Relationship between Density and Early Compressive Strength of Slurry Infiltrated Fiber Reinforced Concrete (SIFCON)

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Abstract. The aim of the study is to study the physical and mechanical characteristics of Slurry Infiltrated Fiber Reinforced Concrete with fiber percentage volume of 5% and lower. For the testing of physical characteristics of the concrete, density test been conducted. For the testing of mechanical characteristics, compression test used to determine strength of concrete sample. The density of Slurry Infiltrated Fiber Reinforced Concrete increased when the usage of steel fiber percentage volume increases from 1% to 5%, nevertheless when compared to density of ordinary concrete, ordinary concrete is denser. For the significant of study, the mechanical properties of Slurry Infiltrated Fiber Reinforced Concrete, compressive strength increased when the fiber content increases from 1% to 5% percentage volume.

1. Introduction

One of the recently discovered type of concrete is a special type of self-compacting high-performance fiber-reinforced concrete (HPFRC) called Slurry Infiltrated Fiber Reinforced Concrete (SIFCON). The SIFCON produced by preplacing short discrete fibers in randomly oriented manner in the mold to the desired volume fraction, thus forming a network. A fine liquid cement based slurry or mortar then infiltrates the fiber network. The percentage of fibers by volume can be anywhere from 5% to 20% [1]. Experiment result based on previous researchers have shown that the different percentage volume of SIFCON give different result of performance of the concrete [2].

Number of cracking of concrete structures and components have been and still is surging, the cracks occurs even when specifications were closely followed and the concrete designed, supplied, placed, and cured in accordance with formal standards and good practices of the construction industry. Often, cracks occurred soon after the concrete hardened, but then continued to grow over many months or even years [3]. Most of the cracks formed due to the inherent weakness of the material to resist tensile forces [4]. Concrete usually exhibits large numbers of micro cracks even before it subjected to any loads [5]. During loading, cracks will typically form at interfacial transition zone, generally the weakest part of most hardened concrete, and influence the mechanical properties of the concrete. Due to its low tensile strain
capacity, concrete has a brittle behavior, and cracks are almost inevitable in any concrete structure [6].

The current practical percentage of fibers ranges from 5 to 12%. Since previous study consider more or equal to 5% of fiber percentage volume in the research, little known about the properties of SIFCON at lower percentage of fiber volume. In this research, the fiber percentage volume used was 1%, 3% and 5%.

2. Materials and Methods

2.1 Design Specimen

The materials used are Portland cement, coarse aggregate with 20 to 15 mm in size, fine aggregate with size less than 4.75 mm, portable water, and hook end stainless still fiber with length of 30 mm, diameter of 70 mm and aspect ratio of 43. M25 concrete chosen as an experimental grade with mix ratio of 1:1.5:3 and w/c ratio of 0.5. A total of 24 cube prisms were casted. In the beginning, 6 control cube specimens was casted using ordinary method of casting concrete with the ratio of 1:1.5:3 and 0.5 water cement ratio. Next, 18 cube specimens was casted using Slurry Infiltrated Fiber Reinforced Concrete (SIFCON) method which is to fully replace the coarse aggregate by steel fibers, so the mixing materials are cement, sand, steel fibers and water. The percentage volume of hook end steel fibers used was 1%, 3% and 5% in this research. After casting the concrete, the concrete placed at a shaded place for 24 hours then the concrete will be cure inside a curing tank. The concrete cured for 7 days and 28 days period inside a curing tank.

2.2 Properties of Hardened Concrete

The properties of hardened concrete need to be determine to evaluate the density and durability of concrete. The density of a hardened concrete is a measurement of concrete’s solidity whereas durability of concrete plays a critical role in controlling its serviceability. The durability of concrete is mainly dependent on the permeability of concrete. Thus, the properties of hardened concrete examined by conducting density test.

2.3 Mechanical Characteristics of SIFCON

Destructive test using universal compression machine been conducted in this research. Compression test is a mechanical test that establishes the compressive force or crush resistance of a material and the ability of the material to recover after a specified compressive force is applied. Compression tests used to determine the material behavior under a load.

3. Results and Discussion

3.1 Density Test Result

From table 1. when the percentage volume of fiber increases from 1% to 5%, the density also increases. The density for 1% fiber percentage volume is the lowest for fresh concrete. At 7 days and 28 days curing which is 2015 kg/m³, 1959 kg/m³ and 1977kg/m³ respectively whereas the highest density is at 5% fiber volume which measured 2380 kg/m³, 2310 kg/m³ and 2340 kg/m³ for fresh concrete state, 7 days and 28 days curing respectively. Since the addition of steel fiber results in an increased in density, varying from 1977 kg/m³ to 2340 kg/m³ at 28 days curing for steel volume fraction ranging from 1% to 5% percentage volume, the density of the sample increase is almost linearly proportional to the fiber content added. Comparatively, the density of ordinary concrete is higher than all SIFCON sample is due to the constituent material used to prepare SIFCON sample only consists of cement, sand and water. With the exclusion of coarse aggregate in the matrix, the density SIFCON samples will be lower than ordinary concrete. Another reason is due to the incomplete penetration of slurry to the preplaced steel fiber inside the mold, there was more entrapped air in between the steel fiber in concrete matrix and this makes the density of SIFCON lower than that of ordinary concrete.
### Table 1. Result of density test for cube sample.

| Curing days | Sample no. | Ordinary Concrete | 1% | 3% | 5% |
|-------------|------------|-------------------|----|----|----|
| Fresh       | Average    | 2473              | 2015 | 2177 | 2380 |
| 7 days      | Average    | 2438              | 1959 | 2105 | 2310 |
| 28 days     | Average    | 2453              | 1977 | 2130 | 2340 |

#### 3.2 Compressive Strength Result

The compressive strength of each sample obtained from compression testing. For each type of cube, 3 samples were tested to get an average and more accurate results. Table 2 and table 3 shows the result of compressive strength and the maximum load of ordinary concrete and SIFCON.

### Table 2. Result of compressive strength test for ordinary concrete.

| Sample     | Curing days | Compressive strength (Mpa) | Maximum load (kN) | Average (Mpa) |
|------------|-------------|-----------------------------|-------------------|---------------|
| Control-1a | 7           | 29.146                      | 291.47            |               |
| Control-1b | 7           | 33.775                      | 337.76            | 29.976        |
| Control-1c | 7           | 27.006                      | 270.06            |               |
| Control-2a | 28          | 25.936                      | 259.36            |               |
| Control-2b | 28          | 28.369                      | 283.69            | 28.635        |
| Control-2c | 28          | 31.600                      | 316.01            |               |

The compressive strength results of normal concrete with 7 days and 28 days curing ages. The ordinary concrete designed to achieve a compressive strength of 25Mpa. From the figure 1, the compressive strength for concrete cube is 29.976 MPa and 28.635 MPa at 7 days and 28 days respectively. The 7 days strength is slightly higher than the 28 days strength, which contradicts, with the theoretical strength of concrete as the compressive strength of a concrete should be higher from 7 days to 28 days due to effect of hydration effect inside the concrete. The of possible cause of this condition might due to environmental factor which is the concrete is cured under a higher temperature of water tank during the 7 days curing period that will increase the rate of hydration inside the concrete. Nonetheless, both 7 days and 28 days strength has achieved the design compressive strength of 25 MPa.
Figure 1. Result of compressive strength for ordinary concrete (MPa).

Table 3. Result of compressive strength test for SIFCON.

| Sample | Percentage of steel fiber (%) | Curing days | Compressive strength (MPa) | Maximum Load (kN) | Average (MPa) |
|--------|-------------------------------|-------------|----------------------------|-------------------|---------------|
| C1-1a  | 1%                            | 7           | 8.651                      | 86.506            |               |
| C1-1b  | 1%                            | 7           | 11.073                     | 110.732           | 10.186        |
| C1-1c  | 1%                            | 7           | 10.835                     | 108.348           |               |
| C2-1a  | 3%                            | 7           | 10.997                     | 109.974           |               |
| C2-1b  | 3%                            | 7           | 11.339                     | 113.388           | 11.762        |
| C2-1c  | 3%                            | 7           | 12.951                     | 129.513           |               |
| C3-1a  | 5%                            | 7           | 21.511                     | 215.107           |               |
| C3-1b  | 5%                            | 7           | 23.189                     | 231.887           | 24.061        |
| C3-1c  | 5%                            | 7           | 27.482                     | 274.819           |               |

Figure 2 shows the result of compression test at 7 days of curing ages. From the chart, the compressive strength of SIFCON with 1%, 3% and 5% of steel fiber percentage volume is 10.186 MPa, 11.762 MPa and 24.061 MPa respectively. Thus, the compressive strength of SIFCON increases with the addition of steel fiber in percentage volume. In addition, compressive strength of SIFCON with 5% steel fiber at 7 days has almost achieved the designed strength of 25 MPa, which is supposed to be achieved at 28 days.
3.3 Relationship between Density test and Compressive Strength

The density of concrete is a measurement of its unit weight. The density of concrete differs depending on the quantity and density of the aggregate, the amount of entrapped air, and water and cement content. A lowered density concrete means that the concrete is with higher water content and thus, lower concrete strength [7]. Adversely, a denser concrete typically provides higher strength and lesser amount of void and porosity. This means that denser concrete become less permeable to water and soluble elements due to smaller void, thus, lowered the absorption capacity and better durability can be expected from a denser concrete.

In figure 3 when the steel fiber percentage volume increases from 1% to 3% to 5%, the density of the concrete and compressive strength also increases but the relationship between density and compressive strength is parabolic relationships.

![Graph of density against early compressive strength.](image-url)
4. Conclusion
SIFCON method could reduce the cracks at the interface as the matrix composed of only fine aggregates without the coarse aggregates. Addition of steel fiber can also grant the concrete with good crack resistance. This is because when steel fiber distributed evenly throughout the SIFCON matrix; there will always be steel fibers near the surroundings of micro-cracks. From the experimental result, density and compressive strength of SIFCON increased when the usage of steel fiber percentage volume increases from 1% to 5%. This means that the quality and compressive strength of SIFCON increases when the fiber percentage volume increased. This also means that SIFCON will be more durable with the increasing usage of steel fiber. Hence, it is determined that the 5% fiber percentage volume is the optimum percentage among three percentages because SIFCON with 5% fiber percentage has better physical and mechanical performance than the other two percentages.

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