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Study on Influence of Water-Cement Ratio on The Strength of Micro Steel Fiber Reinforced Concrete (MSFRC)

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Abstract: Steel fiber reinforced concrete (SFRC) is the most commonly used Fiber FRC in construction industry. SFRC is favored because it can prevent early cracks in concrete. The objectives of this study are to investigate the influence of water cement ratio towards the strength of micro steel fiber reinforced concrete (MSFRC). This study focuses on the strength of MSFRC under different water-cement (w/c) ratio. In this study, a constant 1.0% of fiber volume percentage with 12mm length of copper coated micro steel fiber was added into the mix concrete with different water cement (w/c) ratio. The variation of w/c ratio used in this study are 0.3, 0.4, 0.5 and 0.6. At hardened state, the compressive strength test was conducted at 7th and 28th days of curing and for splitting tensile strength was conducted on the 28th day of curing to show the mechanical properties of concrete tested and slump test is conducted to assess the consistency of concrete at fresh state. The study shows that, the optimum water-cement (w/c) ratio of MSFRC designed grade 30 is 0.4 which is lesser than normal grade 30 concrete.

Keywords: Micro Steel Fiber Reinforced Concrete (MSFRC), Micro Steel Fiber (MSF), Water-Cement Ratio (W/C Ratio)

1. Introduction

Concrete is the most commonly used material in the construction of structures such as towers, bridges, residences, and other structures. Advances in concrete technology have enormous potential in the construction industry, whether for structural or non-structural construction [1]. The fundamental components to creating concrete are sand, aggregate, water, and cement. All these materials affect the strength of concrete with different types or mix ratios [2]. Unreinforced concrete has low tensile strength which can cause fractures. Traditionally, this deficiency is resolved by inserting or pre-stressing reinforcement bars. The steel reinforcement is continuous and is precisely placed in the structure to maximize its performance.

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At the beginning of the 1900s, the use of asbestos fiber was noted. In 1950, fiber-reinforced concrete became an area of concern, as asbestos was recognized as a health risk [3]. Using glass or steel fibers is more workable than using synthetic fibers such as nylon and polypropylene [4]. Researchers believe that both synthetic and natural fibers can efficiently strengthen concrete as a result of a better understanding of the principles behind fiber reinforcement, advanced processing techniques, and new kinds of organic fiber [5]. Micro steel fibers are of cutting drawn wires into micro sizes. Many types of micro steel fibers can be used for either commercial or experimental usage.

Concrete's characteristics are influenced by the water-cement ratio and the cementitious materials employed in the mix. The cement paste would have a higher density if the amount of water in it was reduced, resulting in better paste consistency and hence better compressive strength and lower permeability [6]. The presence of additional water in the mixture is important to make the concrete workable. Low water content of the mixture can result in a stiffer mixture, which decreases workability and increases possible difficulties in placement.

Other than micro steel fiber-reinforced concrete being an alternative construction material, it is also shown that various problems have been encountered due to the reduced workability of MSFRC. The water-cement ratio has a significant impact on MSFRC because a higher w/c ratio causes fibers and aggregates to settle at the bottom of the mould, making concrete mix production more difficult [1]. Due to the accumulation of fibers in the location where the crack was initiated, this will result in the first crack load. The negative impact such as the reduction of workability of MSFRC is because fibers reduced the fluidity of the material [7]. This may cause the fresh concrete to be harder to compact and also leads to the low strength of concrete at a hardened state due to the honeycomb effect. Hence, affecting the sustainability of the construction of concrete materials using MSFRC. The objectives of this paper are to investigate the influence of water-cement ratio towards the strength of MSFRC and to determine the optimum water-cement ratio for mixing of MSFRC.

2. Materials and Methods

The experiments were conducted on MSFRC on targeted days, which was on the 7th and 28th days respectively. The targeted strength for MSFRC at 28 days is 30 MPa.

2.1 Micro steel fiber

In this study, the type of steel fiber used was copper-coated fiber with length and diameter of 12mm and 0.25mm, respectively as shown in Figure 1. The micro steel fiber (MSF) is manufactured by Qingdao Sdgeo Fiber. Table 1 shows the properties of the micro steel fiber.

Figure 1: Copper micro steel fiber

Table 1: Properties of micro steel fiber

Properties	Value
Length (mm)	12
Diameter (mm)	0.25
L/D ratio	50
Tensile strength (MPa	2930

2.2 Mix design

The design mix standard used for this experimental research is the standard British (DOE) mix design. The mix of concrete is designed with different water-cement ratios and a constant micro steel fiber volume fraction of 1.0%. Superplasticizer of 1.0% by volume was poured in the mixture to increase the fluidity of mixture without adding water. The proportion of each specimen is listed in Table 2.

Table 2: Mix design of concrete

Water-cement ratio	Fiber volume fraction (%)	Water (kg/m3)	Cement (kg/m3)	Fine aggregate (kg/m3)	Coarse aggregate (kg/m3)
0.3	1.0	210	700	415.8	1124.2
0.4	1.0	210	525	497.0	1218.0
0.5	0.0	210	420	546.0	1274.0
0.5	1.0	210	420	546.0	1274.0
0.6	1.0	210	350	585.9	1304.1

2.3 Testing procedure

The mixing process of concrete cubes with length of 150mm and concrete cylinders of (100mm X 200mm) was done according to BS EN 12390-1:2012. The samples then are cured with curing in water process for 7 and 28 days. The percentage of MSF used was according to past research. [1] had observed that 1.0% of steel fibers give the optimum compressive strength of SFRC, this is similar to the study done by [9], that suggested the volume fraction of MSF is between 0.5% to 1% considering the workability and mechanical properties, of MSFRC. Thus, in this study, the percentage of micro steel fibers used was fixed at 1%. However, the water-cement ratio used was varied at 0.3, 0.4, 0.5 and 0.6. Table 3 and Table 4 shows the total number of specimens for both compressive strength test and splitting tensile strength test.

Table 3: Total number of specimens for compressive strength test

Specimen	Fiber volume fraction, Vf (%)	Water-cement ratio	Number of specimens	
			7^{th} day	28^{th} day
Control	0	0.5	3	3
A	1	0.3	3	3
B	1	0.4	3	3
C	1	0.5	3	3
D	1	0.6	3	3
Total number of specimens			15	15

Table 4: Total number of specimens for splitting tensile strength test

Specimen	Fiber volume fraction, Vf (%)	Water-cement ratio	Number of specimens on the 28^{th} day of curing
Control	0	0.5	3
A	1	0.3	3
B	1	0.4	3
C	1	0.5	3
D	1	0.6	3
Total number of specimens			15

2.4 Experimental work

The samples were tested for workability of fresh MSFRC by conducting slump test and mechanical strength with both splitting tensile strength test and compressive strength test in this study. At fresh state, slump test was conducted. The equipment used in this test was specified in BS EN 12350-2:2019 which were hollow cone, compacting rod, funnel, rule, base plate/surface, tray, shovel, moist cloth, scoop, timer and trowel. The procedure of this test was accordance to BS EN 12350-2:2019. The design slump is between 30-60 mm. Cube specimens of MSFRC with different w/c ratios were tested for compressive strength. The test was done according to standard BS EN 12390-3: 2019. Moulds were being used to deposit the concrete mix. The hardened samples were then removed from the moulds after 24 hours for curing process. 30 samples were prepared and examined after 7 and 28 days. The splitting tensile strength test was carried out on 15-cylinder samples of MSFRC until it cracked. The tensile tension was applied to the samples indirectly, causing it to crack. The tensile strength test was determined in compliance with BS EN 12390-6:2009 in this investigation. Both tests were conducted using a universal testing machine (UTM), as indicated in Figure 2.

Figure 2: Universal Testing Machine (UTM)

3. Results and Discussion

9 of the total concrete specimens were controlled specimens. The controlled specimen is a plain concrete grade 30 without MSF with w/c ratio of 0.5. The purpose of this controlled specimen is to show the difference in the workability and mechanical strength of concrete grade 30 with and without MSF.

3.2 Slump test

The slump test results in Table 5 and Figure 3 shows all mix falls in the range of design slump, which is 30 – 60 mm except for MSFRC mix design w/c ratio of 0.3 w/c. There was a decrease in the slump result of MSFRC of a 0.5 w/c ratio when compared to a 0.5 w/c ratio of the controlled specimen. In percentage, 25% of differences in the value of slump obtained. This shows that the addition of MSF affects the workability of concrete as steel fibers are prone to clumping due to their relatively rigid nature, this problem can cause the flow of the aggregates and cement paste around them to be restricted [10]. In addition, a higher w/c ratio, which is 0.6 has the best workability of MSFRC at fresh state which is 55 mm. This is because high water content can reduce the possibility of steel fibers from clumping and could ease the flow of the fresh concrete. Consequently, a higher w/c ratio results in greater workability of MSFRC.

Table 5: Slump test result

Water-cement content	Slump (mm)
0.5 (Control)	60
0.3	25
0.4	30
0.5	45
0.6	55

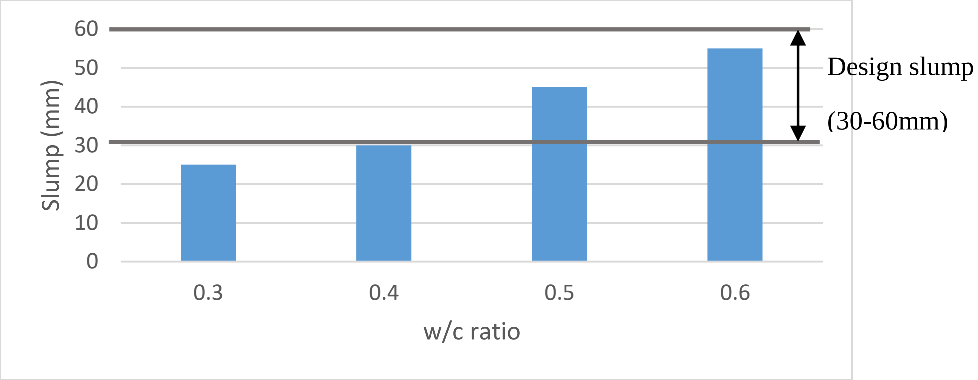

Figure 3: Slump vs w/c ratio

3.3 Compressive strength

3.3.1 Compressive strength for 7 days

From Table 6 and Figure 4, the compressive strength of MSFRC increased to peak before it drops gradually. At a 0.3 w/c ratio, the average compressive strength achieved was 40.9MPa. The strength of MSFRC increases to 43.4 MPa with a w/c ratio of 0.4 before it decreases gradually to 32.3 MPa for a 0.5 w/c ratio and the lowest, 21.5 MPa for a 0.6 w/c ratio. The highest value observed was 43.3 MPa with a w/c ratio of 0.4. When comparing the strength achieved by a 0.5 w/c ratio of MSFRC to normal plain concrete with 34.4 MPa, there was an increase of 26.2% of strength by percentage. Concrete w/c ratio of greater than 0.4 with MSF of 1% has lower compressive strength than normal plain concrete (controlled specimen). In addition, MSFRC with a 0.6 w/c ratio does not even pass the target strength of 30 MPa. Compressive strength of MSFRC decreases when the w/c ratio increases. The strength of concrete at 7 days is only 65%, thus the concrete compressive strength would be higher at 28 days of curing.

Table 6: Compressive strength of MSFRC for 7 days

W/c ratio	fc (MPa)			
	CST1	CST2	CST3	Average
0.5 (control)	32.0	34.3	36.6	34.3
0.3	40.7	41.2	40.8	40.9
0.4	42.0	44.7	43.2	43.3
0.5	31.5	33.2	32.2	32.3
0.6	21.7	21.2	21.6	21.5

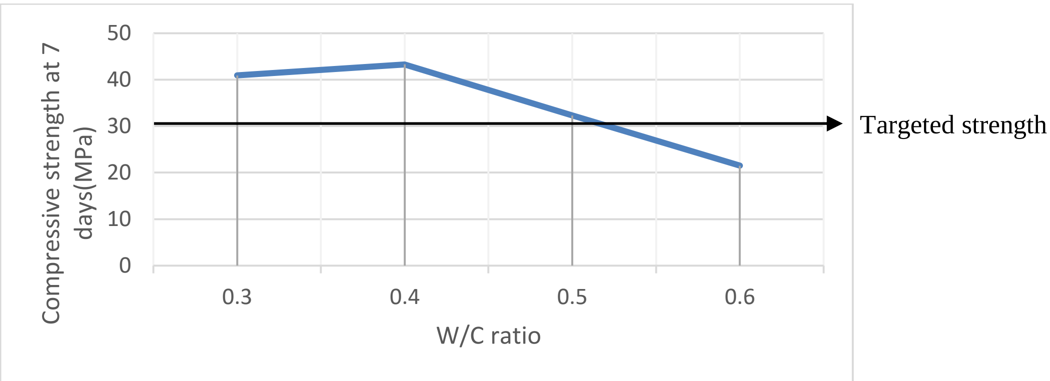

Figure 4: Compressive strength at 7 days vs w/c ratio

3.3.2 Compressive strength for 28 days

Based on observation of the results in Table 7, the optimum w/c ratio was still 0.4 which is lesser than the controlled w/c ratio of 0.5. The compressive strength achieved after 28 days for MSFRC with a 0.3 w/c ratio was 48.5MPa, and it increases at a 0.4 w/c ratio with 53.4MPa before it drops to 40.8MPa for MSFRC of a 0.5 w/c ratio and the lowest strength 28MPa for MSFRC with a w/c ratio of 0.6. When the w/c ratio increases above 0.4, the compressive strength of MSFRC decreases as presented in Figure 5. Concrete w/c ratio of greater than 0.5 with MSF of 1% has a lower compressive strength compared to normal plain concrete with a 0.5 w/c ratio (controlled specimen). Therefore, a lower w/c ratio is needed to achieve the optimum compressive strength of MSFRC. Researchers have previously discovered that adding fibres to concrete improves its compressive strength. MSFRC with a w/c ratio of 0.34 and 1% of microfiber resulted in an increment of 17.6% of compressive strength at 28 days [6]. In addition, [1] observed that with a 0.42 w/c ratio of MSFRC, for 1% of MSF has increased 8.2% of compressive strength at 28 days when compared to the controlled specimen.

A lower w/c ratio gives greater compressive strength of MSFRC. This is because when there is more water, it will result in the settlement of SFs at the base of the mix. There is also an increment of 22.9% of compressive strength when comparing the optimum w/c ratio 0.4 strength to the controlled specimen. According to [11] stated that this is due to crack-closing forces when microcracking happens due to transverse strain forces of ultimate loading compression. Thus, it improves the compressive strength of the MSFRC. On top of that, the inclusion of fibers vitalizes the mode of failure of concrete from brittle to ductile, showing increased strength of MSFRC and its ability to withstand dynamic compression [12].

Table 7: Compressive strength of MSFRC for 28 days

W/c ratio	fc (MPa)			
	CST1	CST2	CST3	Average
0.5 (control)	41.5	41.9	40.1	41.2
0.3	49.7	50.2	50.8	48.5
0.4	51.8	55.1	53.3	53.4
0.5	39.5	41.6	41.2	40.8
0.6	27.5	28.9	27.6	28

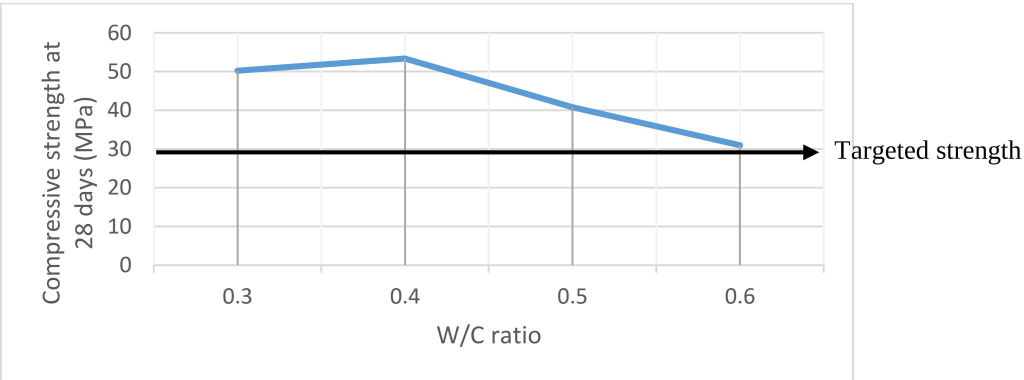

Figure 5: Compressive strength at 28 days vs w/c ratio

3.4 Splitting tensile strength

Table 8 illustrates the results obtained for splitting tensile strength test of the respective MSFRC. All the splitting tensile strength of MSFRC with different w/c ratios has a higher value compared to the plain controlled specimen with a 0.5 w/c ratio. The highest splitting tensile strength achieved was 4.47 MPa at a 0.3 w/c ratio in the mixture of MSFRC. Normal concrete is weak in tension; thus, it is proven that the addition of micro steel fiber into concrete does increase the tensile strength of concrete. To be focused on, it is also proven that a lower w/c ratio has greater splitting tensile strength.

From the graph in Figure 6, the trend is gradually decreasing. The splitting tensile strength of MSFRC decreases as the w/c ratio increases. The optimum w/c ratio of tensile strength is 0.3, which gives an increase of 12.9% in strength than normal plain concrete (control specimen). The optimum splitting tensile strength of MSFRC is 0.3 because lower water content makes the MSF distributes uniformly with aggregate. This can ensure that the bridging effect of MSFRC works when cracking under ultimate load. The previous researcher observed a similar trend of tensile strength. As [12] obtained an increase of 15%, 31% and 35% for w/c ratios of 0.55, 0.45 and 0.35 respectively with 1% fiber volume fraction added into the mixture.

Table 8: Splitting tensile strength results

W/c ratio	Tensile strength (MPa)			
	ST1	ST2	ST3	Average
0.5 (control)	2.16	2.04	2.10	2.10
0.3	4.85	4.08	4.48	4.47
0.4	3.62	3.81	3.73	3.72
0.5	3.56	3.70	3.63	3.63
0.6	3.69	3.51	3.60	3.60

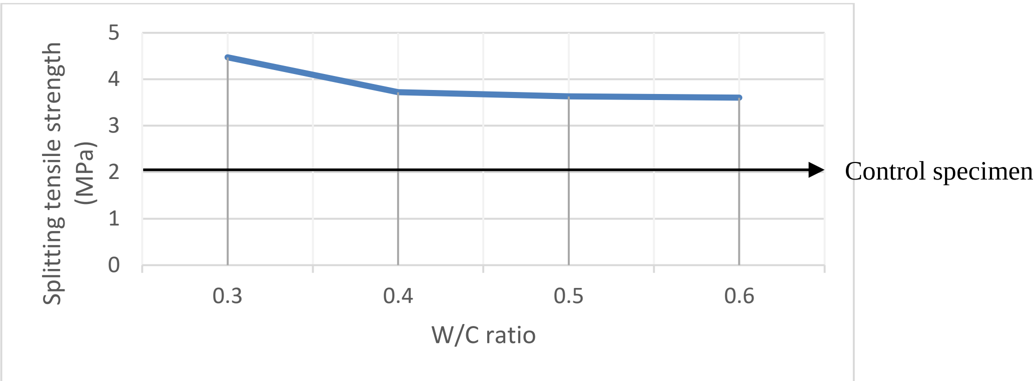

Figure 6: Splitting tensile strength vs w/c ratio

4. Conclusion

Based on this study, it was found that the physical and mechanical properties of MSFRC with a suitable w/c ratio are as follows;

1. The designed slump in this study is between 30 to 60 mm. The maximum result of slump test that still in the range of slump designed is 60 mm which is from the control specimen while the lowest slump falls below the designed slump which is 25 mm with the lowest w/c ratio of 0.3. This proves with the addition of MSF with lower w/c ratio gives lesser workability of MSFRC.
2. The highest compressive strength achieved for MSFRC is with a mixture of w/c ratio of 0.4 with 43.3MPa and 53.4MPa on both 7 days and 28 days of curing respectively. An increase of 22.9% of compressive strength for MSFRC with a 0.4 w/c ratio compared to conventional concrete.
3. The optimum w/c ratio for splitting tensile strength of MSFRC was 0.3 which is the lowest. A lower w/c ratio gives higher splitting tensile strength. The strength achieved was 3.65MPa. Compared to normal plain concrete, there was an increase of 12.9% in splitting tensile strength.
4. In short, lower w/c ratio results in higher strength, a higher w/c ratio gives higher workability of MSFRC.
5. The optimum w/c ratio recommended for MSFRC is 0.3-0.4.

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