The effect of water cement ratio (WCR) on compressive strength of interlocking bricks with mix design variations

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Abstract. Interlocking brick is a material used for wall work in home construction. Called Interlocking Brick or Brick Interlock because the method of arranging the bricks is interlocked with one another. This interlocking brick itself began to be known in Aceh Province after the 2004 tsunami disaster. Interlocking brick is a block of compacted soil, made of cement, silt soil, and dried sand, measuring 300 × 150 × 100 cm³. Interlocking brick can function as a wall that can withstand structural and non-structural components. The purpose of this research is to get the compressive strength value of interlocking bricks designed with variations in the water cement ratio (WCR) so that the optimum compressive strength of interlocking bricks is obtained. The WCR used was 0.3; 0.4; and 0.5, while for the composition of cement, silt, and sand the ratio of 1:2:2 is used. The making of test specimens for testing the compressive strength of interlocking bricks is by cutting the interlocking bricks into cubes measuring 50 × 50 × 50 mm by 5 specimens for each variation so that the total of the total specimens are 45 specimens. Testing is done at the age of 7, 14, and 28 days. The results of the compressive strength of interlocking bricks using WCR 0.3 average compressive strength at the age of 7 days reached 8.10 MPa, 14 days reached 9.49 MPa and 28 days reached 10.94 MPa. For WCR 0.4, compressive strength on average at 7 days reaches 5.69 MPa, 14 days reaches 7.61 MPa and 28 days reaches 9.77 MPa. And for WCR 0.5 the average compressive strength at the age of 7 days reaches 5.36 MPa, 14 days reaches 8.25 MPa and 28 days reaches 9.93 MPa. From the compressive strength test results the interlocking brick with a WCR variation of 0.3; 0.4; and 0.5 with a mixture of 1:2:2 can be used as wall work material in house construction for structural construction and the optimum compressive strength value is obtained at WCR 0.3.

1. Introduction

The wall is one part of a nonstructural building which is generally categorized as a burden on a building. Determination of the wall as a non-structural part of the Indonesian National Standard (SNI) makes the wall not counted as a structural component in planning. However, technological developments in the field of wall materials continue to increase so that the wall material can also function as a structural substitute for sloof, column, and ringbalk. The wall material used is interlocking brick. Interlocking brick is a pair of walls that are installed by the method of interlock, locked, or interlocked. This brick is made of cement, silt, and sand added with water, then printed using a manual press and maintenance by splashing water until it reaches the concrete age of 28 days. In the last two decades, the development of interlocking wall material continues to increase because of this the method of implementing the installation can save time and does not require special labor [1]. Using interlocking bricks can save time and costs when compared to using red bricks because these interlocking bricks do not need to be plastered and painted because of their attractive appearance [2]. For this reason, several innovations in construction materials with interlocking masonry continue to be developed so that these materials...
become environmentally friendly, sustainable, and affordable costs [3-7]. Problems associated with interlocking bricks are low strength, higher water absorption, low fire resistance, and high porosity [8].

To be able to make interlocking brick products according to the planned quality, it is suggested that the concrete composition should be determined through an analysis which in concrete technology is called concrete mix design. One step is to determine the WCR value which is the ratio between the amount of free water and the amount of cement used in a concrete mixture. This WCR value can be predicted by using a curve that connects the compressive strength of concrete and WCR. The smaller the value of the WCR is used, the better the concrete strength will be. Concrete mixes that use a large WCR value, will require less cement paste, conversely, concrete mixes that use a small WCR value, will require more cement paste.

Interlocking brick is included in the type of concrete brick because it is made from the main material of portland cement, water, aggregate which is used for wall pairs. Concrete brick is divided into solid concrete brick and hollow concrete brick. Interlocking bricks are included in hollow concrete bricks because bricks have a cross-sectional area of more than 25% of the cross-sectional area of the brick and hole volume of more than 25% of the total boundary volume. Solid or hollow concrete bricks are distinguished according to their quality level, which is the quality level I for construction which carries loads and is unprotected (outside the roof) and has an average gross compressive strength of at least 7 MPa, quality level II for construction which bears the burden but its use is protected from external weather and has an average gross compressive strength of 5 MPa, quality level III and IV only for constructions that do not carry loads and are protected from rain and sun which have an average gross compressive strength of 3.5 MPa and 2 MPa [9].

In general, industries that produce wall-filling materials do not distinguish their production from wall functions as structural or non-structural and tend classified to be only one quality. This interlocking brick is produced using molding through the compaction process. The quality of interrelated bricks products is influenced by many factors including the ratio of the mixture between the forming materials. The purpose of this study is to determine the compressive strength of interlocking bricks that are designed with WCR type and material composition so that the optimum and minimum compressive strength of interlocking bricks is obtained.

2. Methodology

This research was conducted in several stages of work. Starting from the preparation of materials, examination of materials, the mixture plan is continued with the manufacture of test specimens, maintenance of test specimens, and test specimens. All work is carried out based on the applicable rules/standards. Material inspection is limited to certain materials that are important in mixture calculations. In this study, the testing and examination of the physical properties of the aggregates refer to the Indonesian National Standard (SNI). The mixture planning carried out in this study uses a mixture used in interlocking brick production industries, namely by a mixture composition of 1:2:2 consisting of cement, silt and sand and WCR 0.3, 0.4, and 0.5. The interlocking brick forming material comes from Aceh Besar District which is used by the industry in producing it.

Preparation of test specimens was carried out in the interlocking brick production industry located in Mieruk Lamreudeup Village, Baitussalam District, Aceh Besar Regency, Indonesia. This industry produces interlocking bricks using manual brick machines, called Soeng Thai BP-6 compactor models that produce interlocking bricks with sizes of 100 mm x 150 mm x 300 mm. After interlocking bricks reach the age of 7, 14, and 28 days, they will be cut using concrete cutting tools which are carried out at the Structure and Building Materials Laboratory at the Faculty of Engineering, Syiah Kuala University as a cube-shaped test object with a size of 50 mm x 50 mm x 50 mm as per the compressive strength testing standards for cement paste. However, in this study not all of these measurements were achieved due to difficulties in the process of cutting test specimens, so in this study, 45 specimens were obtained consisting of 5 specimens for each WCR and with interlocked brick ages reaching 7, 14, and 28 days.

Compressive strength testing in this study used a compressive strength universal compression testing machine with the following steps: placing the test object in a centric position in the compressive test instrument; run the pressure test until the test object is destroyed; record the maximum amount of crushed load acting on the test specimen printed on the monitor of the pressure test device.
Compressive strength is the ability of concrete to accept the compressive force of broad unity. Whereas based on SNI the compressive strength is defined as the magnitude of the wide unity load, which causes the concrete specimens to be destroyed when burdened with certain compressive forces produced by the press machine. Compressive strength (kg/cm$^2$) is defined as the Force P (kg) divided by the cross-sectional area of test specimen A (cm$^2$). Many factors affect the strength of concrete including the effect of the concrete constituent material itself consisting of cement, silt soil, aggregates, water, conditions at work, conditions during treatment, caping, and testing processes that also greatly affect the strength of concrete samples made. For concrete compressive strength, measurements refer to the ASTM C-133-97 standard.

3. Results and discussion
The compressive strength test of interlocking brick specimens with cubes measuring 50 × 50 × 50 mm is carried out at the age of 7 days, 14 days, and 28 days. The results of the average compressive strength test of mortar with variations of WCR 0.3, 0.4, and 0.5 with a mixture of 1:2:2 are shown in tables 1, 2, and 3 below.

| WCR | Sample | Dimension | Weight | Load | Compressive Strength | Average Compressive Strength |
|-----|--------|-----------|--------|------|----------------------|----------------------------|
|     |        | Length (mm) | Width (mm) | Height (mm) | (g) | (kgf) | (MPa) | (MPa) |
| 0.3 | 1      | 57.75     | 54.11   | 54.09   | 327.50 | 2420 | 7.60 |
|     | 2      | 54.90     | 50.03   | 53.46   | 273.90 | 2500 | 8.35 |
|     | 3      | 54.84     | 55.11   | 52.14   | 308.10 | 2440 | 8.37 |
|     | 4      | 53.89     | 52.86   | 51.84   | 283.50 | 2360 | 8.28 |
|     | 5      | 51.73     | 53.54   | 50.37   | 275.30 | 2100 | 7.90 |
| 0.4 | 1      | 54.60     | 51.66   | 52.49   | 273.40 | 2860 | 5.61 |
|     | 2      | 56.35     | 52.80   | 51.06   | 283.00 | 2900 | 5.93 |
|     | 3      | 53.98     | 50.89   | 52.23   | 265.20 | 1460 | 5.08 |
|     | 4      | 50.82     | 54.41   | 51.48   | 266.00 | 1620 | 6.07 |
|     | 5      | 54.91     | 52.92   | 50.87   | 267.70 | 1640 | 5.76 |
| 0.5 | 1      | 52.82     | 51.35   | 54.22   | 259.20 | 1640 | 5.62 |
|     | 2      | 51.84     | 55.23   | 51.06   | 260.60 | 1600 | 5.93 |
|     | 3      | 52.53     | 51.42   | 52.41   | 266.90 | 1480 | 5.27 |
|     | 4      | 50.62     | 52.68   | 52.19   | 265.30 | 1280 | 4.75 |
|     | 5      | 53.44     | 53.51   | 51.36   | 261.60 | 1460 | 5.22 |

3. Results and discussion
The compressive strength test of interlocking brick specimens with cubes measuring 50 × 50 × 50 mm is carried out at the age of 7 days, 14 days, and 28 days. The results of the average compressive strength test of mortar with variations of WCR 0.3, 0.4, and 0.5 with a mixture of 1:2:2 are shown in tables 1, 2, and 3 below.

| WCR | Sample | Dimension | Weight | Load | Compressive Strength | Average Compressive Strength |
|-----|--------|-----------|--------|------|----------------------|----------------------------|
|     |        | Length (mm) | Width (mm) | Height (mm) | (g) | (kgf) | (MPa) | (MPa) |
| 0.3 | 1      | 54.14     | 52.30   | 51.42   | 273.30 | 2860 | 10.07 |
|     | 2      | 54.59     | 52.75   | 49.92   | 271.80 | 2900 | 10.44 |
|     | 3      | 53.54     | 50.60   | 52.25   | 269.40 | 2440 | 8.55 |
|     | 4      | 52.49     | 54.23   | 52.00   | 271.10 | 2440 | 8.77 |
|     | 5      | 52.39     | 54.21   | 51.65   | 264.10 | 2660 | 9.64 |
Table 3. Compressive strength of interlocking brick at 28 days old with a mixture of 1:2:2.

| WCR | Sample | Dimension | Weight | Load | Compressive Strength | Average Compressive Strength |
|-----|--------|-----------|--------|------|----------------------|-----------------------------|
|     |        | Length (mm) | Width (mm) | Height (mm) | (g) | (kgf) | (MPa) | (MPa) |
| 0.3 | 1      | 51.47     | 54.13   | 51.48  | 267.70  | 3080 | 11.40 | |
|     | 2      | 54.87     | 54.14   | 51.11  | 281.50  | 2880 | 10.07 | |
| 0.4 | 3      | 51.24     | 51.22   | 52.69  | 262.80  | 3180 | 11.55 | 10.94 |
|     | 4      | 52.28     | 52.60   | 52.89  | 269.10  | 3060 | 10.85 | |
|     | 5      | 52.05     | 51.92   | 53.98  | 275.40  | 3100 | 10.82 | |
| 0.5 | 1      | 53.58     | 50.29   | 54.86  | 259.50  | 2620 | 8.74  | |
|     | 2      | 54.51     | 54.36   | 52.13  | 271.30  | 2920 | 10.08 | |
|     | 3      | 51.78     | 52.54   | 59.93  | 272.70  | 3480 | 11.00 | 9.77  |
|     | 4      | 52.51     | 55.55   | 52.13  | 272.00  | 2780 | 9.96  | |
|     | 5      | 52.95     | 51.07   | 51.80  | 248.90  | 2540 | 9.08  | |
| 0.4 | 1      | 54.05     | 53.70   | 50.17  | 266.40  | 3080 | 11.14 | |
|     | 2      | 50.50     | 52.85   | 53.17  | 262.30  | 2920 | 10.66 | |
|     | 3      | 53.54     | 51.50   | 53.26  | 265.10  | 2640 | 9.08  | 9.93  |
| 0.5 | 4      | 50.81     | 52.59   | 53.89  | 265.50  | 2800 | 10.03 | |
|     | 5      | 54.08     | 49.97   | 53.97  | 259.40  | 2600 | 8.74  | |

From the results of the compressive strength test of the interlocking brick, it can be seen the decrease in compressive strength along with the magnitude of the WCR value, and the longer the life of the concrete, there will be an increase in the compressive strength of the interlocking brick. For WCR 0.3, compressive strength averages at 7 days 8.10 MPa, 14 days 9.49 MPa, and 28 days 10.94 MPa. For WCR 0.4, compressive strength averages 7 days 5.69 MPa, 14 days 7.61 MPa, and 28 days 9.77 MPa. And for WCR 0.5 the average compressive strength at the age of 7 days is 5.36 MPa, 14 days 8.25 MPa, and 28 days 9.93 MPa.

In the mixture of WCR values of 0.4 and 0.5, the mixture of interlocking brick material is difficult to do (workability) so the compaction is not perfect. As a result, the specimen becomes hollow which causes the compressive strength of the concrete to decrease. In general, the higher the WCR value, the lower the concrete quality will be, but the lower WCR value does not always mean the concrete strength will be higher.

The highest compressive strength of interlocking bricks is 10.94 MPa at WCR 0.3 at 28 days and the lowest compressive strength is 5.36 MPa at WCR 0.5 at 7 days. The results of the compressive strength...
test of the interlocking brick with a WCR variation of 0.3; 0.4; and 0.5 with a mixture of 1:2:2, all specimens meet the mechanical requirements of SNI 03-0349-1989 with the quality level I can be used as construction material in wall work for construction that is burdened and unprotected and the compressive strength planned is fulfilled as hollow concrete brick material with a compressive strength of not less than 7 MPa.

![Compressive Strength Graph](image)

**Figure 1.** The graph of compressive strength relationship at 7 days, 14 days, and 28 days with a mixture of 1:2:2.

Interlocking brick can be used as a nonstructural and structural wall material such as replacing sloof, column, and ringbalk. The results showed that interlocking bricks produced included in the level of quality I so that when used for non-structural walls is very cost-saving. Interlocking bricks need to be re-tested using different mix compositions so that we get interlocking bricks with different functions, namely that there are constructions that can carry loads and do not carry loads.

### 4. Conclusion

Based on the results of the study it can be concluded that the highest compressive strength of interlocking bricks at WCR 0.3 is the concrete age reaching 28 days. Interlocking brick compressive strength test results found that all the test specimens with a mixture of 1:2:2 and with variations of WCR 0.3; 0.4; 0.5 meets the mechanical requirements of SNI 03-0349-1989 with a quality level I. This research needs to be developed further by using other types of materials with different mixture designs so that an effective and efficient mixture is obtained.

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