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Investigating the Mechanical Properties of High Performance Concrete with a Steel Fibre Admixture

M.A. Karim[1], Noor Faisal Abas[2,a], M.A. Othuman Mydin[3]

[1,2,3]School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia

Abstract. This paper presents the findings of an experimental investigation of the mechanical properties of concrete containing steel fibre. In the experimental investigation, the properties of steel fibre used in high strength concrete were assessed through 3 different mixes. Steel fibre was added into concrete in percentages of 0% (control), 0.6%, and 1.8%. These different types of mixes were then tested after durations of 3 days, 7 days, 14 days, and 28 days. Three cube specimens and three prism specimens were prepared for each test. In total, 36 cubes specimens and 36 prisms specimens were prepared and tested. The following tests were performed: workability test (slump test), density test, ultrasonic pulse velocity test, compressive strength test, flexural test, and water absorption test. The experimental results of this study indicate that the inclusion of steel fibres in concrete enhances the mechanical properties of high performance concrete and could reduce the severity of cracking problems for normal and high-rise buildings.

1 Introduction

With a better economy comes a higher demand for the rapid, yet efficient, construction of buildings. High-rise buildings and futuristic architectural structures are examples of this demand. While demand for the construction of buildings continues to increase, the quality of buildings, in terms of performance of building materials, needs to be examined [1].

Nowadays, a number of high-rises and modern buildings have been constructed with low quality building materials which could cause building defects such as cracking. Two building collapses received a great deal of media coverage in 2013: the building collapses in Thane, Mumbai, and Savar, Bangladesh [2]. Whereas 74 people lost their lives in the Thane building collapse, the death toll was more than 700 in the Savar building collapse [3]. The cause of the collapses was determined to be due to the use of defective building materials which led to defects in the construction of the buildings. For example, water leakage caused by defective materials can weaken the structure [4].

A problem with cracking will cause long term damage to a building's structural components, thereby reducing the loading capacity of the building. If such a building were to be overloaded, it would result in unwanted tragedy [5]. Moreover, cracking, primarily caused by water, also causes the decay of building materials [6,7]. This can lead to frost damage of the masonry, timber decay, rusting of iron and steel as well as sulphate attacks on cement and concrete [8].

[a] Corresponding author: nfaisal@usm.my

2 Materials

2.1. Portland Cement CEM I

Portland Cement CEM I with a specific surface area of 1043.2 m^2/kg, specific gravity of 3.02 and median particle size of 3.9 μm was used for specimen preparation. It was supplied by the concrete laboratory of the Universiti Sains Malaysia's School of Housing, Building, and Planning.

2.2 Fine Aggregates

For this study, uncrushed fine aggregates were used in mortar mixes as a constituent material with a specific gravity of 2.83 and a maximum aggregate size of 5mm. The fine aggregates were graded in accordance to BS 812: Part 102 and the fitness moduli were determined to be 3.26.

2.3 Aggregates

The coarse aggregates used were mainly those that were retained on a 5 mm test sieve and contained no more finer material than what is permitted for the various sizes in this Standard, where the coarse natural aggregate maximum size did not exceed 20 mm. The fine aggregates were graded in accordance to BS 812: Part 102.

2.4 Water

The water used had to comply with the requirements of MS 28. It had to be clean and free from anything that could affect concrete when in a hardened state. Since water was used to help strengthen the cement gel, the quantity and quality required had to be carefully considered. The water-cement ratio used was 0.56 for M25 concrete.

3 Admixtures

3.1 Steel Fibre

Steel fibres are filaments of wire, deformed and cut to lengths for reinforcement of concrete, mortar and other composite materials. They are cold drawn wire fibres with a corrugated and flatted shape. Steel fibres with hooked ends are made using high-quality, low-carbon steel wire [9]. High-performance steel fibres possess the characteristics of high tensile strength, good toughness, and low cost. As a result, this product is widely used in concrete strengthening. The typical diameter of steel fibre lies in the range of 0.25-0.75 mm. Hook-end steel fibres were used in this project. The length of these types of fibres was 30 mm with an aspect ratio of 55 and a density of 7900 kg/cum.

Table 1. Properties of steel fibre

No	Properties	Description
1.	Cross Section	Straight , hook- end, deformed
2.	Diameter	0.3-0.7mm (max 1mm)
3.	Length	25 – 35mm
4.	Density	7900 kg/m3
5.	Young's Modulus	2.1 x 105 N/mm2
6.	Resistance to Alkalis	Good
7.	Resistance to Acids	Poor
8.	Heat resistivity	Good
9.	Tensile Strength	500-2000 N/mm2
10.	Specific Gravity	7.90
11.	Aspect Ratio	45, 55, 65, 80
12.	General Use	10 kg/m3
13.	Elongation	5-35 %

4 Experimental Method and Setup

For this study, the mix proportion of concrete specimens was calculated based on Standard Mix Design according to the British Department of Environment (DoE) [10]. Table 2 shows the mix proportions of the concrete specimens that were investigated. Cube specimens were prepared at a size of 100 mm in length, 100 mm in width, and 100 mm in height. Prism specimens were prepared at a size of 500 mm in length, 100 mm in width, and 100 mm in height. Specimens of each mix proportion were prepared to determine their mechanical properties via tests on density, ultra pulse velocity, compressive strength, flexural strength, and water absorption. Tests were performed during the curing process at the ages of 3, 7, 14, and 28 days.

Table 2. Mix proportion of concrete specimens

Concrete mix	Cement (kg)	Fine aggregates (kg)	Coarse aggregates (kg)	Steel Fibre (%)	w/c ratio	Water Content (kg)
C	31.05	70.63	79.65	0	0.56	17.39
SFA	31.05	70.63	79.65	0.6	0.56	17.39
SFB	31.05	70.63	79.65	1.8	0.56	17.39

4 Results and Discussion

4.1 Density Test

The results obtained for density of the prism specimens are shown in Figure 1. From Figure 1, it is clear that the 1.8 % steel fibre prism specimens obtained the highest density among the prism specimens of 2.52 kg/m^3 at the age of 3 days. From that point on, the density of the specimens decreased at the age of 7 days and increased again at 14 days. On day 28 the density decreased below that of day 7 to 2.412 kg/m^3. Additionally, the density of the control prism specimens directly increased over time to a reading of 2.391 kg/m^3 at the age of 28 days. The density of the prism specimens with 0.6 % steel fibre was not consistent throughout the duration of testing as density increased until day 14 with a reading of 2.38 kg/m^3 and then decreased at day 28 with a reading of 2.371 kg/m^3.

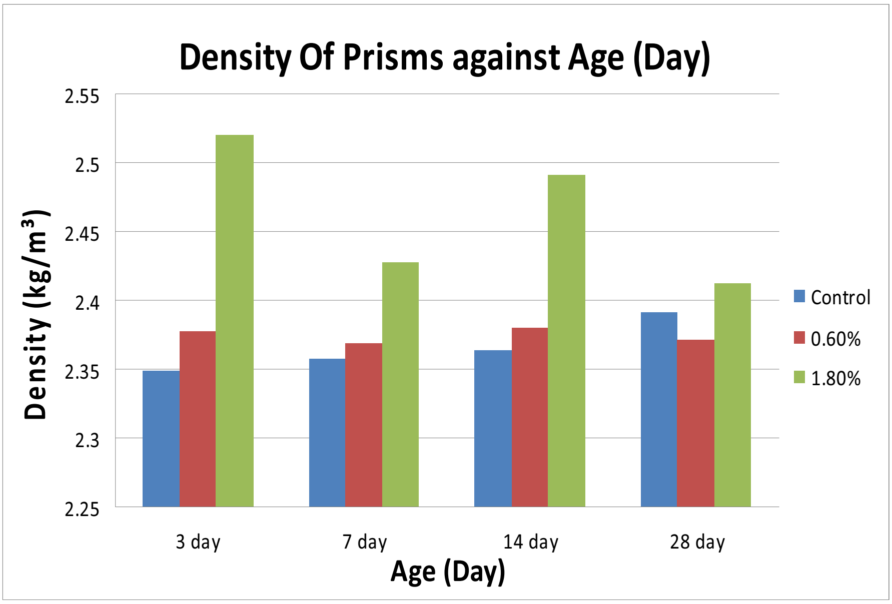

Fig. 1: Density of prisms against age (day)

Figure 2 shows the results for density of cubes against age. The highest density that could be seen was from the cube specimens containing 1.8 % steel fibre at the age of 28 days with a reading of 2.458 kg/m^3. The 1.8 % steel fibre cube specimens' density fluctuated over the duration of the study, increasing from day 3 to day 7 and decreasing at day 14 with a reading of 2.396 kg/m^3. Furthermore, the density of the control cube specimens decreased over time with a reading of 2.37 kg/m^3 at the age of 14 days and then increased back to 2.386 kg/m^3 at 28 days. The same fluctuation in density for the 0.6 % steel fibre cube specimens was witnessed over the course of the study. It was noted that the density decreased from day 3 to day 7 with a reading of 2.358 kg/m^3. Afterwards, the results increased until day 28 with a reading of 2.368 kg/m^3.

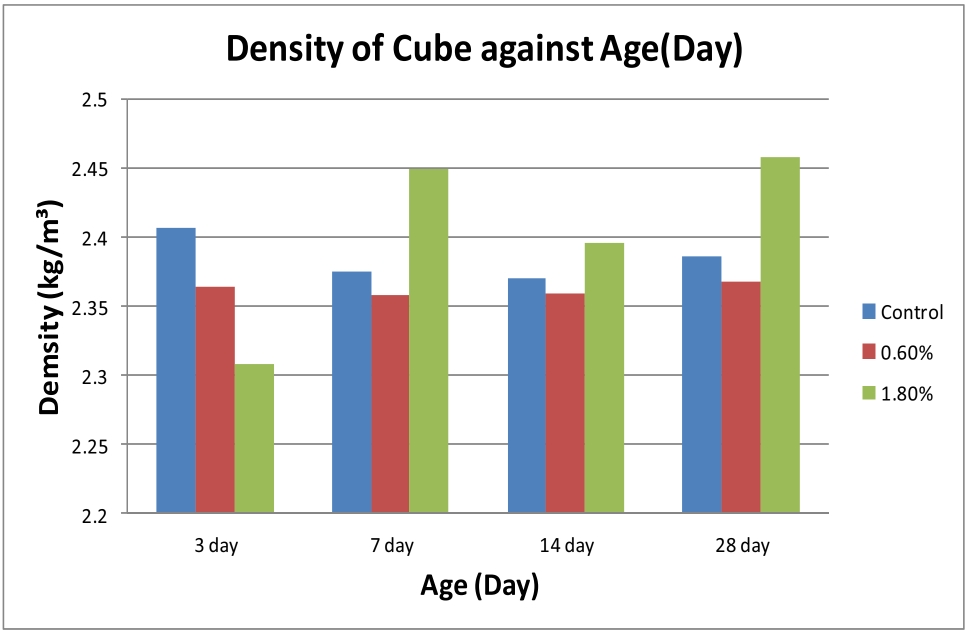

Fig.2: Density of cubes against age (day)

4.2 Ultrasonic Pulse Velocity Test

From Figure 3, it can be seen that the pulse velocity of all the concrete prism specimens directly increased over the course of the study. The control concrete prisms increased from the age of 3 days to 28 day with a reading of 5996 m/s. The 0.6 % steel fibre concrete prisms increased from the age of 3 days to 28 days with a reading of 5642 m/s, which was much lower than the control prism. Moreover, the 1.8 % steel fibre concrete prisms showed an increase in pulse velocity from the age of 3 days to 28 days with a reading of 5912 m/s. The highest reading came from the control specimen, though differing only slightly with the steel fibre concrete prisms. It can be concluded that both the mix proportions of steel fibre enforced concrete showed excellent quality with readings of more than 4500 m/s.

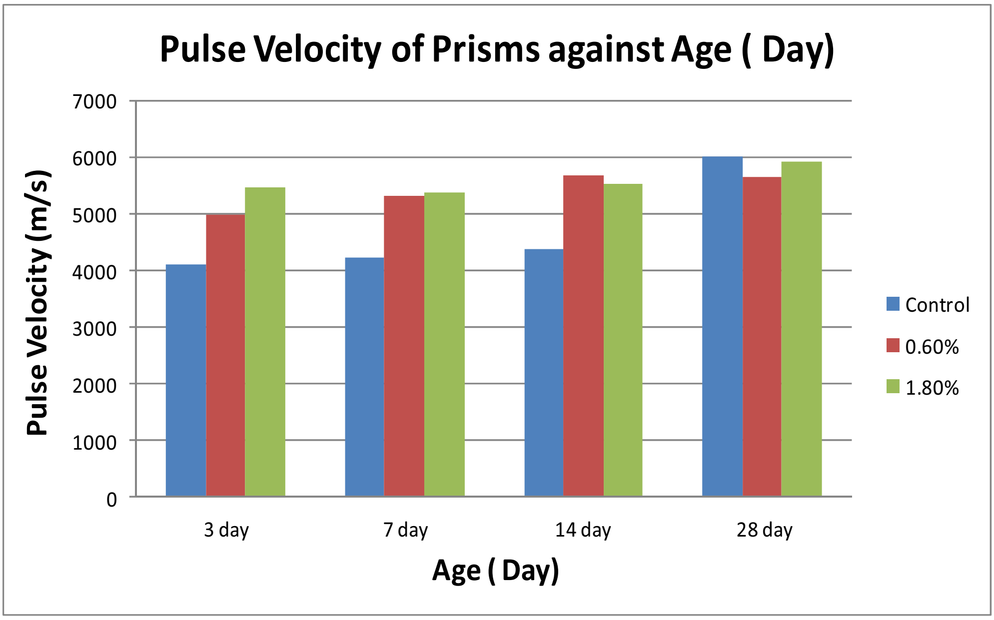

Fig. 3: Pulse Velocity of Prisms against Age (Day)

Figure 4 shows that pulse velocity of all the concrete cube specimens directly increased over the testing period. However, the 0.6 % steel fibre concrete cubes decreased slightly from 5856 m/s at 14 days to 5803 m/s at 28 days. The control concrete prisms increased in pulse velocity from the age of 3 days to 28 days with a reading of 6132 m/s. Additionally, the 1.8 % steel fibre concrete prisms saw an increase from the age of 3 days to 28 days with a reading of 6104 m/s. The highest reading came from the control specimen, though differing only slightly with the steel fibre concrete prisms.

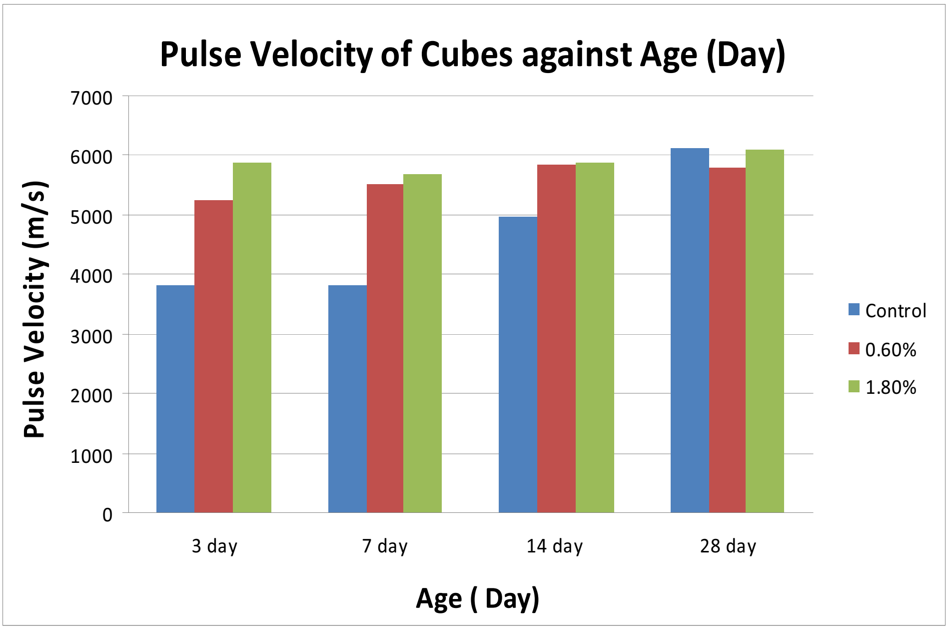

Fig. 4: Pulse Velocity of Cubes against Age (Day)

4.3 Compressive Strength Test

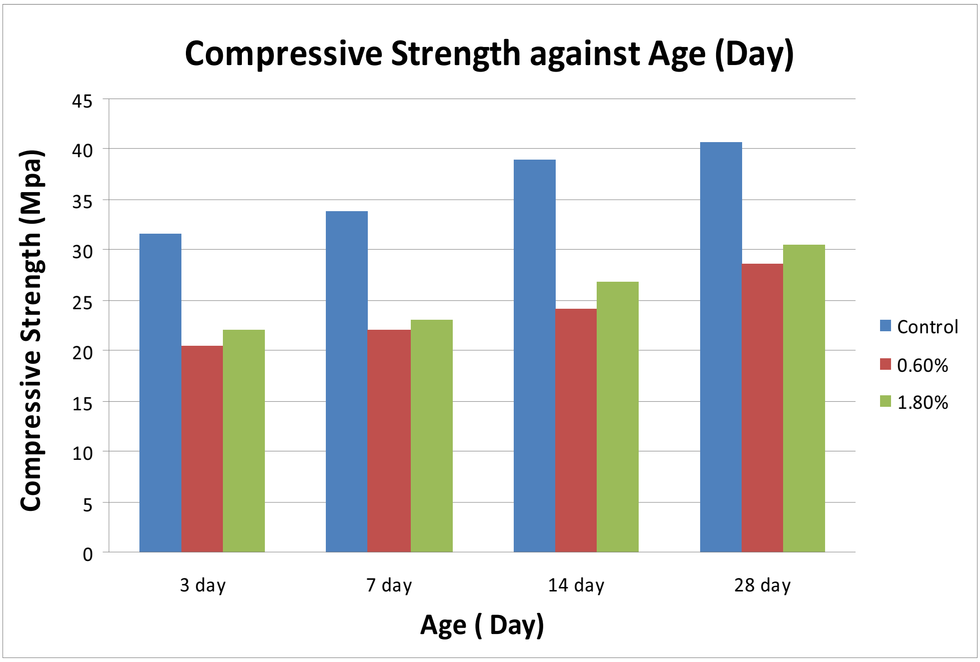

Fig. 5: Compressive Strength against Age (Day)

From Figure 5, it can be seen that the control concrete specimen had the highest strength compared to the steel fibre concrete specimens throughout the entire testing process. At 28 days, the control specimen had a compressive strength of 40.689 Mpa, which was much higher compared to the 0.6 % steel fibre concrete specimens at 28.652 Mpa and the 1.8 % steel fibre concrete specimens at 30.489 Mpa. However, overall results showed that all of the mix proportions of concrete demonstrated positive results over the course of the testing.

From this, it can be concluded that the compressive strength of steel fibre concrete had a lower compressive strength than the control concrete, signifying that it was normal because the steel fibre concrete at a high strength at flexural strength (beam loading).

4.4 Flexural Strength Test

The results of the flexural strength test on steel fibre concrete specimens are shown in Figure 6, which shows the flexural strength for each of the checkpoint days during the curing process. Figure 6 shows that the highest flexural strength was recorded at the age 28 days by the 1.8 % steel fibre concrete specimens with a reading of 5.455 Mpa. The flexural strength of the 1.8 % steel fibre concrete specimens directly increased from day 3, starting with a reading 3.73 Mpa, until 28 day. The 1.8 % steel fibre concrete showed higher values of flexural strength than both the control and the 0.6 % steel fibre concrete for each curing age.

Furthermore, the 0.6 % steel fibre concrete specimens showed an increase from 3.704 Mpa at the age of 3 days to 4.349 Mpa at 28 days. This demonstrates a positive correlation between flexural strength and duration of curing. Compared to the 1.8 % steel fibre specimens, the results for the 0.6 % steel fibre specimens were much lower by a difference of about 1.106 Mpa. The control concrete specimens also showed a direct increase over time from 3.214 Mpa at the age of 3 days to 4.339 Mpa at the age of 28 days. It was found that the difference between the 0.6 % steel fibre concrete specimens and the control concrete specimens was only 0.01 Mpa. From the graph of flexural strength based on days of curing, it can be concluded that all of the concrete specimens showed improvements in flexural strength with age, with the highest flexural strength coming from the 1.8 % steel fibre concrete specimens.

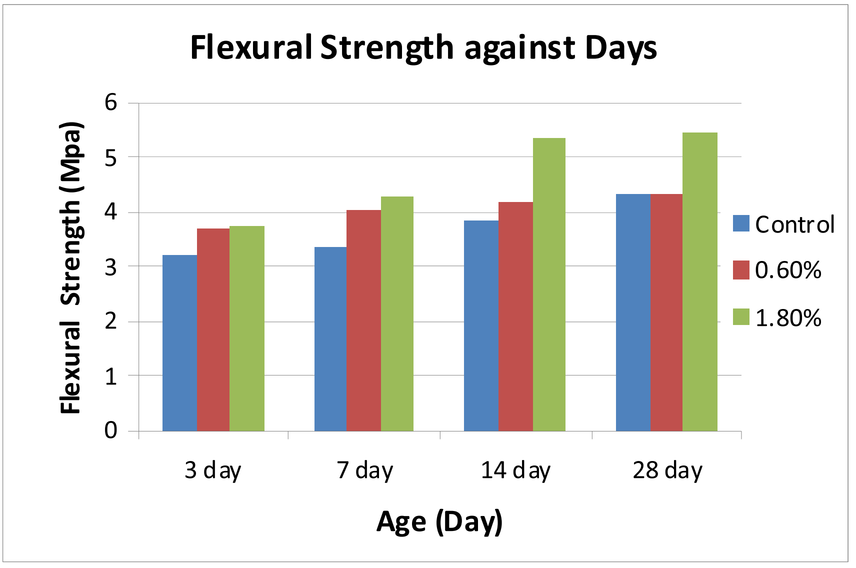

Fig. 6: Flexural strength against age (days)

4.5 Water Absorption Test

The graph in Figure 7 shows that the results for the amount of water absorption for all of the concrete specimens fluctuated over the testing period. The highest result of 6.02 % water absorption was obtained from the concrete specimens with 0.6 % steel fibre at the age of 7 days. For the 0.6 % steel fibre concrete specimens, the results increased from day 3 to day 7 and then decreased until day 28 with a result of 5.38% water absorption.

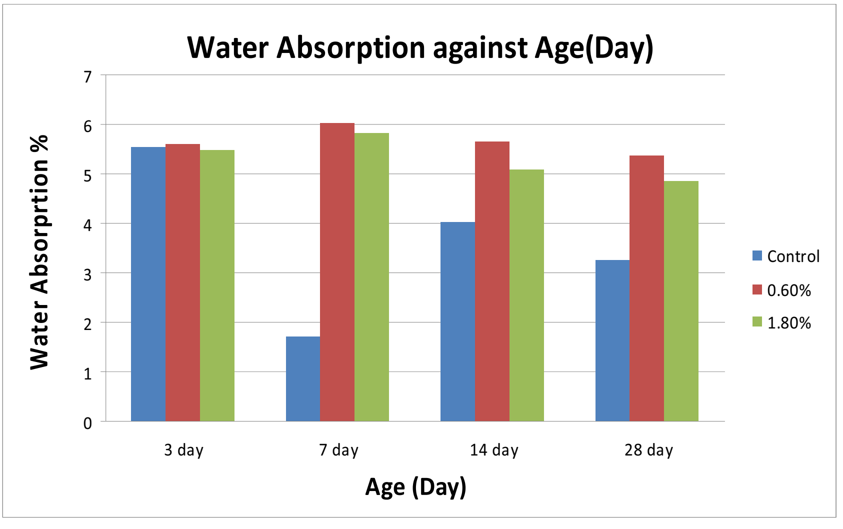

Fig. 7: Percentage of water absorption by concrete specimens

The control steel fibre concrete specimens recorded the lowest percentage of water absorption at the age of 7 days with a reading of 1.72 %. The absorption for the control concrete specimens decreased from day 3 to day 7 and then increased again at the age of 14 days. After that, the results decreased to 3.27 % at 28 days. The water absorption of the concrete specimens with 1.8 % steel fibre increased from the age of 3 days to 7 days with a reading of 5.84 %. However, the results then decreased from day 7 to day 28 to 4.85 %. The conclusion that can be draw from this is that all of the concrete specimens initially showed positive results in terms of percentage of water absorption, but they all decreased at the age 28 days. The best result for percentage of water absorption was obtained by the control concrete specimens, with the lowest reading occurring at the age of 28 days.

5 Conclusion

This study has detailed the various processes starting from the primary stages of steel fibre concrete design up to the analysis of obtained data. Experimental laboratory works were carried out to obtain the data for analysis of strength and durability. The tests performed investigated density, ultra pulse velocity, compressive strength, flexural strength, and water absorption. As a conclusion, steel fibre concrete showed positive results for strength, making it suitable as a high performance concrete. However, steel fibre concrete indicated negative results in terms of durability. Based on the data that were gathered and the analyses done, the steel fibre concrete specimens showed an improvement in strength of 1.8 % greater than that of the control concrete specimens. In regard to the analysis of durability, the steel fibre concrete specimens showed opposite results, in which there was no improvement compared to the control concrete specimens. As a result, steel fibre concrete demonstrated a high strength performance which suggests it is suitable for use as a concrete admixture to minimize the level of cracking in normal and high-rise buildings.

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