Effect of Combination of Steel Fibre and Silica Fume on the Mechanical Strength of Concrete

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Abstract. Concrete currently consists of several types. Among them are Fibrous Concrete, Lightweight Concrete, SCC Concrete, Hollow Concrete etc. All have advantages and disadvantages to each. The use of various types of concrete is adjusted to the needs of construction. In this research, fibrous steel concrete with a combination of silica fume will be the main object to be studied. So far, fibrous concrete has been actively studied in various countries. From the results of previous studies, fibrous concrete can improve the quality of concrete, especially reducing the brittle nature and initial cracking in concrete. While Silica Fume can increase the compressive strength of concrete. The main objective of this study to determine and understand the mechanical properties of concrete with a combination of steel fibre and silica fume such as compressive strength and split tensile strength. The percentage of steel fibre percentage used in this study is from 0 to 3 per cent, while the percentage of silica fume used is 10 per cent by weight of cement. The results of a study are the optimum compressive strength is in the DF1 variation with the percentage of silica fume 10 per cent and 0 per cent steel fibre. The use of steel fibre combined with silica fume does not significantly affect the compressive strength. Although it tends to decrease the compressive strength. The strength of tensile strength obtained ranges from 11 to 14 per cent of the compressive strength.

1. Introduction
Concrete is a material commonly used in various infrastructure buildings. The development of concrete technology from time to time is very rapid. The high volume of utilisation of concrete materials in construction encourages the Engineers and Scientists to continue to innovate to produce concrete material products that have good quality in terms of strength and durability. Concrete with good strength and durability will reduce maintenance costs to achieve economic material criteria. Combining several materials that have different physical and chemical characteristics is an innovative step in producing a quality construction material product such as concrete. Material developed in this study is concrete material that uses silica fume as filler and steel fibres. These two types of material will be combined in a concrete mixture to obtain optimal mechanical strength.

There have been many studies conducted regarding the use of silica fume in concrete. Various combinations of a local natural pozzolan and silica fume were used to produce workable high to very high strength mortars and concrete with a compressive strength in the range of 69±110 MPa [1] Shannag, 2000. Almusallam et al,2004 [2] investigated the effects of silica fume (15%) on the compressive strength of concrete made with low-quality coarse aggregates (calcareous, dolomitic, and quartzitic limestone and steel slag). It was observed that compressive strength increased with age in all the concrete specimens. After 180 days of curing, the highest compressive strength was noted in the 15% silica fume cement concrete specimens (54 MPa) followed by those prepared with 10% silica...
fume (52 MPa). Silica fume (SF) is a by-product of the silicon and ferrosilicon industry. The reduction of high-purity quartz to silicon at temperatures up to 2000 °C produces SiO2 vapours, which oxidises and condense in the low-temperature zone to tiny particles consisting of non-crystalline silica. When silica fume is added to concrete, it results in a significant change in the compressive strength of the mix. This is mainly due to the aggregate-paste bond improvement and enhanced microstructure [3] Siddique et al., 2011.

Steel fibre is widely used in concrete mixtures. Steel fibres have a considerably larger length and higher Young’s modulus as compared to the polypropylene fibre. This leads to an improved potential for crack control [4] Qian et al., 2000. In 2007 Sivakumar et al. has been made to study the synergistic behaviour of hybrid combinations of steel and non-metallic fibres in controlling plastic shrinkage cracks. It revealed Plastic shrinkage cracks were reduced significantly by fibre addition (by 50–99% compared to plain concrete without fibres); hybrid fibres were more effective in crack reduction compared to individual steel fibres [5]. Because of the cases above, the combination of two material components with different characteristics can have a good effect on the mechanical properties of concrete.

2. Materials
The main concrete forming material to be used is prepared in advance, namely, Cement, Split, Sand, Silica Fume and Steel Fiber. The cement used is PCC cement. Silica Fume used is silica fume produced by PT Sika. Whereas steel fibre that will be used as a substitute material is steel fibre produced by Bekaert.

2.1. Aggregates
An aggregate test is performed first to find out the physical and mechanical characteristics of the aggregate. Aggregate testing will later become a reference in the concrete mix design. The aggregates to be tested are coarse and fine aggregates. The test that will be carried out is the Filter analysis test to find out the gradation/size of aggregate grains, sludge content testing, which aims to determine the percentage of sludge content in the aggregate. Sludge levels exceeding the 5% limit must be carried out by aggregate washing. Besides, water absorption and specific gravity testing will be carried out so that the amount of cement water factor can be determined as a factor in determining the compressive strength of concrete.

All of the aggregate testings follow ASTM standards. Physical characteristics of fine aggregate is a reference in determining the water-cement ratio in a concrete mix design. Fine aggregate test results can be seen in Table 1.

| Physical Properties        | Value |
|----------------------------|-------|
| Fine modulus               | 2.73  |
| Specific Gravity (SSD)     | 2.17  |
| Water Absorption (%)       | 2.04  |
| Water Content (%)          | 4.16  |

Coarse aggregates are gravel as a result of natural disintegration of rocks or in the form of broken stones produced by the stone-breaking industry and have grain sizes between 5 mm - 40 mm. Physical Coarse aggregate test results can be seen in Table 2. Aggregate testing is carried out in surface saturated dry conditions (SSD). The total dry aggregate condition will affect the value of the concrete slump. Slump values that are too small will reduce concrete workability.

| Physical Properties        | Value |
|----------------------------|-------|
| Fine Modulus               | 7.11  |
| Specific Gravity (SSD)     | 2.65  |
Water Absorption (%)  
 Dry volume weight (kg/m$^3$)  
 Size (mm)  
 Water Content (%)  

2.2. Silica Fume and Steel Fibre
Compared to cement granules. With a very fine particle size, silica fume can fill the space so that the concrete mixture has a saturation process (tighter) which can increase its compressive strength and impermeability. More than 95% of silica fume particles are finer than 1 µm. Its typical physical properties are given in Table 3 [3].

Table 3. Silica Fume Properties (Silica Fume and Association, 2005 [6])

| Physical Properties | Value |
|---------------------|-------|
| Particle Size       | < 1 µm|
| Bulk Density (as-produced) | 130–430 kg/m$^3$ |
|                     | (slurry) | 1320–1440 kg/m$^3$ |
|                     | (densified) | 480–720 kg/m$^3$ |
| Specific Gravity    | 2.22   |
| Surface Area        | 13000-30000 m$^2$/kg |

Steel fibre Dramix is used in this study. The steel fibres Dramix 3D have 60 mm in length (l), 0.90 mm in diameter (d), 65 length/diameter ratio (l/d), with 1160 MPa of tensile strength and 210 GPa of modulus of elasticity [7]. Silica fume and steel fibre used in this study can be seen in Figure 1.

Figure 1. Silica Fume And Dramix Steel Fibre

3. Experimental Programs
Concrete will reach optimal strength after 28 days of immersion. To test the strength of concrete steps taken is to test the compressive strength of concrete using a compression testing machine that aims to determine the strength of concrete in bearing axial compressive load. In addition, a tensile strength test will be conducted / Split Tensile Test to determine the concrete split tensile capacity. The Unconfined Compression Strength tests were conducted according to ASTM C873 (ASTM International 2010a) and ASTM C496 (ASTM International 2010b), respectively. Test Set up of the specimen can be seen in Figure 2.
In this research, eight variations of concrete cylinder specimens will be made. Each specimen uses 10% silica fume, which will be combined with steel fibre. The composition of Steel Fibre varies from 0 to 3 per cent by weight of cement. The compressive strength of the normal concrete plan used is 21 MPa with a water-cement ratio of 0.674. The variation of the percentage of silica fume and steel fibre can be seen in Table 4.

| Specimen Label | Cement (%) | Silica Fume (%) | Steel Fibre (%) |
|----------------|------------|----------------|-----------------|
| DF0            | 100        | 0              | 0               |
| DF1            | 90         | 10             | 0               |
| DF2            | 89.5       | 10             | 0.5             |
| DF3            | 89         | 10             | 1               |
| DF4            | 88.5       | 10             | 1.5             |
| DF5            | 88         | 10             | 2               |
| DF6            | 87.5       | 10             | 2.5             |
| DF7            | 87         | 10             | 3               |

4. Results and Discussion

Concrete compressive strength is the maximum compressive strength that can be carried concrete per unit area. Normal concrete compressive strength between 20 - 40 MPa. Concrete compressive strength is influenced by water-cement ratio \((w / c)\), the nature and type of aggregate, type of mixture, workability, curing and concrete age. Water Cement ratio \((w / c)\) greatly affects the compressive strength of concrete. The smaller the \(w / c\) value, the less amount of water will produce a large concrete compressive strength. Concrete compressive strength can be calculated by equation 1.

\[
f'c = \frac{P}{A}
\]

Where \(f'c\) is the compressive strength of concrete, \(P\) is the compressive force and \(A\) is the area of the compressive plane. Concrete tensile strength is a measure of the tensile strength of concrete. Concrete has a low tensile strength. The tensile strength of concrete can be measured by conducting a concrete split tensile test. The tensile strength of concrete slabs can be calculated by Equation 2.
\[ T = \frac{2P}{\pi L d} \]  \hspace{1cm} (2)

Where \( T \) is the tensile strength of concrete, \( P \) is the Maximum applied load, \( d \) is the cross-section diameter, and \( L \) is the length of the cylinder. After the concrete compressive strength test and split, tensile test results are obtained as shown in Table 5.

### Table 5. Mechanical Test results of Specimen

| Mixture | Compressive Strength 28 Day (MPa) | Split Tensile Strength 28 Day (MPa) |
|---------|-----------------------------------|-----------------------------------|
| DF0     | 21.40                             | 2.866                             |
| DF1     | 26.32                             | 2.87                              |
| DF2     | 24.57                             | 3.014                             |
| DF3     | 24.33                             | 3.027                             |
| DF4     | 24.20                             | 2.979                             |
| DF5     | 23.52                             | 2.974                             |
| DF6     | 22.18                             | 2.931                             |
| DF7     | 22.11                             | 2.939                             |

Table 5 shows the highest compressive strength obtained by the variation of DF1 specimens of 26.32 MPa. In the DF1 specimen, the percentage of silica fume used was 10 per cent. While the percentage of steel fibre use in DF1 is 0 per cent. In the variation of the DF1 mixture, there has been no contribution to the increase in strength provided by steel fibre. Based on the compressive strength data of DF0 and DF1 specimens, there was an increase in strength of 18.7 per cent with the addition of silica fume. Meanwhile, when there is a contribution from the addition of 5% steel fibre to the mixture, the compressive strength decreases in the DF2 specimen. The decrease in strength that occurs is 6.7%.

![Graphically the relationship of the variation of the composition of the test specimen to the compressive strength can be seen in Figure 3. Figure 3 shows that the strength of DF2 to DF7 has a difference below 6%. The smallest strength occurs between DF6 and DF7 by 0.2%. The tendency of the curve formed is ideally a 3rd order polynomial curve where the value of R square is 0.72. Linear curves are not very relevant to be used to see the number R squared below 0.5 that is equal to 0.117.](image-url)
Based on the data in Table 3 and Figure 4, it can be seen that the highest split tensile strength is in the DF3 specimen with a percentage of Steel fibre of 1%. The difference between the Split tensile strength of concrete to the compressive strength of concrete ranges from 86 to 89 per cent. This shows that the tensile strength of concrete slides ranges from 11 to 14 per cent of the compressive strength. The ideal curve that can be used is the polynomial 3rd order curve with the number R square 0.736.

5. Conclusion
From the results of a study conducted obtained several conclusions. The optimum compressive strength is in the DF1 variation with the percentage of silica fume 10 per cent and 0 per cent steel fibre. The use of steel fibre combined with silica fume does not significantly affect the compressive strength. Although it tends to decrease the compressive strength, the decline is no more than 10 per cent. The highest split tensile strength was obtained in the DF3 variation with the percentage of silica fume 10 per cent and 1 per cent steel fibre. The strength of tensile strength obtained ranges from 11 to 14 per cent of the compressive strength.

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