SOME MECHANICAL PROPERTIES OF STEEL FIBER REINFORCED CONCRETE AT DIFFERENT CURING TEMPERATURES

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Abstract

This paper presents some mechanical properties of hooked-end steel fiber reinforced concrete cured in water at two different temperatures. These temperatures were fixed to be 22˚C and 32˚C. The compressive strength, flexural strength and flexural toughness of these concretes were tested for five different volume fraction of fibers (0, 0.5, 1, 1. 5, 2% by volume of concrete). The maximum increase in compressive strength is obtained to be for 1.5% volume fraction of fibers and maximum increase in flexural toughness was obtained to be for 2% volume fraction for all curing temperatures and testing ages.

Keywords: Compressive strength, Flexural Strength, Flexural toughness, curing temperatures.

1. Introduction

Concrete is the most widely used construction material all over the world due to economic reasons and easy production capability. Although concrete has adequate compressive strength it has very low tensile strength. It is also known that adding discontinues discrete fiber can significantly increase the tensile strength of concrete. Fiber reinforced concrete is a concrete made by hydraulic cement, aggregates and discontinues discrete fibers. Generally, fibers are being used in flat slabs, pavements and tunnel linings [1, 2].

Curing of concrete is a very important process to provide adequate moisture for concrete. Without curing, cement particles cannot hydrate and concrete cannot achieve sufficient strength. Temperature is also a very important factor in curing and increasing curing temperature can increase the rate of hydration and concrete can gain higher early strength. The effects of curing temperature on concrete have been investigated by many researchers [3-5]. Eren [6] investigated the effects of compressive strength of concrete that contains slag and fly ash at five different curing temperatures (6, 20, 35, 60 and 80°C) at the ages of (1, 3, 7, 28, 90 days). This published study reported maximum compressive strength for concrete that contained fly ash and slag cured at 35°C and 20°C.

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However, there are a few investigations about effects of curing temperature on fiber reinforced concrete. Kamkar and Eren [7] investigated the effects of different volume fractions of fibers (0, 0.5, 1, 1.5 and 2%) at three different curing temperatures (8, 22 and 32°C) on compressive strength and they found that concrete with 1.5% volume fraction at 22°C curing temperature has the highest compressive strength compared to other curing temperatures. The main objective of this research is to investigate the effects of curing temperatures (22 and 32°C) and curing ages (7 and 28 days) on compressive strength, flexural strength and flexural toughness of fiber reinforced concrete.

2. Materials and Methods

2.1 Materials

Portland slag cement II/SR (class 32.5) with specific surface weight of 2.97 (g/cm^3) was used for this study. Crushed limestone with maximum size of 10 mm was used. The specific gravity of coarse and fine aggregates was 2.61 and 2.66, respectively. One type hooked-end steel fiber with aspect ratio (length/diameter) of 65 was used. To achieve the desired workability polycarboxylic ether based superplasticizer was employed.

2.2 Mixing, casting, curing and testing of concrete specimens

Mix designs were done for five different percentages of fibers (0, 0.5%, 1%, 1.5% and 2% by volume of concrete). The w/c ratio was kept as 0.43 for all the mixes. The properties of mixtures are as shown in Table 1. Three cubes with size of 150 mm for each set were tested for compressive strength. In order to obtain flexural strength and flexural toughness three beams with a size of 150×150×600 mm were tested. After casting, samples were kept into curing tank with temperatures of 22°C and 32°C for specified ages. Closed-looped servo hydraulic machine was performed to provide load-deflection curves. Specimens were tested in flexural by using four point loading arrangement according ASTM C1609 [8]. Distance between to supports was specified 450 mm and distance between top loadings were arranged 150 mm. ASTM C1609 were recommended end point deflection of samples were L/150. So, the tests were continued up to 3 mm. Figure 1 shows flexural test setup for samples.

Tab 1: Mix proportion

Series	Fiber Dosage	w/c	Cement	Water	Fine	Coarse	SP	Vebe Time
	kg/m^3		kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	sec
Plain	0.00	0.43	581	250	670	810	4.07	1.03
0.50%	39.25	0.43	581	250	670	810	4.07	1.24
1.00%	78.50	0.43	581	250	670	810	4.07	1.67
1.50%	131.25	0.43	581	250	670	810	4.07	1.98
2.00%	157.00	0.43	581	250	670	810	4.07	2.78

Fig 1: Flexural strength/toughness test setup

3. Results and discussion

3.1 Vebe time test

Vebe time test were obtained for all mixtures. The results of Vebe time test were presented in Table 2. It can see from the results that as the volume fraction of fibers increases Vebe time also increases. The highest Vebe time result of 2.78 seconds was obtained for concrete with volume fraction of 2%.

3.2 Compressive strength test results

Figure 2 (a and b) and Table 2 show compressive strength results of all the mixes at curing temperatures of 22°C and 32°C, at ages of 7 and 28 days. As it can be seen, increasing the volume fraction of fiber slightly increased compressive strength up to 1.5%, but at 2% volume fraction compressive strength slightly decreased. The results show that samples cured at 32°C have higher compressive strength at all volume fractions of fiber compared to samples cured at 22°C. Because high temperature increases hydration process and causes to hydrate more cement particles creating stronger bond between cement particles and aggregates. Figure 2 (a) and Table 2 show compressive strengths of concretes at the age of 7 days. The maximum increase in compressive strength was obtained to be with 1.5% fibers at 32°C which is 45% higher compared to plain concrete at curing temperature of 22°C.

Table 2: Compressive strength, Flexural strength and flexural toughness test results

Age (days)	Curing temperatures (°C)	Volume Fraction (%)	Compressive Strength (MPa)	Flexural Strength (MPa)	Flexural Toughness (kN.mm)
7	22	0	30.5	3.09	1.29
7	22	0.5	33.1	4.98	49.93
7	22	1	34.2	4.52	75.75
7	22	1.5	35.45	5.51	92.43
7	32	2	32.25	6.60	125.85
7	32	0	42.45	3.54	2.71
7	32	0.5	43.65	3.78	61.47
7	32	1	44	5.18	96.29
7	32	1.5	44.3	7.69	149.1
7	32	2	36.05	8.15	160.14
28	22	0	55.4	4.03	4.72
28	22	0.5	54.7	6.98	99.28
28	22	1	56.7	6.74	120.04
28	22	1.5	60.1	9.15	165.38
28	22	2	57	10.60	186.19
28	32	0	49.85	4.23	5.34
28	32	0.5	51.57	6.85	107.29
28	32	1	52.95	7.87	141.23
28	32	1.5	55.47	9.15	158.47
28	32	2	48.85	10.27	194.83

Figure 2 (b) and Table 2 show compressive strength results of concretes at the ages of 28 days. Increasing volume fraction of fibers causes to increase compressive strength up to 1.5% but at a volume fraction of 2% compressive strength slightly decreased. The samples cured at temperature of 22°C have higher compressive strength compared to samples that were cured at 32°C for all volume fractions of fibers, because high temperature cause to decomposition of hydration products and destruction of cement gel structure at later age of concrete [9], this process is names as “crossover effects” due to high temperature in concrete [10].The maximum increase in compressive strength at 28 days was 20.56% higher with 1.5% fibers at 22°C curing temperature compared to plain concrete at the curing temperature of 32°C.

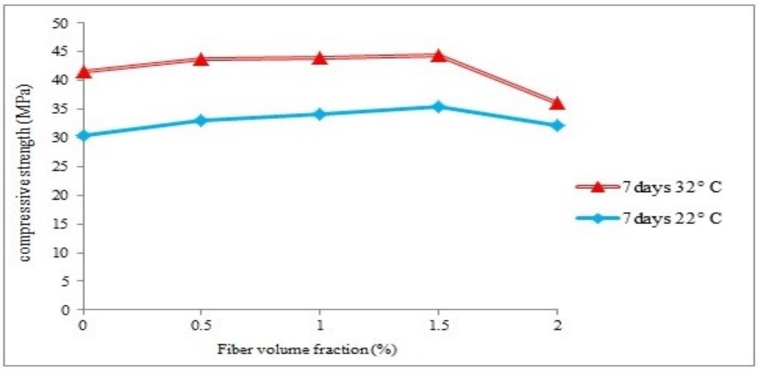

Fig 2 (a): Compressive strength test results at 7 days

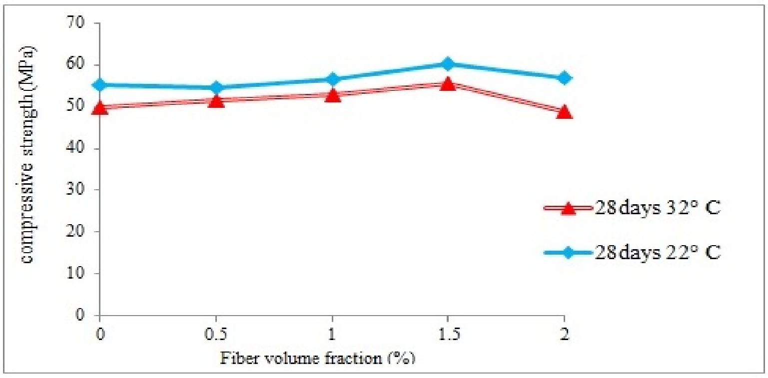

Fig 2 (b): Compressive strength test results at 28 days

3.3 Flexural strength test results

Figure 3 (a and b) shows load-deflection curves of mixes at 7 and 28 days for both 22°C and 32°C curing temperatures. In both curing temperatures the relations of load deflection curve in plain concrete were linear. Load raise up to peak strength and sample collapsed due to brittle behavior of plain concrete. The concrete with 0.5% and 1% volume fraction load-deflection curve have sudden strain-softenig due to low fiber content. Concretes containing 1.5% and 2% volume fraction have strain-hardening for both curing tempratures at the age of 7 days.

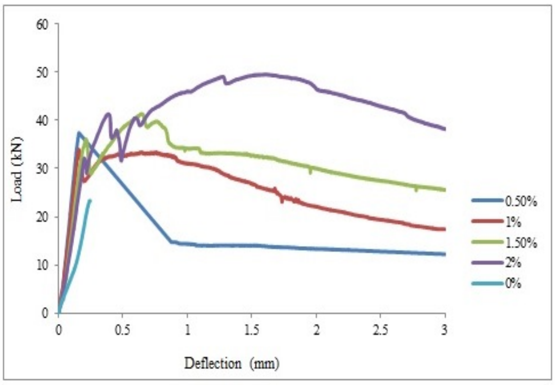

Fig 3 (a): Load-deflection curves at 22°C and 7days

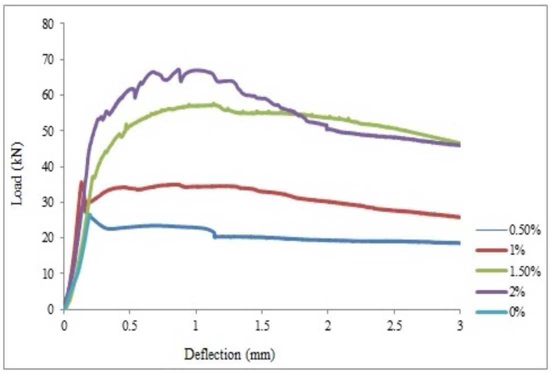

Fig 3 (b): Load-deflection curves at 32°C and 7days

Figure 3 (c and d) shows the load deflection curves of 0.5%,1%, 1.5% and 2% volume fraction with curing temperatures of 22°C and 32°C at age 28 days. Plain concrete has linear behavior for both 22°C and 32°C same as 7 days samples. Concrete having 0.5% volume fraction of fiber have strain-softening behavior for both 22 and 32 °C. At fiber volume fraction of 1, 1,5 and 2% the load-deflection curve had strain-hardening behavior.

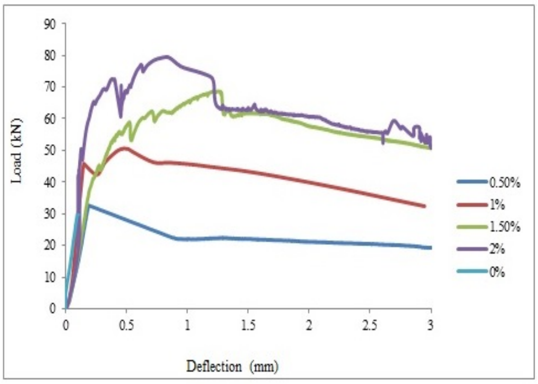

Fig 3 (c): Load-deflection curves at 22°C and 28days

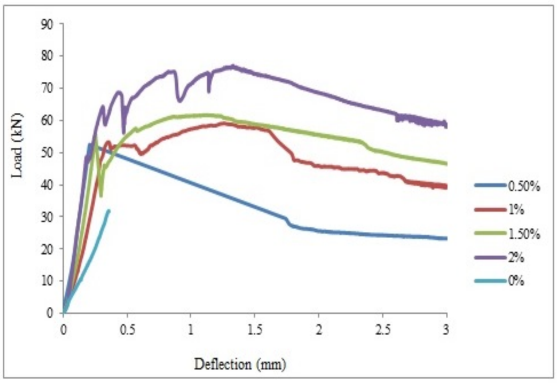

Fig 3 (d): Load-deflection curves at 32°C and 28days

Figure 4 (a and b) shows the flexural strength of the samples with five different volume fractions of fibers (0, 0.5, 1, 1.5, 2% by volume of concrete) cured at two different temperatures (22°C and 32°C) at the ages of 7 days and 28 days. The results show that flexural strength increased by increasing volume fraction of fibers for both curing temperatures. As it is can see from figure 4 (a), the flexural strength at 32°C have higher value compared to 22°C curing temperature at the same volume fraction at 7 days due to high heat of hydration. The maximum increase in flexural strength at the age of 7 days was for mixes having volume fraction of 2%. It was observed that this concrete has 2.63 times higher flexural strength compared to plain concrete at 32°C curing temperature.

Figure 4 (b) shows flexural strength of mixes at 28 days. The behavior of flexural strength at 28 days was similar to the 7 days for all volume fractions of fibres. Maximum increase for flexural strength at the age of 28 days was for concrete with 2% volume fraction that increased 2.55 times compared to plain concrete at curing temperature of 22°C.

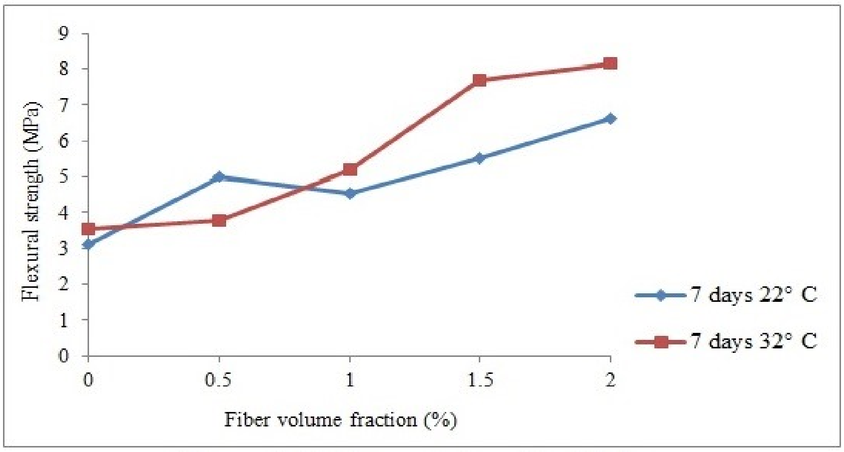

Figure 4 (a): Flexural strength at 7 days

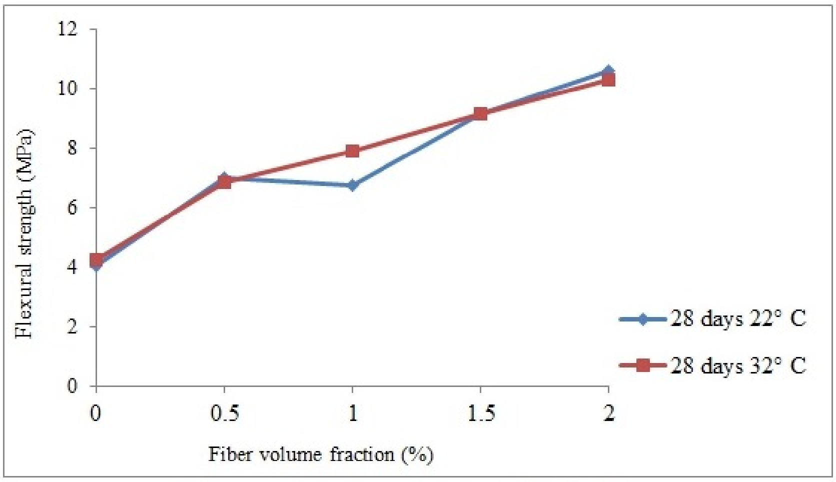

Figure 4(b): Flexural strength at 28 days

3.4 Flexural toughness test results

Figure 5 (a, b) and Table 2 showed flexural toughness of samples at the ages of 7 days and 28 days. As it can be seen, increasing the volume of fraction of fibers increased the flexural toughness. The samples cured at 32°C have higher flexural toughness compared to samples cured 22°C for all volume fractions. At the age of 7 days, the maximum increase in flexural toughness was obtained for 2% volume fraction that increased flexural toughness 123 times compare to plain concrete cured at 22°C. At the age of 28 days, the maximum increase in flexural toughness was obtained for 2% volume fraction that increased flexural toughness 41 times compared to concrete cured at 22°C.

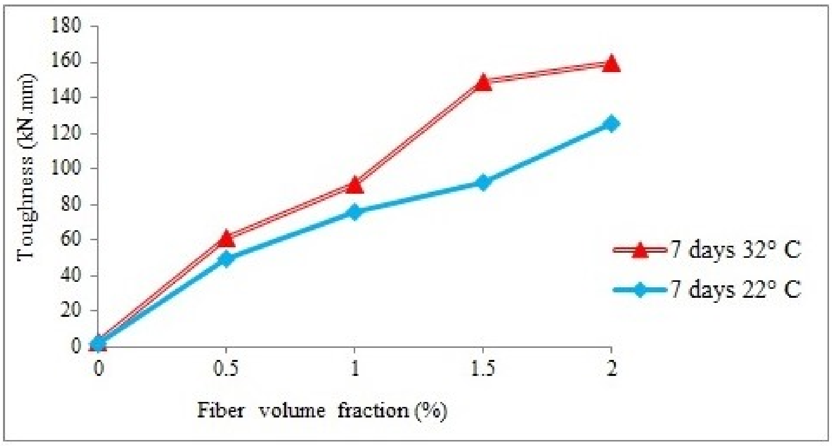

Figure 5 (a): Flexural toughness results at 7 days

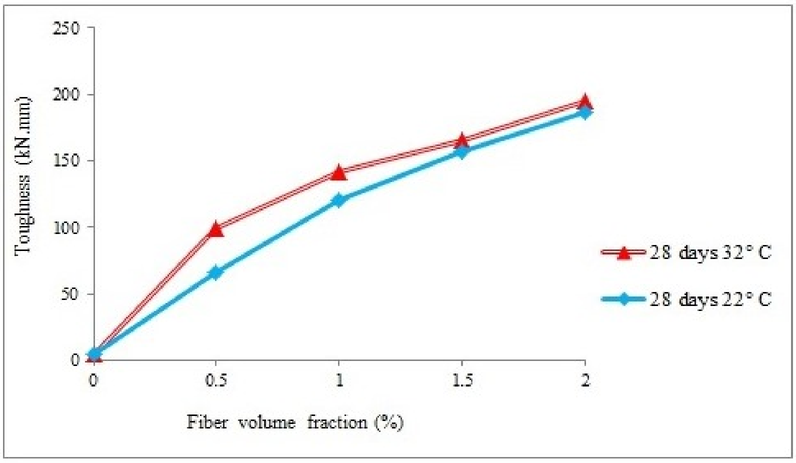

Figure 5 (b): Flexural toughness results at 28 days

4. Conclusions

- The maximum increase in compressive strength at 7 days age was obtained to be with 1.5% fibers at 32°C with 45% increase compared to plain concrete at curing temperature of 22°C.
- The maximum increase in compressive strength at 28 days was 20.56% higher with 1.5% fibers at 32°C curing temperature compared to plain concrete at the curing temperature of 22°C.
- The maximum increase in flexural strength at 7 days age was 2.63 times higher with 2% fibers at 32°C curing temperature compared to plain concrete at the curing temperature of 22°C.
- At the age of 28 days maximum increase for flexural strength was 2.55 times that was obtained for 2% volume fraction at 32°C curing temperature compared to plain concrete at 22°C curing temperature.
- At the age of 7 days, the maximum increase in flexural toughness was obtained for 2% volume fraction that increased flexural toughness 123 times compared to plain concrete cured at 22°C.
- At the age of 28 days, the maximum increase in flexural toughness was obtained for 2% volume fraction that increased flexural toughness 41 times compared to concrete cured at 22°C.

References

[1] American Concrete Institute-ACI.ACI544.1R_96 (1988), State of art report on fiber reinforced concrete.

[2] BENTUR, A. and MENDESS, S. Fiber Reinforced Cementitious Composites. London and New York. Taylor & Francis, 2007, ISBN10: 0–203–08872–7.

[3] ALAXENDAR, K. M. and TAPLIN, J. H. Concrete Strength. Cement Hydration and the Maturity Rule, Australian Journal of Applied Science, c 1962. ISBN: 13-277- 284.

[4] HYUN, S. and YEON, J. H. Strength development characteristics of UP-MMA based polymer concrete with different curing temperature. Construction and Building Materials, c2014. ISBN: 37- 387–397.

[5] BOUBEKEUR, T. EZZAINE, K. and KADRI, E. H. Estimation of mortars compressive strength at different curing temperature by the maturity method. Construction and Building Materials, c2010. ISBN: 71- 299–30.

[6] EREN, Ö. Strength Development of Concretes with Ordinary Portland Cement, Slag or Fly Ash Cured at Different Temperatures. Journal of Materials and Structures (RILEM), c2002, ISBN: 35-253- 536-540.

[7] KAMKAR, S. and EREN, O. Estimating compressive strength of steel fiber reinforced concrete by maturity method 11th International Congress on Advances in Civil Engineering. 21-25 October 2014. Istanbul, c2014.

[8] ASTM C1609/C 1609M_10.Standard test method for flexural performance of fiber-reinforced concrete (using beam with third-point loading). ASTM International, c2014.

[9] KHOURY, G. A. Compressive strength of concrete at high temperature: a reassessment. Magazine of Concrete Research, c1992. ISBN: 44-161-291-309.

[10] CARINO, N. J. and LEW, H. S. The maturity method: from theory to application. Building and Fire Research Laboratory National Institute of Standards and Technology Gaithersburg, c2001. MD 20899-8611 USA