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Effect of Waiting Time before Re-vibration on Mechanical Properties of Fiber Reinforced Concrete

Abstract- *A knowledge of the concrete vibration after casting have led to improve the mechanical properties of concrete, reduce the deformations due to creep and shrinkage and reduce the concrete permeability. At the Structural and Material Laboratories- Building and Construction Engineering Department, University of Technology, series experimental tests on prisms, cubes and cylinders were carried out to investigate the effect of waiting time after initial vibration on the flexural-tensile strength, compressive strength and splitting tensile strength of fiber reinforced concrete. The variables considered in this study were; the amount of steel fiber and waiting time after initial vibration. The test results showed that the concrete prisms without steel fiber show approximately linear behavior till the maximum flexural-tensile load due to brittle behavior of concrete. The maximum improvement in flexural-tensile strength of concrete prism occurs after the initial setting of concrete i.e after 90 minutes of waiting time. The re-vibration after time period increase the stiffness of concrete prism in case of presence of steel fiber compared with the prisms initially vibrated only. The modulus of rupture of concrete prism increased with the increasing of steel fiber content for all waiting time before re-vibration.*

Keywords- *Re-vibration, Concrete prism, Steel fiber, Tensile Strength.*

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1. Introduction

There are some difficulties in determining the real tensile strength of concrete using direct tensile test (uniaxial tensile strength) due to misalignments of uniaxial applied load and due to consternate of stress in the clamping device. Therefore, tensile strength of concrete for many years was calculated in terms of modulus of rupture (f_r) [1]. The specimen used to compute f_r is prismatic beam with the dimension of 100 mm x 100 mm x 400 mm. The four-point load is the best due to pure bending moment occurs at the location of concrete fracture. The assumptions of flexural-tensile strength test are: the concrete is an elastic material and the bending stress is localized at the extreme surface [1]. Vibration of fresh concrete is useful to improve the mechanical properties of concrete especially in the case of successive layers of concrete were placed. Re-vibration is the process of vibrated the fresh concrete after time period. This, beneficial to concrete through re-arranged the aggregate particles and eliminates entrapped water which may improve the mechanical properties of concrete. Further, re-vibration may reduce the plastic shrinkage cracks. This study focus on the effect of waiting time before the re-vibration on the flexural-tensile strength, compressive strength and splitting tensile strength of fiber reinforced concrete elements. Auta et al. [1] studied the flexural strength of re-vibrated concrete beam. The beams were with the size of 150 x 150 x 600 mm reinforced with 12 mm steel bar. The beams were re-vibrated for 20 second at a time interval of 10 minutes continuous up to one hour after initial vibration. The results showed that the flexural strength of beam was improved by the operation of re-vibration. Rao et al. [2] investigated the re-vibration effectiveness on the concrete compressive strength with a wide range of water-cement ratio between 0.35 to 0.7 and with time of re-vibration ranged from 0.5 to 4 hours. The results showed that, the compressive strength of concrete increased with the time of re-vibration up to 60 minutes then decreased. Abdel Rahman [3] investigated experimentally beams of size 100 x 100 x 500 mm to study the effect of vibration and re-vibration on the flexural strength of beams. The results showed that the re-vibration increased the flexural strength of concrete within the first one hour. Kassim [4] studied the effect of re-vibration on the compressive strength of retarded concrete cylinders. The time interval was between 2 to 8 hrs. The results finding was, at the

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time of 2.35 hrs from the concrete casting, the maximum compressive strength of concrete is achieved. Omar et al. [5] studied the effect of both re-vibration time and amount of steel fiber on the properties of concrete made with crushed cement-sand mortar as coarse aggregate. The results showed that the concrete compressive and splitting tensile strength was improved due to re-vibration by about one hour after initial vibration with volume fraction of steel fiber of about 0.5 percent. In addition, the steel fibers improve the compressive and splitting tensile strength of concrete by about 11 and 10.3 percent respectively for the same period of re-vibration. According to the literature review, there is no clear understanding to the effect of waiting time before the process of re-vibration on the flexural-tensile strength, compressive strength and splitting tensile strength of fiber reinforced concrete elements. Therefore, the main scopes of this investigation are to study the effect of waiting time before the process of re-vibration and steel fiber content on:

- Flexural-tensile strength of fiber reinforced concrete prisms through four point load test.
- Compressive strength of fiber reinforced concrete cubes.
- Splitting tensile strength of fiber reinforced concrete cylinders.

2. Materials and Mix proportions

The materials used in constructed the fiber reinforced concrete prisms, cubes and cylinders were: Ordinary Portland cement –type I with specific gravity 3.15; fine aggregate, sand with specific gravity 2.57, coarse aggregate 5-12 mm in size with specific gravity 2.62. Figure 1 shows the steel fiber type that was used in this study. This fiber has a length of 15 mm, diameter of 0.25 mm, aspect ratio of 75 and the ultimate tensile strength of 2000 MPa. The physical and chemical properties of Portland cement were checked with the provisions of Iraqi specification No.5/1984. The properties of coarse and fine aggregate were checked with the provisions of Iraqi specification No.45/1984. The initial setting time of cement was 1.5 hrs and the final setting time of cement was 7.45 hrs. These values were calculated according to Iraqi specification No.5/1984. At least three of 150 x 150 x 150 mm concrete cubes were used to measure the compressive strength of concrete at 28 days according to BS1881-116. The target compressive strength of concrete was 31 MPa. Average values of three cylinders of 150 mm x 300 mm were used to calculate the splitting tensile strength of concrete according to ASTM C496. The compositions of the mix design adopted for the present investigation are presented in Table 1.

Figure 1: Steel fiber used in constructing the specimens.

Table 1: Compositions of concrete mix design

Materials (kg/m^3)	$f_{c'}$=31 MPa
Cement (kg/m3)	413
Fine aggregate	775
Coarse aggregate	912
Water	214.7
W/C	0.52

3. Experimental Program

An experimental program presented in this study was conducted in the laboratories of Building and Construction Engineering Department, University of Technology. A total of 144 fiber reinforced concrete specimens divided into four groups were tested: 36 concrete prisms were used to study the effect of steel fiber content and waiting time before re-vibration on the flexural-tensile strength of concrete; 36 cubes were used to investigate the effect of steel fiber and waiting time before re-vibration on the compressive strength of concrete and finally, 36 concrete cylinders were used to investigate the effect of steel fiber content and waiting time before re-vibration on the splitting tensile strength of concrete. For each group, the waiting time after initial vibration was 0, 30, 60 and 90 minutes. The steel fiber content was 0%, 0.5%, 1% and 1.5% for group W, A, B and C respectively. The characteristics of tested specimens were presented in Table 2.

4. Tested Specimens

The tested specimens are: concrete prism had dimensions of 100 x 100 x 400 mm, concrete cubes of 150 x 150 x 150 mm and concrete cylinders of 150 mm in diameter and 300 mm in length.

Table 2: The characteristics of tested specimens

Group	specimen	f_{cu} (MPa) (28 days)	Steel fiber Content (%)	Waiting time after initial vibration (min)
W	W-DT0	29.7	0	-
	W-DT0.5	32.5	0	30
	W-DT1	31.3	0	60
	W-DT1.5	34.1	0	90
A	A-DT0	31.5	0.5	-
	A-DT0.5	33.1	0.5	30
	A-DT1	32.7	0.5	60
	A-DT1.5	34.7	0.5	90
B	B-DT0	35.1	1	-
	B-DT0.5	36.2	1	30
	B-DT1	38.3	1	60
	B-DT1.5	39.6	1	90
C	C-DT0	38.1	1.5	-
	C-DT0.5	40.2	1.5	30
	C-DT1	43.1	1.5	60
	C-DT1.5	45.5	1.5	90

5. Test Setup

The tests for prisms were carried out using the hydraulic jacks of 2000 kN in the Concrete Laboratory of the Building and Construction Department. The prisms were subjected to four points vertical forces using steel channel as shown in Figure 2. The applied load was measured using an accurately calibrated load cell. The vertical displacement at the middle of the specimen was measured using LVDT. The vertical load was applied to the specimens by displacement control of 0.06 MPa/sec. In all tests of prisms, loading was continued until fracture of concrete, to see clearly hardening and softening zone of the load-deformation behavior. The cylinders were tested according to ASTM C496 using hydraulic jacks of 2000 kN in the Concrete laboratory in Building and Construction Department with loading increments of 0.06 MPa/sec. Figure 3 shows the concrete cylinder under test. The cubes were tested according to BS1881-116 using hydraulic jacks of 2000 kN with loading increments of 0.6 MPa/sec. Figure 4 shows the concrete cubic under test.

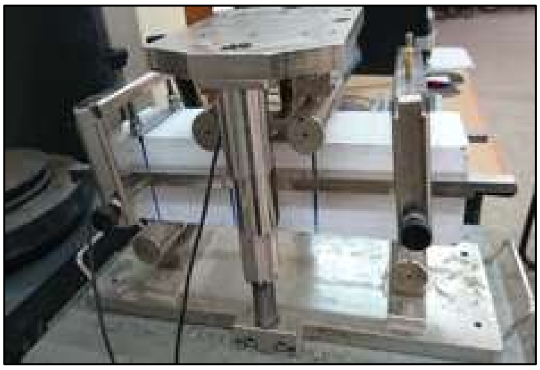

Figure 2: Flexure test

Figure 3: Splitting Tensile test

Figure 4: Compressive Strength test

6. Test Results

I. The Effect of Waiting Time before Re-vibration on the Behavior of Prisms, Cubes and Cylinders in Group W

In this section, the concrete prisms, cubes and cylinders of group W were tested to investigate the effect of waiting time before re-vibration on the mechanical properties of concrete. All specimens in group W have 0% steel fiber content. The results are listed in the following sections.

1) Flexural-Tensile Strength of Concrete Prisms

All The prisms were initially vibrated with 15 second and re-vibrated with 15 seconds after waiting time. The test results were listed in Table 3. The modulus of rupture which represents the flexural-tensile strength of concrete could be calculated according to the equation:

$$f_r = P.L/(b.d^2) \quad (1)$$

Where: P is the load at failure in flexural-tensile test; L is the span length of prism; b is the width of concrete prism; and d is the total depth of concrete prism. According to Table 3, the modulus of rupture of prism without waiting time was 2.81 MPa. This increased by 10.6%, 3.9% and 14.9% when the waiting time before re-vibration was 30, 60 and 90 minutes respectively. The increase in modulus of rupture due to re-vibration after time interval is due to fact that, the re-vibration re-arranged the coarse aggregate, eliminated the micro-cracks and escape the entrained air in the mix, which consequently improve the flexural-tensile strength of the concrete. Some of non-linear behavior in the beginning of relation between the applied load and vertical displacement due to test setup is disregarded. This relation shows approximately linear behavior until the maximum flexural-tensile load due to brittle behavior of concrete in tension (there is no softening zone after peak load), see Figure 5.The main scope of the present study was to investigate the effect of waiting time before the operation of re-vibration on the flexural-tensile strength of concrete. This depicted in Figure 6, in which the modulus of rupture increased for 30 minutes waiting then decrease with 60 minutes waiting then increased with 90 minutes waiting. Nevertheless, the operation of re-vibration for all waiting time improved f_r in comparisons with the initially vibrated specimen. In fact, the maximum improvement in flexural-tensile strength of concrete prism occurs at W-DT1.5 specimen. Figure 7 shows the failure modes of prisms under four points load test, in which, the flexural failure crack occurs at the middle-third length of the specimen i.e in the area of constant bending moment and zero shear force.

Table 3: Results of flexural-tensile test of prisms

Group	Specimen	Initial vibration time (sec)	Waiting time after Initial vibration (min)	Load at Failure (kN)	Maximum deflection (mm)	Modulus Of rupture f_r (MPa)
W	W-DT0	15	-	9.36	1.48	2.81
	W-DT0.5	15	30	10.36	0.85	3.11
	W-DT1	15	60	9.73	1.30	2.92
	W-DT1.5	15	90	10.76	0.70	3.23

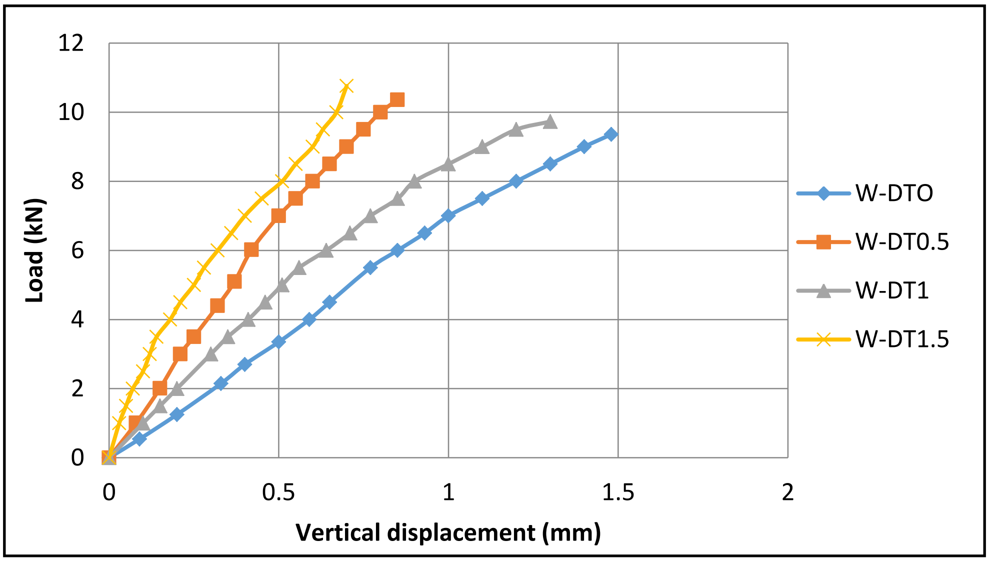

Figure 5: load-deformation behavior of prisms

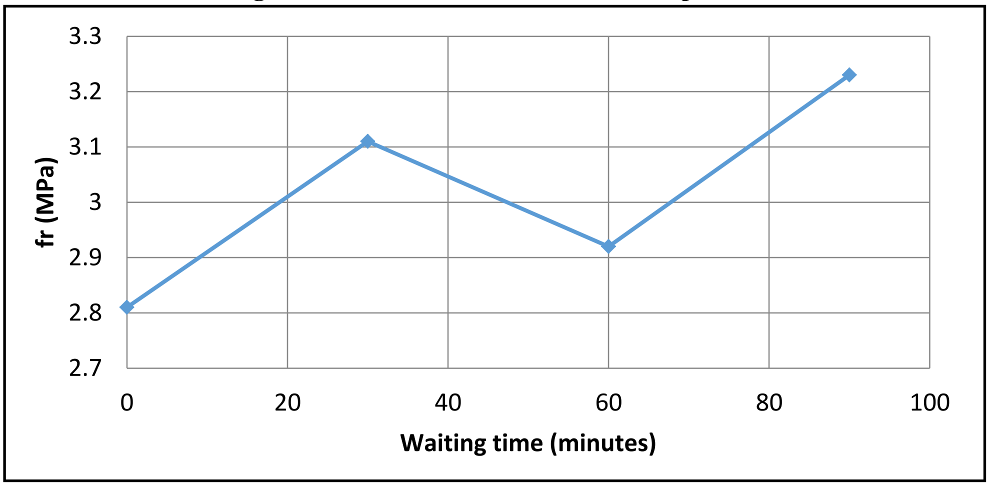

Figure 6: Effect of waiting time before re-vibration on flexural-tensile strength

Figure 7: Modes of failure of concrete prisms

2) Compressive and Splitting-Tensile Strength of Concrete

The results of Compressive strength of cubes and tensile strength of cylinders for group W listed in Table 4. In which, the tensile strength of concrete was increased by 11.5% for 30 minutes waiting time, by 3.8% for 60 minutes waiting time, and by 15.4% for 90 minutes waiting time. The compressive strength of concrete was increased by 9.4% for 30 minutes waiting time, by 5.4% for 60 minutes waiting time, and by 14.8% for 90 minutes waiting time.

Table 4: Compressive and tensile strength of concrete of group W

Specimen (cubes and cylinders)	Waiting time before re-vibration (minutes)	Average compressive strength of cubes (MPa)	Average tensile strength of cylinders (MPa)
W-DT0	0	29.7	2.6
W-DT0.5	30	32.5	2.9
W-DT1	60	31.3	2.7
W-DT1.5	90	34.1	3.0

II. The effect of waiting time before re-vibration on the behavior of prisms, cubes and cylinders in group A

In this section, the concrete prisms, cubes and cylinders of group A were tested to investigate the effect of waiting time before re-vibration on the mechanical properties of concrete. All specimens in group A have 0.5% steel fiber content. The results are listed in the following sections.

1) Flexural-Tensile Strength of Concrete Prisms

All The prisms were initially vibrated with 15 second and re-vibrated with 15 seconds after waiting time. The test results were listed in Table 5. According to Table 5, the modulus of rupture of prism without waiting time was 3.21 MPa. The 30 minutes waiting before re-vibration increase the modulus of rupture by 9.6%, 60 minutes waiting before re-vibration increase the modulus of rupture by 4.3% and finally, 90 minutes waiting before re-vibration increase the modulus of rupture by 19.3%. Figure 8 shows the load-deformation behavior of prism in group A, in which, the stiffness of re-vibrated specimens is more than that of initially vibrated. In addition, the specimens show only matrix tensile strength due to small value of steel fiber content in specimen. To study the effect of waiting time before re-vibration on the flexural-tensile strength of concrete, Figure 9 was depicted which shows the relation between modulus of rupture and waiting time before re-vibration. The maximum flexural-tensile strength achieved in 90 minutes waiting time before re-vibration.

Table 5: Results of flexural-tensile test of prisms of group A

Group	Specimen	Steel fiber content (%)	Initial vibration Time (sec)	Waiting time after Initial Vibration (min)	Load at Failure (kN)	Maximum deflection (mm)	Modulus of rupture f_r (MPa)
A	A-DT0	0.5	15	-	10.70	3.01	3.21
	A-DT0.5	0.5	15	30	11.73	1.81	3.52
	A-DT1	0.5	15	60	11.16	1.52	3.35
	A-DT1.5	0.5	15	90	12.76	1.71	3.83

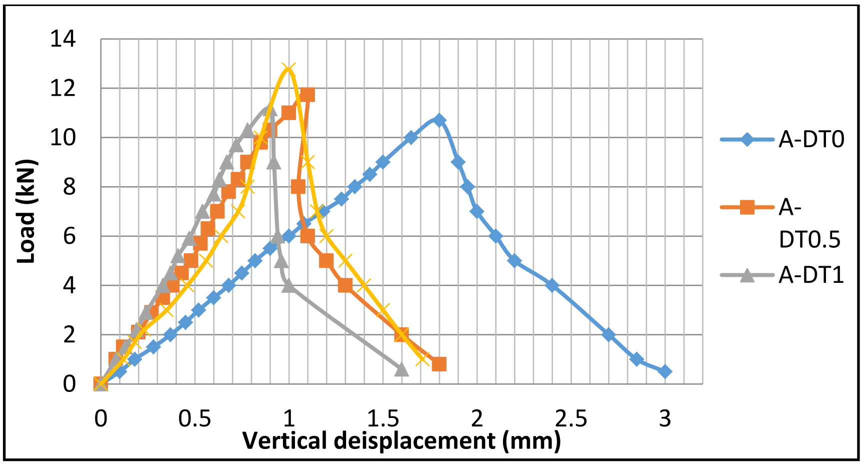

Figure 8: load-deformation behavior of concrete prism

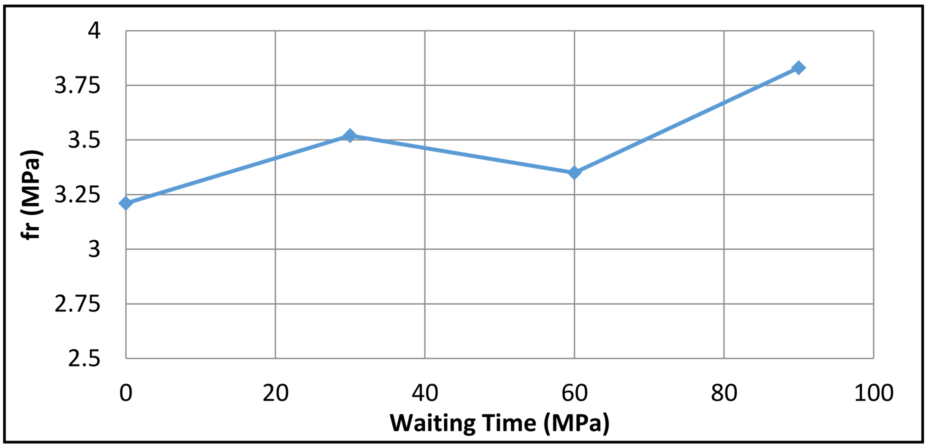

Figure 9: Effect of waiting time before re-vibration on flexural-tensile strength

2) Compressive and Splitting-Tensile Strength of Concrete

In comparisons with initially vibrated specimen, the compressive strength of cubes were increased by 5.1%, 3.8%, and 10.1% when the specimens re-vibrated after 30, 60 and 90 minutes respectively. While, the tensile strength of cylinders were increased by 10%, 3.3% and 13.3% when the specimens re-vibrated after 30, 60 and 90 minutes respectively. Test results were listed in Table 6.

Table 6: Compressive and tensile strength of concrete

Specimen (cubes and cylinders)	Waiting time before re-vibration (minutes)	Average compressive strength of cubes (MPa)	Average tensile strength of cylinders (MPa)
A-DT0	0	31.5	3.0
A-DT0.5	30	33.1	3.3
A-DT1	60	32.7	3.1
A-DT1.5	90	34.7	3.4

III. The effect of waiting time before re-vibration on the behavior of prisms, cubes and cylinders in group B

In this section, the concrete prisms, cubes and cylinders of group B were tested to investigate the effect of waiting time before re-vibration on the mechanical properties of concrete. All specimens in group C have 1% steel fiber content. The results are listed in the following sections.

1) Flexural-Tensile Strength of Concrete Prisms

According to test results of flexural-tensile test of prisms listed in Table 7, the modulus of rupture increased by 7.8%, 11% and 21.2% when the re-vibration occurs after 30, 60 and 90 minutes respectively in compares with the specimen vibrated without waiting time. The improvement in the modulus of rupture is due to redistributed of both the aggregate and steel fiber in cement paste. The load-deformation behavior of concrete prisms was depicted in Figure 10. In this relation, the behavior is approximately linear until matrix tensile strength (steel fiber not yet activated) then, unstable drop in tensile strength occurs due to opening of the first crack. Another ascending in the load-deformation curve occurs due to activation of steel fiber in concrete matrix (post matrix tensile strength). This value depends on steel fiber content and type of steel fiber. Further, the stiffness of specimen in this relation was increased with increasing the waiting time before re-vibration. To study the effect of waiting time before re-vibration on the flexural-tensile strength of concrete, as explained in Figure 11, the modulus of rupture increased with the increasing of waiting time before re-vibration, and the maximum flexural-tensile strength achieved in 90 minutes waiting time. This behavior is different from that in prisms of group W and A due to relatively high steel fiber content.

Table 7: Results of flexural-tensile test of prisms of Group B

Group	Specimen	Initial vibration time (sec)	Waiting time after Initial vibration (min)	Load at Failure (kN)	Maximum deflection (mm)	Modulus of rupture f_r (MPa)
	B-DT0	15	-	12.70	1.48	3.81
B	B-DT0.5	15	30	13.70	0.85	4.11
	B-DT1	15	60	14.10	1.30	4.23
	B-DT1.5	15	90	15.40	1.00	4.62

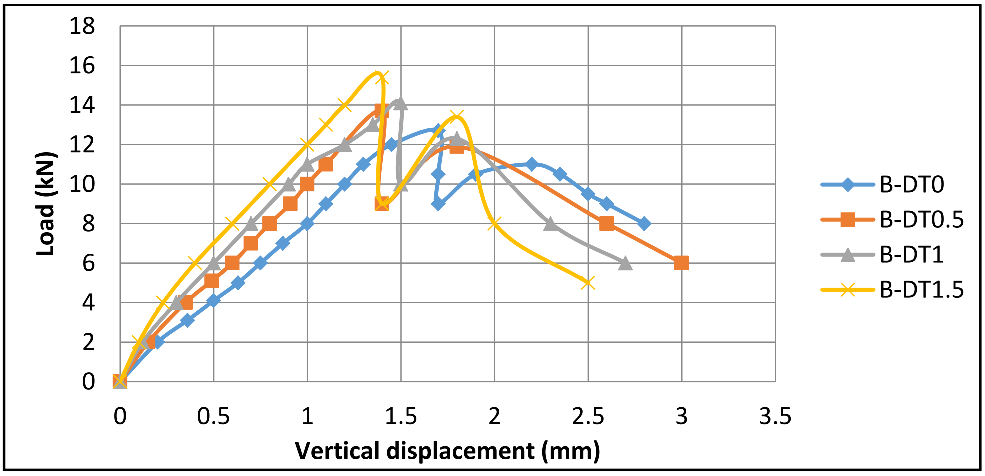

Figure 10: load-deformation behavior of tested specimen

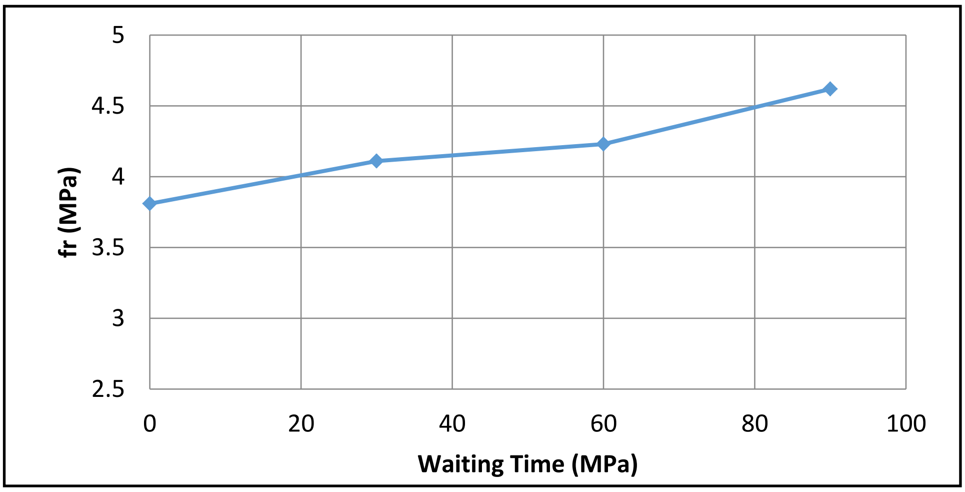

Figure 11: Effect of waiting time before re-vibration on flexural-tensile strength

2) Compressive and splitting-tensile strength of concrete

The compressive strength of initially vibrated cubic was 35.1 MPa. This increased by 3.1%, 9.1%, and 12.8% when these cubes were re-vibrated after 30, 60 and 90 minutes respectively. Whereas, the tensile strength of cylinders increased by 8.3%, 11.1% and 16.6% when these cylinders were re-vibrated after 30, 60 and 90 minutes respectively, see Table 8.

IV. The Effect of Waiting Time before Re-vibration on the Behavior of Prisms, Cubes and Cylinders in Group C

In this section, the concrete prisms, cubes and cylinders of group C were tested to investigate the effect of waiting time before re-vibration on the mechanical properties of concrete. All specimens in group C have 1.5% steel fiber content. The results are listed in the following sections.

1) Flexural-Tensile Strength of Concrete Prisms

All The prisms were initially vibrated with 15 second and re-vibrated with 15 seconds after waiting time. The test results were listed in Table 9. According to Table 9, the modulus of rupture of prism initially vibrated with 15 second was 4.81 MPa. The modulus of rupture increased by 8.5%, 17% and 29.7% in comparisons with initially vibrated specimen when the prism is re-vibrated with 15 seconds after waiting time of 30, 60, and 90 minutes respectively. The increasing of modulus of rupture is due to fact that, the re-vibration redistributed both aggregate particles and steel fibers in the concrete matrix. According to Figure 12, the ratio between post matrix tensile strength of concrete to the matrix tensile strength is 1.2, this ratio referred to fiber efficiency of tensile strength. In addition, the stiffness of specimens increased with increasing the waiting time before the re-vibration. Figure 13 shows the relations between the modulus of rupture and the waiting time before re-vibration, in which, f_r increased with the increasing the waiting time before re-vibration.

Table 8: Compressive and tensile strength of concrete

Specimen (cubes and cylinders)	Waiting time before re-vibration (minutes)	Average compressive Strength of cubes (MPa)	Average tensile strength of cylinders (MPa)
B-DT0	0	35.1	3.6
B-DT0.5	30	36.2	3.9
B-DT1	60	38.3	4.0
B-DT1.5	90	39.6	4.2

Table 9: Results of flexural-tensile test of prisms of Group C

Group	Specimen	f_{cu} (MPa)	Initial vibration time (sec)	Waiting time after Initial vibration (min)	Load at Failure (kN)	Maximum deflection (mm)	Modulus of rupture f_r (MPa)
C	C-DT0	29.7	15	-	16.03	2.51	4.81
	C-DT0.5	32.5	15	30	17.40	3.02	5.22
	C-DT1	31.3	15	60	18.76	2.53	5.63
	C-DT1.5	38.3	15	90	20.80	3.56	6.24

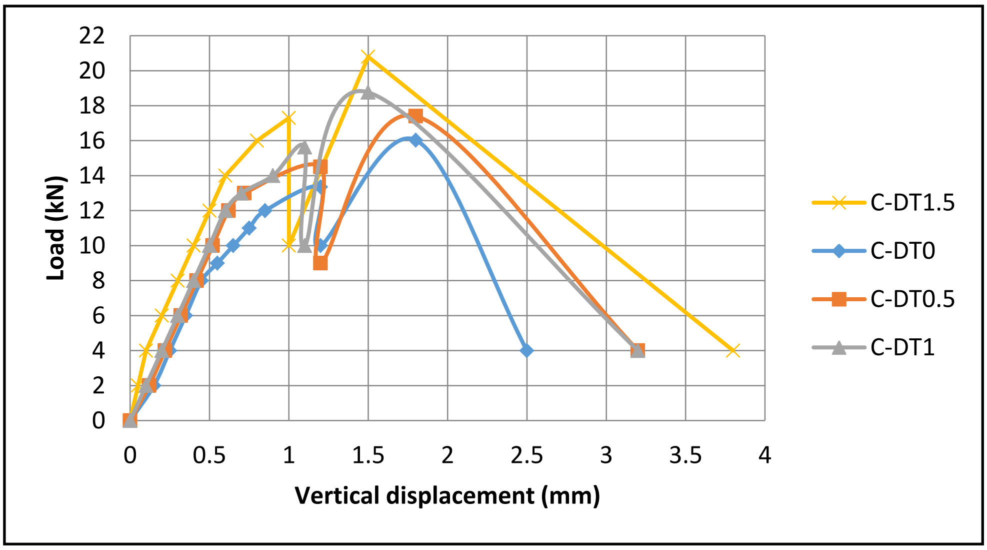

Figure 12: load-vertical displacement of concrete prism

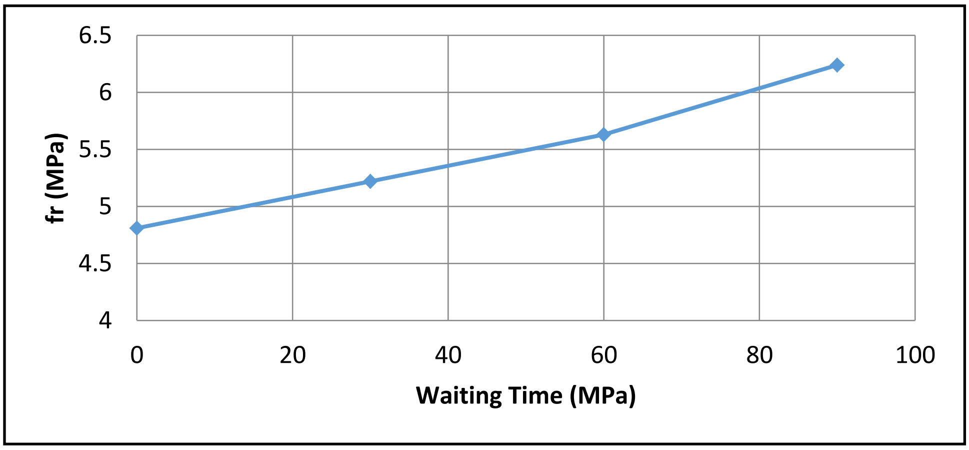

Figure 13: Modulus of rupture-waiting time relationship

2) Compressive and Tensile Strength of Concrete

Table 10 shows the results of compressive strength of cubes and tensile strength of cylinders after initial vibration and re-vibration after 30, 60 and 90 minutes of waiting time. In comparisons with initially vibrated specimen, increasing by 6.6%, 15.5% and 31.1% was occurred in tension strength at 30, 60 and 90 minutes of waiting time before re-vibration respectively. Further, increasing by 5.5%, 13.1% and 19.4% was occurred in compression strength at 30, 60 and 90 minutes of waiting time before re-vibration respectively.

Table 10: Compressive and tensile strength of concrete

Specimen (cubes and cylinders)	Waiting time before re-vibration (minutes)	Average compressive strength of cubes (MPa)	Average tensile strength of cylinders (MPa)
C-DT0	0	38.1	4.5
C-DT0.5	30	40.2	4.8
C-DT1	60	43.1	5.2
C-DT1.5	90	45.5	5.9

V. Effect of Fiber Content on Flexural-Tensile Strength of Concrete for the Same Waiting Time

To confirm the effect of steel fiber content on the flexural-tensile behavior of concrete prism, a relationship between the modulus of rupture and steel fiber content for the same waiting time before re-vibration in each group was depicted. Figure 14 shows this relation, in which, the modulus of rupture increased with the increasing of steel fiber content for all waiting time before re-vibration, which is expectedly.

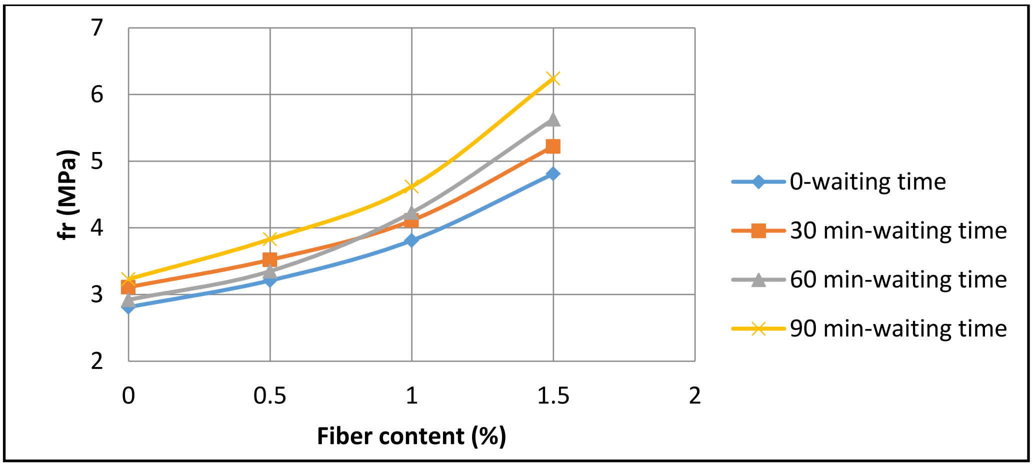

Figure 14: Effect of steel fiber content on modulus of rupture

7. Conclusions

- In the presence and absence of steel fiber in concrete, the maximum improvement in flexural-tensile strength of concrete prism occurs after the initial setting of concrete i.e after 90 minutes waiting time.
- Concrete prisms without steel fiber shows approximately linear behavior till the maximum flexural-tensile load due to brittle behavior of concrete.
- The modulus of rupture of concrete prism increased with the increasing of steel fiber content for all waiting time before re-vibration.
- The re-vibration after time period increased the stiffness of concrete prism in case of presence of steel fiber compared with the prisms initially vibrated only.
- The maximum improvement in compressive strength and splitting tensile strength of concrete occurs at 90 minutes of waiting time before re-vibration.
- The prisms with steel fiber show matrix tensile strength and post matrix tensile strength. While, in absence of steel fiber, the matrix tensile strength exists only.
- The modulus of rupture shows continued improvement with 30, 60 and 90 minutes waiting time for 1% and 1.5% steel fiber content. While, in 0% and 0.5% steel fiber content, there is increase then decrease then increase in the modulus of rupture for 30, 60 and 90 minutes waiting time respectively.

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