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# AN EXPERIMENTAL STUDY OF SPRAYED MORTAR FOR REPAIRING APPLICATION

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**ABSTRACT :**

This study is to develop mix proportions of sprayed mortar and to investigate the performance of sprayed mortar regarding fresh and hardened properties, including mini slump flow, setting time, sagging resistance, build-up thickness, compressive strength, bond (pull-off) strength, drying shrinkage and age at cracking for repairing application. The research focuses on the maximum size of aggregate of 0.6 mm. with the addition of admixtures and the percentage of fly ash used for cement replacement. The results have shown that sprayed mortar with 0.01% starch ether, 0.5% water reducing agent and 8% shrinkage compensating admixture is the optimum mix proportion for use with cement and fly ash. The maximum build-up thickness of each layer is 50 mm. that can be applied without sagging. The cement replacement of 40% fly ash also produces satisfactory performance including workability, pumpability and sprayability. The compressive strength, bond strength, drying shrinkage and age at cracking of this mix are 38 MPa, 1.81 MPa, 145 millionths (expansion) at 28 days and no cracking after 60 days, respectively. The hardened performance is higher when mortar is sprayed compared with hand application. For demonstration, this sprayed mortar is applied to repair a damaged column. After repairing, ultrasonic pulse velocity (UPV) is used to check the quality of concrete. The result shows that the quality of concrete is good. Additionally, the cost of this sprayed mortar is much lower than the commercial product with similar properties and application. Therefore, the development of sprayed mortar with fly ash used for cement replacement has been satisfied with high performance and low cost for repairing application.

**KEYWORDS:** Mortar, Sprayed Mortar, Wet-mix Sprayed Mortar, Repair Applications, Column repair

## 1. Introduction

Nowadays, many buildings around the world include residential buildings, commercial buildings, low-rise buildings and high-rise buildings. On May 5, 2014, Mae Lao earthquake of about 6 on the Richter scale struck northern Thailand, resulting in considerable damage in urban areas where structures were not built to withstand seismic loading. After the earthquake, repairing of damaged structure is important. Each structure requires concrete repair and restoration, not only surface repair but also the strength and long-term performance of the repair. There are many concrete repair methods that can be used to repair the buildings such as general surface treatment, application of shotcrete or sprayed concrete, cast-in-place concrete, and grout etc. [1]. More than 80 years, shotcrete has been developed and used in repairing and rehabilitation projects [2]. The repair of structural members such as beams, columns, and connections is common for structures damaged by earthquake [3]. However, shotcrete or sprayed mortar repairing application needs to be developed in order to obtain the highest performance with lower cost and ease of application.

## 2. Shotcrete or sprayed mortar for repair

Shotcrete is one of the most economical and effective methods of concrete repair. There are two processes for applying shotcrete: dry-mix process and wet-mix process. The dry mix process defined as shotcrete in which most of the mixing water is added at the nozzle. On the other hand, the wet mix process can be additionally defined as shotcrete in which the ingredients, including water, are mixed before introduction into the delivery hose; while accelerator, if used, is normally added at the nozzle [3]. Shotcrete has been described by several terms such as sprayed concrete, sprayed mortar and gunite. This study uses the terminology standardized by American Concrete Institute. The maximum aggregate size used in this work is 0.6 mm and these mixes are classified as sprayed mortar that can be defined as a mortar which is shot at high speed onto a surface by compressed air. It has similar properties and procedures as shotcrete.

## 3. Objective of the Research

The main objective of this study is to determine the appropriate mix proportions of sprayed mortar and to understand wet-process sprayed mortar for repairing structures by using economical materials.

## 4. Methodology

The experimental programs are divided into two phases. Each phase in the program is described as follows.

*4.1 Phase I: Determination of mix proportion of sprayed mortar*

This phase is the preliminary test to determine the optimized mix proportion of sprayed mortar by hand application. Physical and mechanical properties of the sprayed mortar are determined. Testing Program in Phase I includes sagging resistance, build-up thicknesses, mini slump flow, setting time, shrinkage, age at cracking, bond strength and compressive strength at 7 days and 28 days. The mix proportion which gains the highest performance is developed by using fly ash. The percentage of fly ash to replace the amount of cement varies at 20%, 30% and 40% by weight of binder. The mix proportion which satisfies the target requirement (Table 1) for repairing application is used in Phase II.

**Table 1** Target requirements of sprayed mortar

| Property | Target | Standard of Testing | References |
|---|---|---|---|
| Initial setting time | 3 hr. (180 mins) | ASTM C191 | - |
| Mini Slump flow | 21-22 cm. | ASTM C1437 | - |
| 28-day compressive strength | > 30 MPa | ASTM C109 | - |
| Bond strength (pull-off) | > 0.8 MPa | ASTM C1583 | [4] |
| Drying shrinkage | < 500 millionths | ASTM C596 | [5] |
| Age at Cracking | No cracks after 60 days | ASTM C1581 | [6] |

*4.2 Phase II: Sprayed mortar for general repair application*

This phase is the continuation where this sprayed mortar is adopted to spray on a panel and a damaged column. All mix proportions used in this phase can be pumped and sprayed with the grout pump. The performance such as sagging resistance, build-up thickness, bond strength and compressive strength at 7 days and 28 days are evaluated. Finally, sprayed mortar is used to repair a damaged column and ultrasonic pulse velocity (UPV) is used to assess its uniformity and quality. The total material cost of sprayed mortar is also computed.

## 5. Results and Discussion

*5.1 Materials*

Ordinary Portland Cement Type I according to ASTM C150, fine aggregate with fineness modulus of 2.60 and maximum size of 0.6 mm. and Mae Moh fly ash are used in this experimental program. Commercial water reducing agent and shrinkage compensating admixture locally available are used.

*5.2 Mix Design*

The mix proportions of sprayed mortars are designed using Portland cement type I, starch ether, water reducing agent, shrinkage compensating admixture and fly ash replacement as shown in Table 2. Their properties exceed the target requirement. In these mixes, water/ binder ratios are in the range of 0.56 to

0.61 depending on their workability and pumpability. A mini slump flow of 215 mm. is considered to be a good compromise between workability and pumpability.

**Table 2** Mix proportions of sprayed mortar which exceed the target requirements.

| No. | C | S | W | FA | SE | WR | SA |
|---|---|---|---|---|---|---|---|
| | (kg/m$^3$) | | | | | | |
| 1 | 593 | 1186 | 356 | - | - | - | - |
| 2 | 576 | 1152 | 322 | - | 0.058 | 5.8 | 46 |
| 3 | 561 | 1122 | 342 | - | 0.056 | 2.8 | 45 |
| 4 | 423 | 1057 | 317 | 106 | 0.042 | 2.1 | 34 |
| 5 | 393 | 1122 | 337 | 168 | 0.039 | 2.0 | 31 |
| 6 | 302 | 1007 | 290 | 201 | 0.030 | 1.5 | 24 |

Note: C = Cement, S = Sand, W = Water, FA = Fly ash, SE = starch ether, WR = Water reducing agent, SA = Shrinkage compensating admixture

*5.3 Fresh properties of sprayed mortar*

5.3.1 Mini slump flow

From the trial mixes with different admixtures, the mini slump flow of all mix proportions must be around 215 mm. to control the workability of sprayed mortar. If mini slump flow of sprayed mortars is lower than 215 mm, it is difficult to be pumped and sprayed. Therefore, control of water to binder ratio is an important factor in the development of sprayed mortars.

5.3.2 Setting time

In this investigation, a minimum requirement of initial setting time is 180 minutes. The setting time of sprayed mortar and that of the control mortar are more than the minimum requirement. It is found that addition of water reducing admixture and fly ash replacement increased the initial setting time of mortars. When the percentage of water reducing admixture increases, the initial and final setting time increases. Moreover, the initial and final setting times increase as the percentages of fly ash replacement increase. It can be concluded that water reducing admixture and fly ash play significant roles in controlling the setting time of sprayed mortar.

5.3.3 Sagging resistance and build-up thickness

In phase I, all mixes are plastered onto a vertical 200 x 200 mm. substrate by hand application to investigate the sagging resistance and measure the build-up thickness. It is found that 0.01% starch ether can decrease sagging and increase in build-up thickness. All mixes with 0.01% starch ether are plastered onto a vertical 200 x 200 mm. substrate up to a maximum of 2 cm. for a single layer whereas it also increases up to 5 cm. for double layers. In phase II, all mixes which pass the minimum requirement of sprayed mortar are sprayed onto a vertical 200 x 200 mm. substrate and overhead substrate. The maximum build-up thickness of sprayed mortar in vertical surface is 5 cm. whereas the overhead surface is 2 cm. The thickness can be increased by spraying in double layers within an elapsed time of around 30 minutes.

*5.4 Hardened properties of sprayed mortar*

5.4.1 Compressive strength

The compressive strength is obtained from the cast and sprayed cubes at 7 and 28 days. Each reported value is the average of 3 cube specimens. The compressive strength of sprayed mortar with 0.01% starch ether, 0.5% water reducing agent and 8% shrinkage compensating admixture exceeds the minimum requirement of 30 MPa. In this case, the amount of cement is replaced with fly ash at 20%, 30% and 40% by weight of binder. The compressive strength of cast cube and sprayed cube at 7 days and 28 days with 20%, 30% and 40% of fly ash are shown in Table 3.

**Table 3** Compressive strength of sprayed mortar

| Mix constituents | Cast cubes (MPa) | | Sprayed cubes (MPa) | |
|---|---|---|---|---|
| | 7 days | 28 days | 7 days | 28 days |
| Control | 35 | 46 | - | - |
| SE+WR+SA | 39 | 45 | 37 | 47 |
| SE+WR+SA+FA20% | 33 | 38 | 34 | 40 |
| SE+WR+SA+FA30% | 31 | 37 | 33 | 39 |
| SE+WR+SA+FA40% | 26 | 36 | 27 | 38 |

The result shows that the compressive strength of sprayed mortar with fly ash replacement is lower than that of the control mortar. It can be concluded that the compressive strength decreases when percentage of fly ash replacement increases. On the other hand, it can be seen that the sprayed specimens have a small differences of compressive strengths when compared with the cast specimens. The different process seemed to have little effect on the compressive strength.

5.4.2 Bond Strength

Pull-off method according to ASTM C1583 is used to determine the bond strength of a repair mortar. The pull-off test is performed on the 7 and 28 days after the mortar is applied on the concrete substrates. The bond strength at 28 days of all mixes exceeds the research target of 0.8 MPa. All failure modes of specimen occur at the mortar interface and overlay mortar. The bond strength of each mix is shown in Table 4.

**Table 4** Bond strength of sprayed mortars

| Mix constituents | Cast panels (MPa) | | Sprayed panels (MPa) | |
|---|---|---|---|---|
| | 7 days | 28 days | 7 days | 28 days |
| Control | 1.50 | 1.60 | - | - |
| SE+WR+SA | 1.82 | 1.97 | 1.79 | 2.63 |
| SE+WR+SA+FA20% | 1.44 | 1.94 | 1.70 | 2.52 |
| SE+WR+SA+FA30% | 1.34 | 1.89 | 1.66 | 2.11 |
| SE+WR+SA+FA40% | 1.23 | 1.62 | 1.54 | 1.81 |

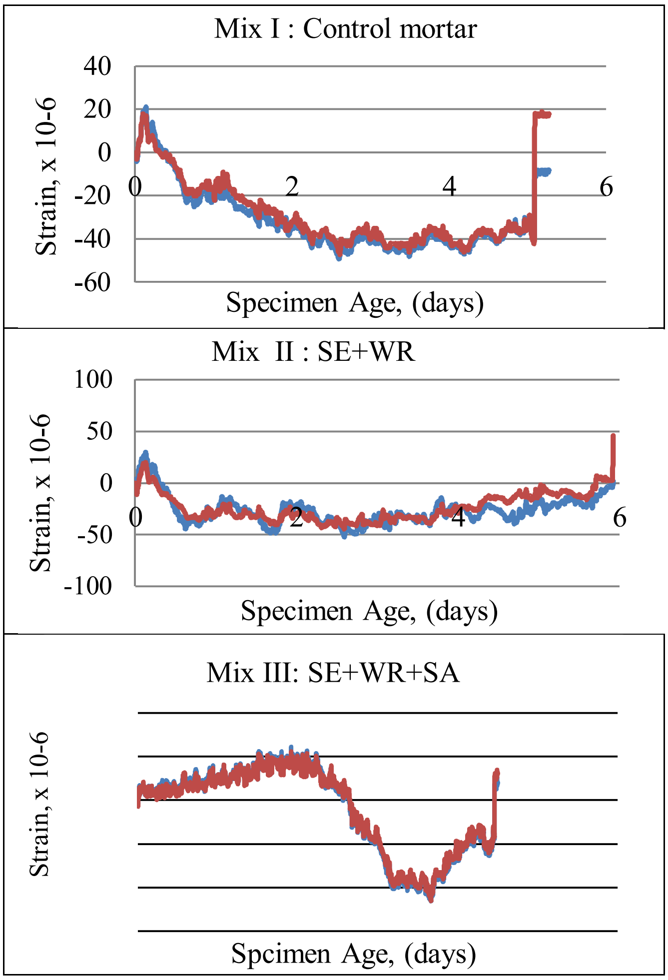
The result shows that the bond strengths at 28 days of the sprayed mortars is higher than that of the control mortar. An increase in percentage of fly ash replacement decreases bond strength of the sprayed mortars due to the fact that fly ash replacement can cause reduction in the strength especially at early age. Comparing the bond strengths between cast panels and sprayed panels, it is obvious that the sprayed panels have higher bond strength possibly due to the effect of higher pressure from machine application while using sprayed mortars resulting in better adhesion property.

5.4.3 Drying Shrinkage

Sprayed mortar with 0.01% starch ether, 0.5% water reducing agent and 8% shrinkage compensating admixture is selected to replace with fly ash. The drying shrinkages at 28 days with 20%, 30%, 40% of fly ash and without fly ash are -261 millionths, -120 millionths, 145 millionths (expansion) and -361 millionths, respectively. Moreover, drying shrinkage of sprayed mortar with fly ash replacement is smaller than that of the control mortar (-927 millionths). It can be concluded that an increase in percentage of fly ash replacement can lead to reduction in the drying shrinkage of sprayed mortar.

5.4.4 Age at Cracking

This test method is performed according to ASTM C1581. There are 5 mixtures used to determine age at cracking. The first specimen is the control mortar. The second is the sprayed mortar without the addition of shrinkage compensating admixture. The third is the sprayed mortar with the addition of shrinkage compensating admixture. The fourth and fifth are the sprayed mortar with 20% and 40% fly ash replacement. The relationship between steel ring strain and specimen age of each mix is shown in Figure 1. The ages at cracking are shown when the strain of steel ring increased rapidly. The results show that ages at cracking are 5 days, 6 days, 30 days, longer than 60 days and longer than 60 days, respectively. Typical cracking of ring test is shown in Figure 2.



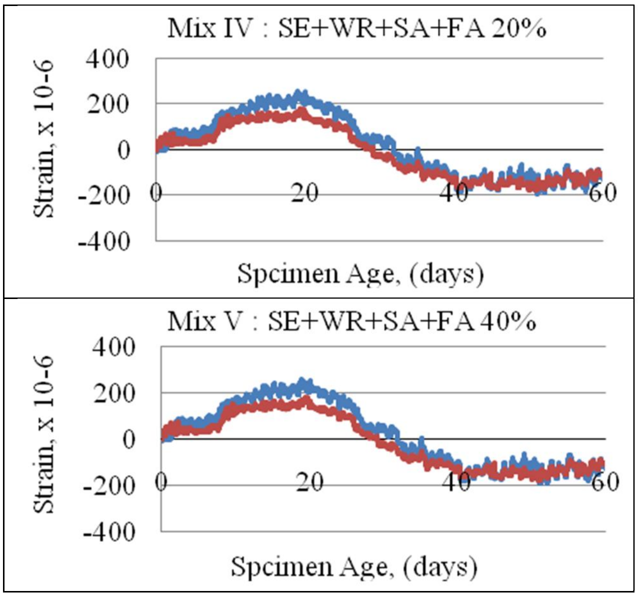



**Figure 1** The relationship between steel ring strain and specimen age of each mix

**Figure 2** Typical cracking of control mortar

*5.5 Repairing Application*

Sprayed mortar with 0.01% starch, 0.5% water reducing agent, 8% shrinkage compensating admixture and 40% of fly ash replacement is selected to repair a 30x30x70 cm. damaged column. This mixture is sprayed into the column from bottom up and cured for 7 days. Figure 3 shows the column before and after repairing. It can be seen that the repair of the damaged column by using sprayed mortar is similar to cast-in-place concrete. Moreover, the measurement of ultrasonic pulse velocity through concrete is 4.3 km/sec which is considered to be good quality. It can be concluded that sprayed mortar with fly ash replacement can be used successfully and effectively in repairing application. However, additional load test should be studied further.

**Figure 3** Repairing of damaged column

*5.6 Cost comparison*

The cost of sprayed mortar with different types of admixtures, including starch ether, water reducing agent, shrinkage compensating admixture and fly ash replacement, shows that all mixes have higher cost than the control mortar because of the addition of admixtures. However, addition of admixtures and 40% fly ash replacement can give the lowest cost. The cost of this mix is similar to that of control mortar but the performance is higher than that of the control mortar such as high compressive strength, high bond strength, low shrinkage and no crack after 60 days. Moreover, the properties and the cost of sprayed mortar are compared with commercial products of similar properties and applications, as shown in Table 6. It shows that the properties of the selected sprayed mortars are similar to the commercial products. The cost of the developed sprayed mortar with the addition of admixtures and fly ash replacement is lower than that of the commercial products. The cost saving can be up to 97.6% when compared with the cheapest commercial products.

## 6. Conclusion

Based on the results obtained from this experimental study, it can be concluded that the performance of mix no.6, the sprayed mortar with 0.01% starch ether, 0.5% water reducing agent, 8% shrinkage compensating admixture and 40% fly ash replacement, exceeds the target requirement of high compressive strength (>30 MPa), high bond strength (>0.8 MPa), low shrinkage (<500 millionths) at 28 days and no crack after 60 days, as shown in Table 5. This mixture can be applied in repairing application, including vertical surface, overhead surface and damaged column with high performance similar to expensive repair mortar material. Moreover, the developed sprayed mortar has 97.6% lower cost than the commercial product (1,678 THB/cubic meter vs. 71,200 THB/cubic meter).

**Table 5** Properties of commercial products and sprayed mortars

| Test | Commercial product I | Commercial product II | SE+WR+SA | SE+WR+SA+FA20% | SE+WR+SA+FA30% | SE+WR+SA+FA40% |
|---|---|---|---|---|---|---|
| Cost (THB/cu m) | 99,600 | 71,200 | 2,442 | 2,031 | 1,838 | 1,678 |
| Thickness | 30 mm. | 35 mm. | 50 mm. | 50 mm. | 50 mm. | 50 mm. |
| Initial setting time | 2 h 40 | 1 h 30 | 3 h 50 | 4 h 05 | 4 h 15 | 4 h 30 |
| Compressive strength (7 days) (28 days) | 45 MPa 60 MPa | 26 MPa 36 MPa | 40 MPa 47 MPa | 34 MPa 40 MPa | 33 MPa 39 MPa | 27 MPa 38 MPa |
| Bond strength (28 days) | > 2 MPa | > 1.5 MPa | 2.63 MPa | 2.52 MPa | 2.11 MPa | 1.81 MPa |
| Drying shrinkage (28 days) | < 560 millionths | Not Tested | -361 millionths | -261 millionths | -120 millionths | 145 millionths (expansion) |
| Age at cracking | Not Tested | Not Tested | 30 days | 60 days no crack | 60 days no crack | 60 days no crack |

## 6. References

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