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# STUDIES ON EARLY COMPRESSIVE STRENGTH OF ECC MORTAR COMPOSED BY RICE HUSK ASH AND SILICA FUME

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## Abstract

In general, mortars have low characteristics and performance. Mortar technology is constantly evolving for better achievements. Meanwhile, there is a lot of waste or residual production materials that has not been used optimally. Related to that, in this research, the utilization of these waste materials, including silica fume and rice husk ash has been carried out. Cylindrical specimens with a diameter of 100 mm and a height of 200 mm were prepared in 16 variations of mixes proportion, where the addition percentage of silica fume (SF) and rice husk ash (RHA) were 0%, 5%, 10% and 15% respectively by weight of cement. In this study, mechanical properties only considered the early compressive strength at the age of 1 day, while flowability was conducted to check the consistency of the fresh mixes of engineered cementitious composites (ECC) mortar. The test results show that the workability of the ECC mortar is in accordance with the European Federation of National Associations Representing for Concrete (EFNARC) standard. Meanwhile, the optimum compressive strength of ECC mortar at the age of 1 day was achieved in ECC mortar with RHA proportion of 0% and 5% combined by SF of 15%. Higher percentage of RHA or SF, can lead to decrement the early compressive strength of ECC mortar.

**Keywords:** Mortar; Silica Fume; Rice Husk Ash; ECC Mortar; Flowability; Early Compressive Strength.

## Introduction

To maintain sustainable availability of mortar-forming materials, it is necessary to innovate other alternative materials that can be renewed, so that future mortar needs can be met. In addition, also in order to create a mortar that is more environmentally friendly. The development of mortar technology is naturally in line with the need for better mortar characteristics, as well as to cover the shortcomings of mortar in general. One of the technological developments that can be done is the use of Engineered Cementitious Composites (ECC) mortar, where ECC mortar is composite that does not

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use fiber. To eliminate the bad influence on ductility, usually ECC does not use gravel. In addition, the main characteristic of ECC is that it always uses materials cementitious, such as fly ash, silica fume, nano silica, metakaolin, rice husk ash, palm shell ash, and so on. The cementitious materials are sourced from inorganic or organic materials.

The tropical climate has had a good effect on the fertility of agricultural lands in areas in Indonesia. One of the popular agricultures in Indonesia is rice. Based on data from the Central Statistics Agency (Statistik, 2018), in 2018 rice production in Indonesia was 83,037 million tons with a rice consumption rate of 29.57 million tons, of which the area of agricultural harvested land was 15.99 Ha. However, rice farming also contributes quite a lot to the production of organic waste in the form of rice stalks and husks. Sometimes the rice waste is burned, or left alone without being processed into a suitable material to use. Based on research conducted by Putra (2006), rice husk is a waste from a rice milling factory. While rice husk ash is waste combustion from rice husks, which are usually used as fuel in brick making. Rice husk ash contains 88.92% silica dioxide (SiO2) which has the potential to be pozzolanic. The results of laboratory examinations showed that rice husk ash always had high levels of silica dioxide ($SiO_2$).

Furthermore, it can be reported that silica fume is a very fine pozzolanic material with a grain size of less than 0.1 μm. Silica fume is the residue from the production of silicon metal or ferrum-silicon alloys. Silica content is usually more produced from blast furnaces. Silica fume can be used as one of the ingredients for forming concrete or composites. Silica (Si) is the main component of silica fume, while other elements are complementary components in small amounts such as Fe, Al, Ca, Mg, K, Na and S, where the content of silica dioxide ($SiO_2$) is more than 90%.

Cementitious material will be effective if it can react with Calcium Hydroxide which is the result of cement hydration, which can then form Calcium Silicate Hydrate (CSH). CSH is a binder and reinforcement of cement paste. In addition, the heat of hydration is also expected to be reduced, so as to reduce cracking, as well as shrinkage during/after hardening. Rahman (2006) stated that silica sand is a mineral consisting of silica oxide ($SiO_2$) crystals and contains compounds carried during the deposition process. To be able to create a mortar that is stronger and more environmentally friendly, it is necessary to utilize the remaining production materials, as well as existing organic wastes.

Based on the descriptions above, this research will examine the ECC mortar, in which the remaining production materials such as silica fume and rice husk ash will be utilized. The study of mechanical properties only examines the compressive strength, while for the fresh properties it only examines the flowability of the fresh mortar mix. The benefits of this ECC mortar basically can be used as a grouting material, as well as for non-structural uses.

## Research Methodology

This research was conducted experimentally, which includes preparation work to testing the test object. All research procedures were carried out systematically. The main research stages carried out are:

**Checking availability of materials**

The materials used to form the ECC mortar are cement, water, silica sand, rice husk ash, silica fume (SF), and superplasticizer (SP). The cement used was Portland Type-I, while the silica sand used was about 100 µm (0.1 mm) in diameter. Rice husk ash comes from the combustion of rice husks obtained from agricultural land in Indonesia around Deli Serdang-North Sumatra, while silica fume was supplied by Sika Indonesia.

**Supply of materials**

The main tools used include a hand drill mixer, flowability test tools, cylindrical mold with a diameter of 100 mm and a height of 200 mm, and a compression test machine. All equipments are checked for the suitability for use.

**Mix Design**

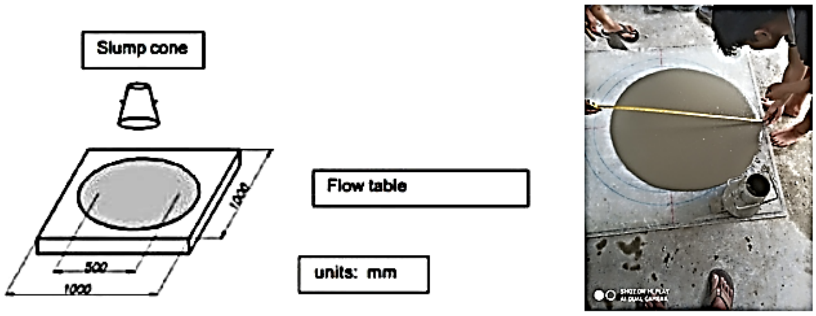
The cementitious materials in this study use silica fume and rice husk ash, where the cementitious materials as the cement addition material (CAM). The constant ingredient of the ECC mortar in 1 m3 cover among cement of 490 kg, silica sand of 245 kg, w/c ratio of 0.3. In the meantime, the proportion values of SF and RHA are the same, namely 0%, 5%, 10% and 15% by weight of cement. While the percentage of SP is adjusted to the proportion of cementitious material used. The matrix of mixes of the ECC mortar in this study can be seen in Table 1.

**Table 1. Mixes matrix of ECC mortar**

| Silica Fume (SF) | | | | Rice Husk Ash (RHA) |
|---|---|---|---|---|
| 0% | 5% | 10% | 15% | |
| $SF_0RHA_0$ | $SF_5RHA_0$ | $SF_{10}RHA_0$ | $SF_{15}RHA_0$ | 0% |
| $SF_0RHA_5$ | $SF_5RHA_5$ | $SF_{10}RHA_5$ | $SF_{15}RHA_5$ | 5% |
| $SF_0RHA_{10}$ | $SF_5RHA_{10}$ | $SF_{10}RHA_{10}$ | $SF_{15}RHA_{10}$ | 10% |
| $SF_0RHA_{15}$ | $SF_5RHA_{15}$ | $SF_{10}RHA_{15}$ | $SF_{15}RHA_{15}$ | 15% |

**Flowability Test**

After all the materials were mixed evenly, then the flowability test was carried out on the fresh ECC mortar mix. Slump flow and T500 time are tests to assess the flowability and flow rate of self-compacting concrete (SCC) without any obstacles. The test equipment needed is an Abrams cone and a square acrylic table as shown in Figure 1. The flowability table with a side length of 1000 mm has several circular markings, including diameters of 200 mm, 500 mm, 650 mm and 850 mm. Abrams cone is located in the center and will later be filled with ECC fresh mortar without vibration or compaction. Timing begins as soon as the cone is lifted vertically, and is recorded when the ECC mortar flow reaches the 500 mm mark line. The time obtained is referred to as T500 (seconds). The maximum spread (diameter) of the ECC mortar flow was also recorded. Horizontal spread is measured from the average value of the two diameters in the direction perpendicular to each other. The flowability diameter measurement of fresh ECC mortar mortar can be seen in Figure 1. The procedure for testing the flowability of ECC mortar follows EFNARC provisions (2002, 2005).




(a) (b)

**Figure 1. Slump-flow test (EFNARC, 2002; 2005)**

### Production of specimens

All related materials are mixed together in a dry container, and then stirred evenly until a good mix consistency is achieved. The mixing process usually takes about 9 to 12 minutes. Then the fresh mix of ECC mortar was put into a cylindrical mold (100 mm in diameter and 200 mm in height). At least 8 hours after that, the mold may be opened, then all specimens are ready for the compression testing at age of 1 day.

## Result And Discussion

### Chemical contents of Cementitious Materials

The results of the examination of the chemical content of cementitious materials, those are the rice husk ash and the silica fume can be seen in Table 2 and 3 for each. Examination of the chemical content of these materials was carried out at Pusat Penelitian Kelapa Sawit (PPKS) Medan, North Sumatra. Based on the results of the examination, it can be seen that the levels of $SiO_2$ in rice husk ash and silica fume are 78.45% and 94.81%, respectively.

**Table 2. Chemical content of rice husk ash**

| Oxide | Unit | Test Result | Test Method |
|---|---|---|---|
| $K_2O$ | % | 3,46 | IK.01.P.04 (AAS) |
| CaO | % | 0,28 | IK.01.P.05 (AAS) |
| MgO | % | 0,25 | IK.01.P.05 (AAS) |
| $Fe_2O_3$ | % | 0,15 | AAS |
| $Al_2O_3$ | % | 1,72 | Spektrofotometri |
| $SiO_2$ | % | 78,45 | IK.01.P.08 (Gravimetri) |
| Water content | % | 3,05 | IK.01.0.01 (Oven) |

**Tabel 3. Chemical content of silica fume**

| Oxide | Unit | Test Result | Test Method |
|---|---|---|---|
| $K_2O$ | % | 0,29 | IK.01.P.04 (AAS) |
| CaO | % | 0,25 | IK.01.P.05 (AAS) |
| MgO | % | 0,42 | IK.01.P.05 (AAS) |
| $Fe_2O_3$ | % | 0,09 | IK.01.P.07 (AAS) |
| $Al_2O_3$ | % | 0,66 | Spektrofotometri |
| $SiO_2$ | % | 94,81 | IK.01.P.08 (Gravimetri) |
| Water content | % | 1,05 | IK.01.P.01 (Oven) |

**Results of Flowability Test**

The results of the flowability test can be seen in Table 4.

**Table 4. Flowability of ECC mortar**

| Specimen Type | Label | Slump Flow | |
|---|---|---|---|
| | | Diameter (mm) | $T_{500}$ (sec) |
| SF 0% - RHA 0% | $SF_0$ $RHA_0$ | 870 | 3 |
| SF 0% - RHA 5% | $SF_0$ $RHA_5$ | 890 | 4 |
| SF 0% - RHA 10% | $SF_0$ $RHA_{10}$ | 890 | 2 |
| SF 0% - RHA 15% | $SF_0$ $RHA_{15}$ | 880 | 4 |
| SF 5% - RHA 0% | $SF_5$ $RHA_0$ | 870 | 3 |
| SF 5% - RHA 5% | $SF_5$ $RHA_5$ | 910 | 2 |
| SF 5% - RHA 10% | $SF_5$ $RHA_{10}$ | 930 | 2 |
| SF 5% - RHA 15% | $SF_5$ $RHA_{15}$ | 940 | 2 |
| SF 10% - RHA 0% | $SF_{10}$ $RHA_0$ | 880 | 4 |
| SF 10% - RHA 5% | $SF_{10}$ $RHA_5$ | 890 | 3 |
| SF 10% - RHA 10% | $SF_{10}$ $RHA_{10}$ | 930 | 1 |
| SF 10% - RHA 15% | $SF_{10}$ $RHA_{15}$ | 940 | 2 |
| SF 15% - RHA 0% | $SF_{15}$ $RHA_0$ | 890 | 4 |
| SF 15% - RHA 5% | $SF_{15}$ $RHA_5$ | 900 | 4 |
| SF 15% - RHA 10% | $SF_{15}$ $RHA_{10}$ | 890 | 3 |
| SF 15% - RHA 15% | $SF_{15}$ $RHA_{15}$ | 900 | 4 |

Based on the values listed in Table 5, the results of the flowability test in this study are still within reasonable limits, and meet the specified requirements.

**Tabel 5. Standard value of flowability (EFNARC, 2002; 2005)**

| **Test Tipe** | **Criteria limit** | | **Unit** |
|---|---|---|---|
| | **Minimum** | **Maximum** | |
| *Slump flow* | 650 | 800 | mm |
| $T_{500}$ | 2 | 5 | sec |

## Compression Test

The compressive strength of the ECC mortar is taken based on the maximum stress that causes the mortar to collapse due to the applied compressive force. The specimen used is a cylinder with a diameter of 100 mm and a height of 200 mm. Each variation of ECC mortar mix has three samples. The test was carried out at the age of 1 day using a compression testing machine with a capacity of 3000 kN, as shown in Figure 2. The compressive strength value is the average value of the three samples. The test procedure is in accordance with ASTM C39. The results of the compression test of all ECC mortar specimens can be seen in Figure 3 and Figure 4.

**Figure 2. Experimental setup**

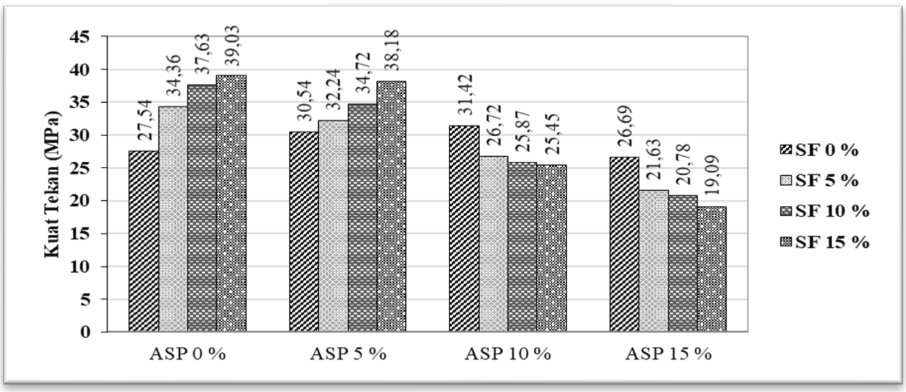



**Figure 3. Compressive strength of ECC mortar-based on RHA 0-15% and varied by SF 0-15%**

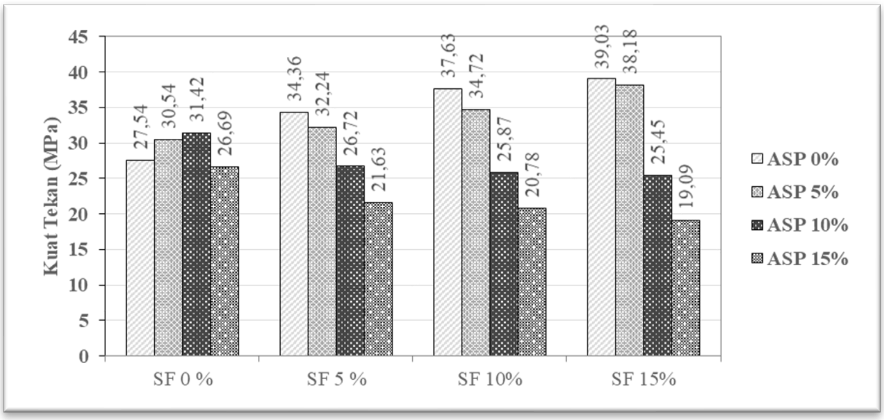



**Figure 4. Compressive strength of ECC mortar-based on SF 0-15% and varied by RHA 0-15%**

Based on the results of the compressive test at the age of 1 day, as shown in Figures 3 and 4, it can be seen that the maximum compressive strength produced by ECC mortar with the addition proportion of 0% RHA and 15% SF is 39.03 MPa. Meanwhile, the compressive strength of ECC mortar with the addition proportion of 5% RHA and 15% SF has the second largest compressive strength of 38.18 MPa. ECC mortar mix containing 0% RHA; 5% and 15% SF provide ideal conditions, so as to provide the optimal compressive strength.

Meanwhile, the lowest compressive strength was produced by ECC mortar with 15% RHA and 15% SF content. Rice husk ash and silica fume are materials that absorb a lot of water. This condition certainly can affect the hydration process of cement, so it is estimated that it can interfere with the formation of CSH.

## Conclusion

Based on the results of the tests that have been carried out, it can be concluded that the addition of rice husk ash and silica fume in the manufacture of ECC mortar can have an effect on the compressive strength and consistency of the fresh mix. The percentage of addition of rice husk ash and silica fume turned out to have certain limits so that it reached the optimum condition. The maximum compressive strength produced by ECC mortar with the addition percentage of 0% RHA and 15% SF is 39.03 MPa. Meanwhile, the compressive strength of ECC mortar with the addition percentage of 5% RHA and 15% SF has the second largest compressive strength of 38.18 MPa. If the percentage limits for the addition of RHA and SF are exceeded, the compressive strength will decrease. Meanwhile, the flowability test showed that the workability of the fresh ECC mortar was in accordance with the EFNARC standard.

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