International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-9 Issue-3, February 2020

Flexural Behaviour of Reinforced Rapid Hardened Concrete Beams

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Abstract*: In the last decades concrete technology has made it easier to reach early strength, Rapid Hardened Concrete is one of the construction concretes used widely. The use of rapid hardened concrete is increased due to the possibility to limit the construction time. The purpose of this paper is to investigate the mechanical properties of Rapid Hardened Concrete (RHC). Properties studied include compressive strength, tensile strength, and flexural behavior. Mechanical properties were evaluated based on the compressive, tensile, and bend test results for both normal and rapid hardened concrete. The effect of admixture percentages (Sikament-nn) on hardening properties of rapid concrete was studied. The experimental investigation indicated that the flexural and compressive strength of concrete increased with the addition of Sikament-nn at the age of 1, 3, 7, and 28 days and the optimal percentage of Sikament-nn was 2%. In addition, test results show that rapid hardened concrete exhibit ductile failure and significant displacement before failure. The ultimate displacement of rapid hardened concrete was an increase more 50% than control RC beams.

***Keywords*: RHC Beams, Flexural Behavior, Tensile Behavior.**

I. INTRODUCTION

The fundamental understanding of the behaviour of rapid hardening concrete is essential to ensure safety during construction, as well as adequate durability and long-term properties. Moreover, accelerated construction schedules aiming at economic gains have led to tragic failures during construction due to the inadequate knowledge of the rapid hardening concrete behavior [1].

Many researchers investigated the rapid hardening concrete [2-7-8]. Generally, the rapid hardening concrete is characterised by two main processes: setting (progressive loss of fluidity) and hardening (gaining strength). Hence, the coupling between thermal and mechanical characteristics of RHC is more critical compared to that in mature concrete.

Recently, many papers presented the results of mechanical behavior of rapid hardening concrete. As such, little information is available on ultimate deformation capability. In consideration of the importance of these characteristics on application of rapid hardening concrete, the present work was aimed to study the flexural behavior of reinforced rapid hardened concrete beams and ultimate deformation. In this study, three different tests were conducted.

Revised Manuscript Received on February 05, 2020.

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The compression, splitting tensile and flexural test were performed to investigate the rapid hardening concrete.

Four types of specimens were used to determine and study the rapid strength of the concrete including (i) 57 cylinders (D=150 mm and length L=300), (ii) 39 cubes 150 mm (iii) 18 plain concrete prisms with 150x150x600mm, and (iv) RC beams with 100x200x2000 mm.

II. EXPERIMENTAL PROGRAM

A. Experimental program matrix

The experimental program matrix consists of 4.0 series as show in Table I. Two different concrete types (normal and rapid) were studied, and four different tasting ages (1, 3, 7 and 28 days) were imposed. Also the admixture percentage % was varied, in order to assess its influence on the early-age compressive strength of concrete. Measurements of the load-deflection for all plain/reinforced beams were performed.

The reinforced concrete beams are divided into two groups, a control group with normal concrete and second group with rapid compressive strength. The RC beam study having a total length (L = 2000 mm), overall depth (h= 200 mm) and width (b = 100 mm). The RC beams are reinforced with 2 Ø 10 as top reinforcement and 2 Ø 16 as bottom reinforcement as show in Fig. (1).

Table- I: Experimental program matrix

Serie	Specimen	Concrete Type	Age (day)			
			1	3	7	28
S1	39 Cube	normal concrete	-	3	3	3
		Rapid concrete	3	12	12	3
S2	57 Cylinder	normal concrete	-	3	3	3
		Rapid concrete	3	21	21	3
S3	18 Plain concrete Beam	normal concrete	-	3	3	3
		Rapid concrete	3	3	-	3
S4	5 reinforced concrete Beam	normal concrete	-	-	1	1
		Rapid concrete	1	1	1	-

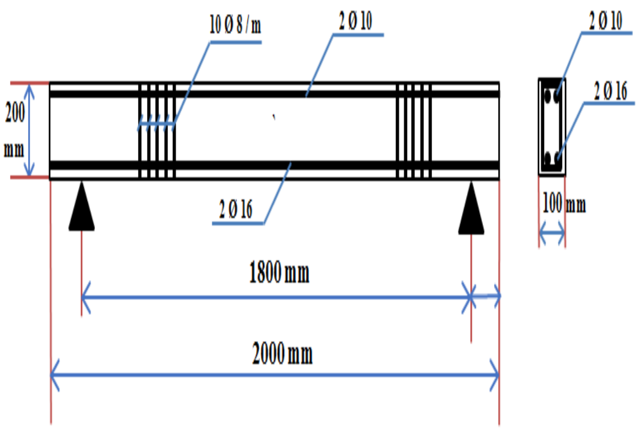

Fig. 1.RC Beam dimensions and reinforcement details.

B. Material Properties

The average compressive strength of the normal / rapid concrete based on ASTM C 39 [3] is 40 MPa and the average tensile strength is 3.60 MPa. The average yield strength of steel reinforcement is 400 MPa with a modulus of elasticity of 200 GPa (DIN 50145) [9] and the ultimate strength is 600 MPa. The mix composition of the studied normal and rapid concrete is shown in Table II & III.

Table- II: Normal concrete mix composition.

Sand (kg/m^3)	500
Gravel (kg/m^3)	1200
Cement (kg/m^3)	400
Water (L/m^3)	180
W/C	0.45

Table- III: Rapid concrete mix composition.

Sand (kg/m^3)	500
Gravel (kg/m^3)	1200
Cement (kg/m^3)	450
Water (kg/m^3)	180
Admixture 2% (L/m^3)	10
W/C	0.40

C. Test Set-up

Compressive tests were done by using a compression testing machine with a capacity of 2,000 kN. The load was measured by using a 2,000-kN-capacity load cell. The loading was applied through the displacement control method at a rate of 0.005 mm/s. The overall view of the compressive test setup is shown in Fig. (2).

The beams were tested at their age of 1, 3, 7 and 28 days. A steel frame consisting of horizontal and vertical I-sections were used to support the beam specimens. The load was applied by a hydraulic cell. All beam specimens were painted with lime to facilitate crack observation during the test as shown in Fig. (2). The specimens were tested under the effect of two loads using a hydraulic jack with increment equal to 5 kN. The test setup allowed a constant moment region of 600 mm along the middle third where the splice length is located and two shear spans at the terminal thirds 600 mm each. The beams were supported at 100 mm apart from the both ends using two metal beams restrained to a horizontal flat surface of the testing frame.

Fig. 2. Test Set-up.

D. Instrumentation

In order to record the beams vertical deflection, three vertical dial gages with 0.01 mm accuracy were used for vertical measurements were used under beams at the mid span as well as the two thirds of the span between the two supports as shown in Fig. (3). The mid-span tensile steel strain (S1) was measured by one electrical strain gauge of 20-mm length and 120-Ohm resistance.

Fig. 3.Dial gauges positions.

E. Test Procedures

Compressive Strength Test

The compressive strength of the concrete was determined by testing three 150 mm size cubes at ages 1, 3, 7, and 28 days for each mix. The test was carried out according to ASTM C 39 [3] using a compressive machine with capacity of 2,000 KN.

Splitting Tensile Strength Test

The splitting tensile strength was determined following the procedure outlined in ASTM 496/C 496M-2004 [4]. Cylinders (150 mm x 300 mm) were used.

Flexural Strength Test

This flexural strength test for plain concrete was carried out on (150 mm x 150 mm x 600 mm) prisms in accordance with ASTM C293-2002 [5], using a simple beam with 4-point loading. For reinforced beams, the flexural strength test was carried out on (100 mm x 200 mm x 2000 mm), using a simple beam with four-point load.

III. TEST RESULTS AND DISCUSSION

This experimental program is conducted in order to study the behavior the flexural behavior of reinforced rapid hardened concrete (RHC) beams. In the present experimental investigation, the following tests were carried out namely: compressive strength, split tensile strength, and flexural strength. Tests for normal and rapid strength concrete have been attempted over the concrete specimens such as cubes, cylinders, prisms and beams respectively. The admixture with varying percentages of 0%, 0.60%, 1.0%, 2.0% and 3.0% percentages of total cement content were used for structural concrete.

For each admixture percentages of total cement content, 9 cubes & 9 cylinders were cast. Totally 39 cubes & 57 cylinders were cast with locally available admixture are taken for testing in this investigation. Totally 18 prisms & 5 RC beams for 1, 3, 7, and 28 days were used for finding flexural strength. The four series of tests have been carried out as show in Table I.

A. Series S1and S2

Results of cubes and cylinders compressive strength are reported in Tables IV & VI. The results represent the average value of three specimens. Mixture A, made with admixture with 2.0% percentages shows, as expected, both the fastest strength and the highest value at 7 days, followed by Mixture D. The strength of Mixtures B and C develops slowly. Similar trends are found for the splitting tensile strength. This early rapid increase in strength is directly related to the increase in the admixture percentages (Sika mint -NN) [10].

B. Tensile Strength

Tensile strength is a key property of early-age concrete; it has a chief influence on the resistance of concrete to plastic shrinkage, thermal stresses during hydration, and early-age loading and cracking which can affect the stiffness of the structure [13]. Measuring the early-age tensile strength of concrete is complicated since concrete is viscous and inelastic at that stage [1]. Following Table V states results of determining tensile strength of different mix designs of different ages - from 1 day to 28 days. Comparison of tensile strength of individual mix designs is shown in Fig. 4. In addition, the present tests in Table V show that the average tensile strength for rapid concrete at 7 days is equal average tensile strength for normal concrete at 28 days.

Table- IV: Series 1- Concrete compression strength-Cubes.

Concrete Mix	Age (day)	Load (KN)	Compression Strength (N/mm²)	Average strength (N/mm²)
		537	24	
		4517	20	
	3 days	489	22	22
		658	29	
		678	30	
	7 days	780	35	31
		784	38	
		833	37	
Normal concrete	28 days	875	39	38
Mixture A R.H.C. 2%		546	24	
		537	24	
	1 days	576	26	25
		604	27	
		707	31	
	3 days	697	31	30
		951	42	
		889	40	
	7 days	866	38	40
		853	38	
		1086	48	
	28 days	939	42	43
Mixture B R.H.C. 0.6%		514	23	
		739	33	
	3 days	589	26	27
		744	33	
		718	32	
	7 days	856	38	34
Mixture C R.H.C. 1%		649	29	
		595	26	
	3 days	623	28	28
		549	24	
		786	35	
	7 days	804	36	32
Mixture D R.H.C. 3%		800	36	
		726	32	
	3 days	636	28	32
		509	23	
		1077	48	
	7 days	905	40	37

Table- V: Series 2- Concrete tensile strength - Cylinders.

Concrete Mix	Age (day)	Load (KN)	Tensile Strength (N/mm²)	Average tensile strength (N/mm²)
Normal concrete	3 days	170	4.8	5.0
		188	5.3	
		213	6.0	
	7 days	185	5.3	6.0
		234	6.6	
		227	6.4	
	28 days	227	6.4	6.0
		217	6.1	
		223	6.3	
Mixture A R.H.C. 2%	1 days	215	6.1	5.0
		170	4.8	
		181	5.1	
	3 days	235	6.7	6.0
		227	6.4	
		217	6.1	
	28 days	304	8.6	8.0
		336	9.5	
		260	7.3	

Table-VI: Concrete compressive strength - Cylinders.

Concrete Mix	Age (day)	Load (KN)	Compression Strength (N/mm^2)	Average strength (N/mm^2)
		289	16	
		317	18	
	3 days	350	20	18
		380	22	
		292	17	
	7 days	662	38	19
		526	30	
		448	25	
Normal concrete	28 days	412	23	26
		401	23	
		40	22	
	1 days	37	21	22
		37	21	
		51	29	
	3 days	52	30	27
		61	35	
		53	30	
	7 days	50	28	27
		34	15	
		72	32	
R.H.C. 2%	28 days	47	21	33
		25	14	
		36	20	
	3 days	29	16	19
		45	26	
		35	20	
R.H.C. 0.6%	7 days	33	19	21
		32	18	
		42	24	
	3 days	34	19	20
		48	27	
		45	26	
R.H.C. 1%	7 days	30	17	23
		51	29	
		48	27	
	3 days	45	26	27
		50	28	
		40	24	
R.H.C. 3%	7 days	52	29	27

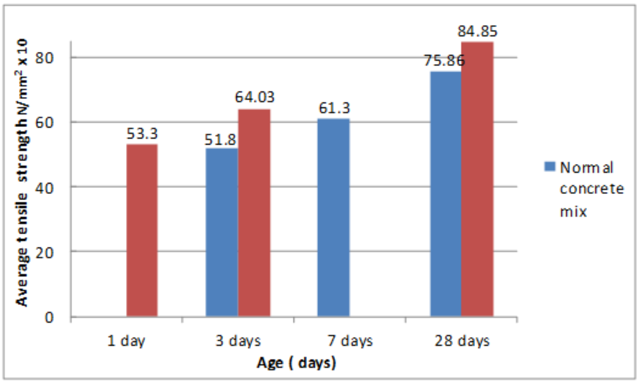

Fig. 4.Comparison of tensile strength.

C. Modulus of elasticity

The modulus of elasticity is indicates the concrete capability to deform elastically and thus is related to its serviceability. Generally, it is obtained from the stress– strain curve [11-12]. This stress value is 40% of the ultimate strength according to ASTM C469-94 [4], and about 33% in the British Standards (BS 1881) [6]. Fig. 5 shows the Young's moduli for 3, 7, and 28 days concrete specimens.

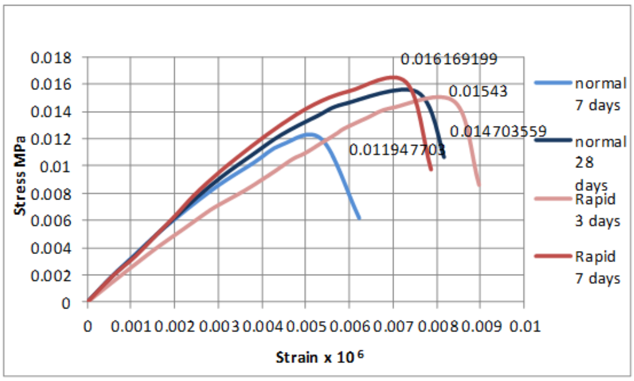

Fig. 5.Stress-strain responses.

D. Series S3and S4

The evolution of the flexural strength of concrete during hardening was studied experimentally by means of a four-point bending test on un-notched prisms. Table VII summarizes the test results for the peak loads, displacements and flexural strength at the peak loads for the tested beams. Table VII also shows the increase of peak load and flexural strength according to the age of concrete. Also the flexural strength at 28 days for normal concrete was equal value at 7 days for rapid hardening concrete. It was observed that the specimens failed instantaneously after reaching peak load splitting into two halves**.** The load – deflection carve at the age of 1, 3, 7 and 28 days were shown in Fig. 6. Comparison of the data of the 1, 3, 7 and 28 days prisms showed that the flexural strength varied with the age.

E. Load-Deflection Relationship

Figures 7, 8 and 9 show the comparison of the average load-displacement curves at each concrete type and age. The comparison of the load - deflection at each age is showed that the load-displacement varied with the age.

Retrieval Number: C5301029320/2020©BEIESP
DOI: 10.35940/ijeat.C5301.029320

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Blue Eyes Intelligence Engineering
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The rapid hardening concrete beams exhibited similar load - deflection behavior. The rapid hardening concrete beams with containing 2% admixture achieved the highest flexural strength. The peak loads, displacements and flexural strength at the peak loads of reinforced concrete beams at the age of 3, 7, and 28 days are presented in Table VIII.

Table- VII: Series 3 - Plain concrete prisms.

Beam	*Concrete type*	*Age* (day)	*Peak load* $P_{Ultimate}$ *(kN)*	*Displacement (mm)*	*Flexural Strength* $f_{b\ avg.}$ *(MPa)*
B1	Normal concrete	3	28	2.1	3.46
B2			27	2.4	
B3			22	2.2	
B4		7	30	1.7	3.59
B5			30	1.8	
B6			26	1.9	
B7		28	31	1.5	3.88
B8			32	1.6	
B9			29	1.8	
B10	Rapid Concrete	1	29	1.2	3.90
B11			32	1.4	
B12			28	1.3	
B13		3	31	1.2	3.98
B14			29	1.5	
B15			27	1.7	
B16		7	34	1.0	4.36
B17			34	1.0	
B18			31	1.0	

Table- VIII: Series 4- Reinforced concrete beams.

Beam	*Concrete type*	*Age* (day)	*Peak load* $P_{Ultimate}$ *(kN)*	*Displacement (mm)*	*Flexural Strength* $f_{b\ avg.}$ *(MPa)*
B1	Normal concrete	7	72	21	32.45
B2		28	80	15	35.88
B3	Rapid Hardening Concrete	3	72	20	32.45
B4		7	72	22	32.45
B5		28	81	24	36.46

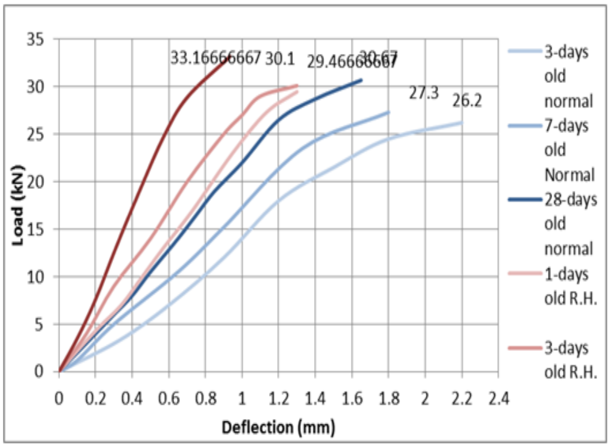

Fig. 6.Load-deflection responses.

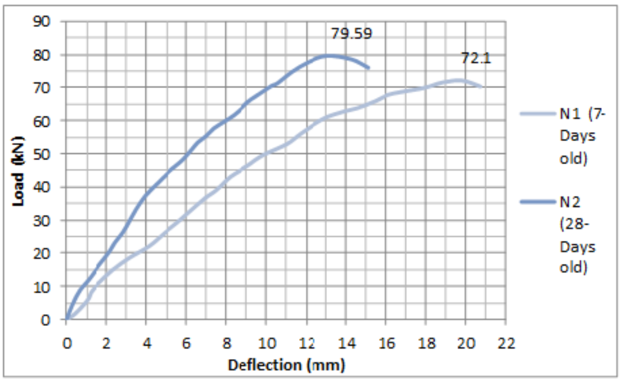

Fig. 7.Load - deflection responses for normal concrete beams.

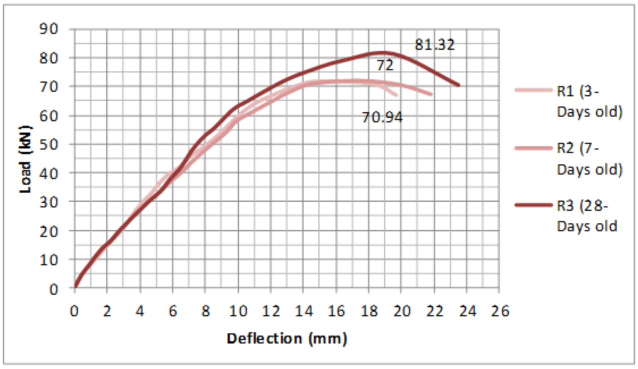

Fig. 8.Load - deflection responses for rapid hardening beams.

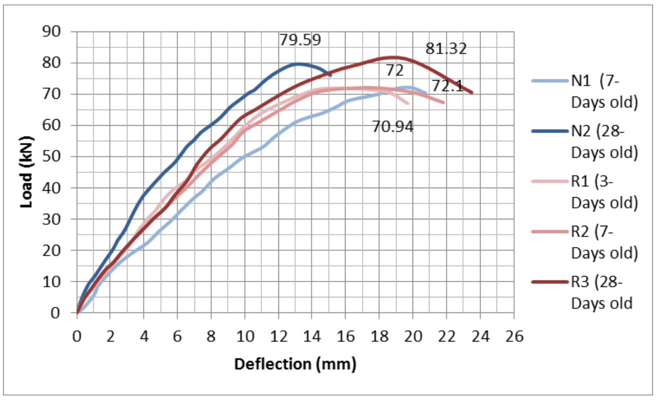

Fig. 9.Load - deflection responses for all beams.

IV. CONCLUSIONS

According to the experiments, the following conclusions can be drawn:

1. Proprietary rapid-hardening concrete needs to be used when stringent early strength is required, for example, 30 MPa within 3 days.
2. The rapid-hardening strength providing compressive stress in concrete can be produced by using 2% admixture Sikament -NN.
3. The rapid-hardening concrete in general show significant deflection-hardening behaviour. The flexural strength reaches 32 MPa in 3 days.
4. The experimental results lead to the conclusion that the rapid-hardening concrete has the same linear stress strain relationship as that of conventional strength concrete.

5. The rapid-hardening concrete exhibited ductile failure and underwent significant displacement before fracture.
6. The compressive strength and modulus of elasticity of rapid-hardening concrete increased rapidly after 1.0 day, following the concrete casting.
7. The non-notched three-point flexural tests verified that, the flexural strength of rapid-hardening concrete manifested rapidly until the age of 3 days, and the strength at 7 days was almost equal to the strength at 28 days normal strength concrete.
8. Based on the test results presented in this paper, it was concluded that a mixture design with 2% admixture Sikament-NN was optimal in increasing early strength while maintaining an adequate workability.
9. The tensile stress-strain response of rapid-hardening concrete was observed to be very linear even at early ages (e.g., 3 days old).

REFERENCES

1. Abel J and Hover K (1998) Effect of water/cement ratio on the early-age tensile strength of concrete. Transportation Research Record: Journal of the Transportation Research Board No. 1610, 33–38.
2. Atrushi DS (2003) Tensile and Compressive Creep of Early-age Concrete: Testing and Modeling. PhD thesis, The Norwegian University of Science and Technology, Norway.
3. ASTM C 39. Test method for compressive strength of cylindrical concrete specimens. Annual Book of ASTM Standards, 04.02, 1988:19-23.
4. ASTM C496 / C496M – 04. Standard test method for splitting tensile strength of cylindrical concrete specimens.
5. ASTM C293 – 02. Standard test method for flexural strength of concrete.
6. BSI (British Standards Institution) (1983) BS 1881: Part 121: Method for determination of static modulus of elasticity in compression. BSI, London, UK.
7. Bentur A (ed.) (2003) Early-age Cracking in Cementitious Systems. RILEM Technical Committee 181-EAS: Early-age Shrinkage Induced Stresses and Cracking in Cementitious Systems. RILEM, R. 25, 335 pp.
8. Bissonnette B and PigeonM (1995) Tensile creep at early-ages of ordinary, silica fume and fiber-reinforced concretes.
9. DIN 50145 (1975) Testing of Metallic Materials; Tensile Test.
10. Neville AM (ed.) (1996) Properties of Concrete, 4th edn. Wiley, New York, USA.
11. Oluokun FA, Burdette EG and Deatherage JH (1991a) Elastic modulus, Poisson's ratio, and compressive strength relationships at early-ages. ACI Materials Journal 88(1): 3–10.
12. Tia M, Liu Y and Brown D (2005) Modulus of Elasticity, Creep and Shrinkage of Concrete. Department of Civil and Coastal Engineering, University of Florida, FL, USA, Report U.F Project No. 49104504973-12, 165 pp.
13. Zhao J (1990) Mechanical Properties of Concrete at Early-ages. Master thesis, University of Ottawa, Canada.

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