shotcrete during the samples through wet-dry cycles.

MB01G4 demonstrated the highest compressive strength in six cycles. The compressive strength of MB01G4 was higher than MB01 and MB01G8 approximately 4-10%. Moreover, the compressive strength of MB01G4 was higher than MB01G12 approximately 15% - 23%. The remaining compressive strength of MB01G4 in cycle six was 115 ksc.

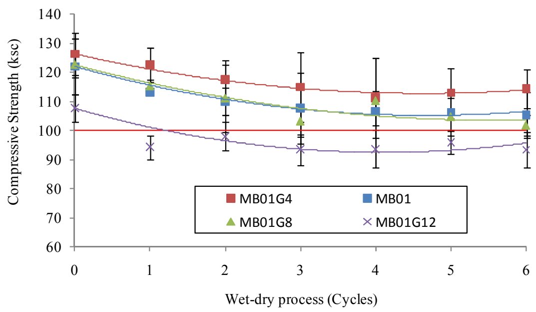


Fig.10 Compressive strength of deteriorated shotcrete for each mixture.

The results demonstrated that the deterioration severely effects to decrease the compressive strength of MB01G12. The reduction of the compressive strength was approximate to 12% in the first cycle followed by slight decreased. However, the reduction in the compressive strength of MB01, MB01G4, and MB01G8 in the first cycle was 7%, 3%, and 6%, respectively. The samples mixed with 4% of FGD gypsum shown a slight reduction of the compressive strength.

The requirement for the compressive strength of shotcrete through the wet-dry process in six cycles should be higher than 100 ksc. The remaining compressive strength of MB01, MB01G4, MB0G8, and MB01G12 in cycle six was 105 ksc, 115 ksc, 102 ksc, and 93 ksc, respectively. The compressive strength of the samples mixed with FGD gypsum at 12% was lower than the requirement. Moreover, the influence of FGD gypsum on the compressive strength of deteriorated samples is shown in Fig.11. The highest strength was demonstrated in the samples mixed with 4% of FGD gypsum. The compressive strength tends to decrease with FGD gypsum increment when FGD gypsum contains in the mixture exceed 4%.

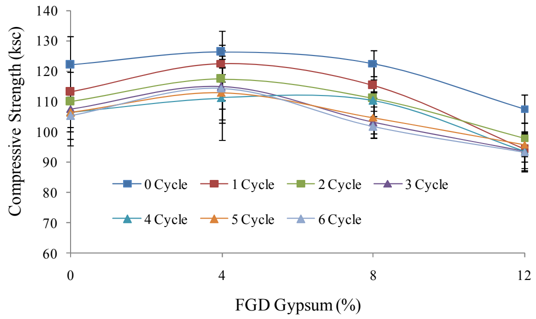


Fig.11 Influence of FGD gypsum on the compressive strength of deteriorated shotcrete.

Moreover, the results show the compressive strength was similar in cycle 3-6. This is demonstrated the most deterioration in the compressive strength of shotcrete due to wet-dry cycles. The reduction in the compressive strength of MB01G4 in six cycles was 9%. However, the compressive strength of the samples without FGD gypsum and the samples contain FGD gypsum at 8% and 12% in the mixture was reduced to approximately 13-17% as shown in Fig.12.

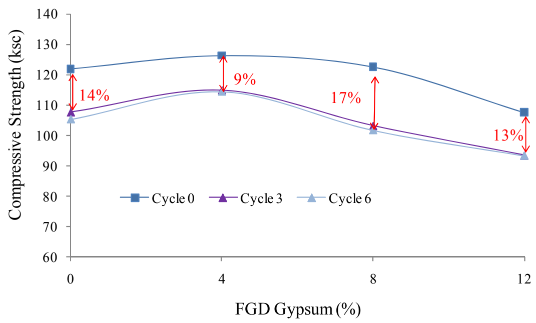


Fig.12 The reduction of the compressive strength of shotcrete in 3 and 6 cycles.

## 6. THE INVESTIGATION ON SUITABLE MIXTURE OF SHOTCRETE

The properties of shotcrete for each mixture obtained from experiments used to consider the suitability mixture for stabilizing slopes. The properties of a suitable mixture must pass the minimum requirement. Table 3 presented the comparison of the properties of shotcrete for each mixture and the required properties.

The mixture contains FGD gypsum at 4% and 8% shown the properties passed the requirement. In order to determine the suitable mixture of shotcrete, the properties of MB01G4 and MB01G8 has been reconsidered. The results showed the compressive strength of MB01G4 was nearly MB01G8 at 56 days. However, MB01G4 was more durable than MB01G8 in six wet-dry cycles.

Table 3 Properties of shotcrete for each mixture

| Test | Target | Amount of FGD Gypsum (%) | | | |
|---|---|---|---|---|---|
| | | 0 | 4 | 8 | 12 |
| Initial setting time (min) | > 180 | × | √ | √ | √ |
| Slump flow (mm) | 203-248 | √ | √ | √ | × |
| Compressive strength (ksc) 28 days | >100 | √ | √ | √ | √ |
| Drying shrinkage (Microstrain) 56 days | < 800 | √ | √ | √ | √ |
| Durability (ksc) 6 cycles | > 100 | √ | √ | √ | × |

The compressive strength of MB01G4 was reduced by approximately 9% in six cycles. However, the compressive strength of MB01G8 reduced approximately 17% in six cycles. Moreover, the remaining compressive strength of MB01G4 was higher than MB01G8. The compressive strength of MB01G4 and MB01G8 in cycle six was 115 ksc and 102 ksc, respectively. Therefore, the suitable mixture of shotcrete mixed with by-product materials from Mae Moh power plant was MB01G4.

Considering the cost of shotcrete, the mixture of normal shotcrete was more expensive than the mixture of shotcrete mixed with by-product materials. The cost of shotcrete mixed with by-product materials from Mae Moh power plant was cheaper than the normal shotcrete approximately 40%.

## 7. CONCLUSION

In order to investigate the effect of FGD gypsum addition in the mixture of shotcrete used bottom ash as fine aggregate. This study investigated the fresh properties and hardened properties of the shotcrete for each mixture. The fresh properties were carried out by setting a time test and the slump flow test. The hardened properties were carried out by the compressive strength test, drying shrinkage test and durability test.

Based on the experimental test obtained in this study, the following conclusion was made:

1. The slump flow of shotcrete used bottom ash as fine aggregate decreased with FGD gypsum increment. However, the initial setting time and final setting time of shotcrete were longer with FGD gypsum increment.

2. The compressive strength of shotcrete mixed with 4% of FGD gypsum can be developed the strength 8-20% of shotcrete without FGD gypsum. However, the compressive strength tends to decrease with FGD gypsum increment when the mixture contains FGD gypsum exceeds 4%.

3. The addition of FGD gypsum in the mixture of shotcrete can reduce the shrinkage of shotcrete. FGD gypsum adds in the mixture at 12% can reduce shrinkage approximately 100 microstrains of shotcrete without FGD gypsum at 56 days.

4. Shotcrete mixed with FGD gypsum at 4% demonstrated the highest compressive strength after shotcrete through the wet-dry process in six cycles. The remaining compressive strength in the sixth cycle was 115 ksc. The mixture of shotcrete mixed with FGD gypsum at 4% was the most efficient to develop the durability of shotcrete.

5. Shotcrete mixed with by-product materials from Mae Moh power plant can be reduced the cost by approximately 40% of the normal shotcrete.

## 8. ACKNOWLEDGEMENTS

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