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Modeling and simulation of flexure strength of self-compacting concrete modified with fly ash and super plasticizer

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Abstract

This paper explained the application of deterministic techniques simulated numerically and analytically to monitor the behaviour of flexural strength of self- compacting concrete, Flexural strength, or bend strength, could be known as a material's that has the ability to resist deformation under load, the mix design of self-compacting concrete was developed as a model concrete that will solve the characteristics of higher strength base on the variation of addictive's within shorter period of curing age; the study try to monitor the rate of load resistances under deformation, this explained the variation of strength attained from the model concrete through the application of these addictive's, thus applied to modified the concrete formation. Normal strength monitored are seven days interval, but the application of deterministic modeling techniques for such non-homogeneous system were applied to predict the behaviour of flexural strength for self-compacting concrete, the derive solution from non-homogeneous system generated theoretical values from simulation, these results were compared with experimental data, and both parameters correlated favorable fits.

Keywords: modeling, flexural strength, self-compacting concrete, super plasticizers and fly ash.

1. Introduction

A concrete that has the ability of self-consolidating, that is, able to occupy the entire space in a form without the application of any external effort (such as mechanical vibration, floating, poking etc.) is known as self-compacting concrete (Tande & Mohite, 2007) [11]. A self-compacting concrete must have an acceptable level of passing ability, filling ability and stability in order to fill up the entire space, flowing through the congestion in the form, without applying any external efforts. A self-compacting concrete must have a satisfactory level of passing ability, keeping in mind the end goal of filling up the whole space in a form for casting of concrete, without applying any external mechanical effort. Based on the fact that concrete is a composition of materials consisting of different specific gravities, it is challenging for its constituents to be kept in a cohesive form. This challenge can be solved by addition of more quantity of finer material (lesser than 100 microns) in unit content of concrete and the use of super-plasticizers (Bapat *et al*, 2004). This has necessitated the need for the design of concrete that is able to self-consolidate without applying any external effort. One answer for the accomplishment of durable concrete structures free of the nature of the quality of the construction work is the utilization of self-compacting concrete (Aydin, 2007) [2]. Self-compacting concrete is characterized by its filling ability, passing ability and resistance to segregation. A number of methods have been developed to characterize the properties of self- compacting concrete. No single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mix has been tested by more than one test method for the different workability parameters (Aggarwal *et al*, 2008) [1]. A number of researches have been carried out in Nigeria in establishing a standard design mix of self-compacting concrete using local materials. Kayode & Ilesanmi (2013), investigated the prospects of corn-cob ash (CCA) as effective constituent in self-compacting concrete. The structural value of the composite was evaluated with consideration for its suitability as self-compacting concrete.
Elinwa & Mamuda (2014) carried out an investigation to find

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out the fluidity of Portland cement paste and its compatibility with sawdust ash (SDA) as powder material for self-compacting concrete blends. Consequences of the examination demonstrated that saturation was accomplished at water content proportions of 0.40 and 0.420, at measurements of naphthalene sulfonate super plasticizers of 3.50% and 2.0%, separately. Mahmoud *et al* (2013) [7], studied the likelihood of creating fiber reused self-compacting concrete (FRSCC) utilizing decimations as coarse aggregate (crushed red brick and crushed ceramic). Polypropylene strands were utilized as a part of reused self-compacting concrete (RSCC) to enhance the fresh and hardened properties of this sort of concrete. Ovri & Umukoro (2015) [10], investigated the compressive and flexural strengths of concrete using rice husk ash (RHA) as partial replacement for cement.

The most common tests used in the industry are the three point and four point bending flexural tests as shown below provides values for the modulus of elasticity in bending, flexural stress, flexural strain and the flexural stress-strain response of the material. Results of the testing method are sensitive to specimen and loading geometry and strain rate. Flexural strength, or bend strength, is defined as a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. Three and four point bend tests are commonly used to determine the flexural strength of a specimen. Currently there are no standard mix design methods for self-compacting concrete as intensive research works are being done on this new type of concrete. Empirical mix design methods as discussed below are frequently used in various countries for self-compacting concrete design. Okamura & Ozawa (1995) [8-9], proposed a rational mix design method in which the coarse and fine aggregates contents of the mix are fixed so that self-compatibility is achieved by adjusting the water-powder ratio and super plasticizer dosage only. The coarse aggregate content in concrete is fixed at 50% of the solid volume. The fine aggregate content is fixed at 40% of the mortar volume. The water-powder ratio in volume is assumed as 0.9 to 0.10, depending on the properties of the powder. The super plasticizer dosage and the final water-powder ratio are determined so as to ensure self-compatibility. Edamatsu *et al* (2003) [5] proposed a customary blend plan strategy for self-compacting concrete based on enhancing Okamura's technique by joining the strategies for fixing fine aggregate ratio, volumetric water-powder proportion and super plasticizer measurements. In the Edamatsu's technique, the constraining coarse aggregate volume proportion is fixed at 0.50. The fine aggregate proportion, for this situation, is then altered utilizing V-funnel test with standard coarse aggregate (glass beads). Water-to-powder proportion and super plasticizer dose are decided from slump flow and funnel tests. EFNARC (2002) also proposed an empirical mix design method which is an improvement of the method proposed by Okamura and Ozawa (1995) [8-9].

Saak *et al* (2001) proposed a state of the art segregation-controlled design method for self-compacting concrete. Their method was based on the theory that aggregate segregation is controlled by the viscosity, density and yield stress of the cement paste matrix. The Japanese Ready-Mixed Concrete Association (JRMCA, 1998) proposed a standardized mix design method of self-compacting concrete based on Okamura's procedure which is also a rational mix design method. This method can be used in the production of self-compacting concrete with a large amount of powder materials, and a water/powder ratio of < 0.30. Aggarwal *et al* (2008) [1] proposed an experimental procedure for the design of self-compacting concrete by ensuring deformability and stability in their work self-compacting concrete - procedure for mix design

2. Theoretical Background

$$\frac{d^2{}_{cu}}{dz^2} = \left(\frac{w}{c} + \frac{c}{pk} + \frac{c_{sg}}{s} + \frac{sp}{w}\right)\frac{d_{cu}}{dz} \quad (1)$$

$$\frac{d^2{}_{cu}}{dz^2} + \left(\frac{w}{c} + \frac{c}{pfa} + \frac{c_{sg}}{sand} + \frac{sp}{w}\right)\frac{d_{cu}}{dz} + (K + \phi + V) f_{cu} = 0 \quad (2)$$

Let $\alpha = \frac{w}{c} + \frac{c}{pfa} + \frac{c_{sg}}{sand} + \frac{sp}{w}$ and $\beta = \gamma + \phi$

$$\frac{d^2 f_{cu}}{dz^2} + \alpha \frac{df_{cu}}{dz} + \beta f_{cu} = 0 \quad (3)$$

Auxiliary equation becomes

$$m = \frac{-\alpha \pm \sqrt{\alpha^2 - 4\beta}}{2}$$

Hence, $f_{cu}(z) = ae^{\left(\frac{-\alpha + \sqrt{\alpha^2 - 4\beta}}{2}\right)z} + be^{\left(\frac{-\alpha - \sqrt{\alpha^2 - 4\beta}}{2}\right)\beta}$ (4)

If $a = b$;

Then $_{Cu}(z) = 2aCos\left(\frac{-\alpha + \sqrt{\alpha^2 - 4\beta}}{2}\right)z$ (5)

3. Materials and Method

3.1. Flexural and Tensile strength

Concrete has relatively high compressive strength in the range of 10 to 50 Nmm^2 and 60 to 120 Nmm^2 for high strength concrete. Tensile strength significantly low constitutes about 10% of the compressive strength (Neville & Brooks, 1996; Popovics, 1998).

Flexural test is done to find out the tensile strength of concrete. A typical set up recommended by British Standard is illustrated in Fig.1.

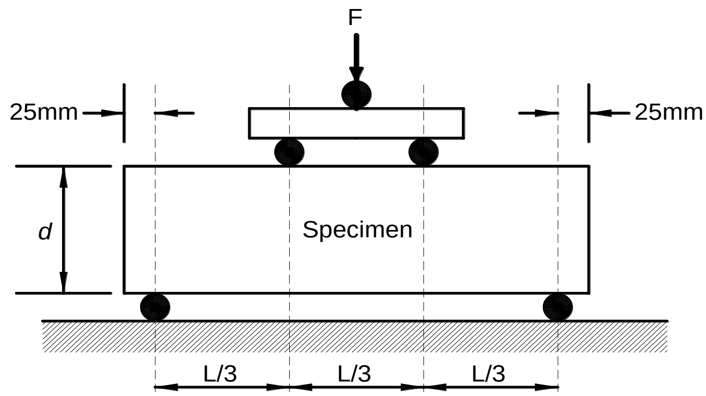

Figure 1: Flexural Beam Test Set-up

From Mechanics of Materials and analysis of Fig.1, maximum tensile stress is expected to occur at the bottom of the constant moment region within which pure bending occurs. The modulus of rapture can be calculated as:

$$f_{tb} = \frac{FL}{bd^2} \qquad (1)$$

Where L= Span of specimen beam
F = Maximum applied loads
B = Breadth of beam
D = Depth of beam

Other method used in determining the tensile strength of concrete is the indirect tension test (split cylinder test or Brazilian test, Fig.2) BS 1881: Part 117:1983 and ASTM C496-71. As recommended in these standards, the splitting test is done by applying compression loads at a loading rate 0.0112 to 0.0231 MPa/s along two axial lines that are diametrically opposite on a specimen 150 x 300 mm cylinder.

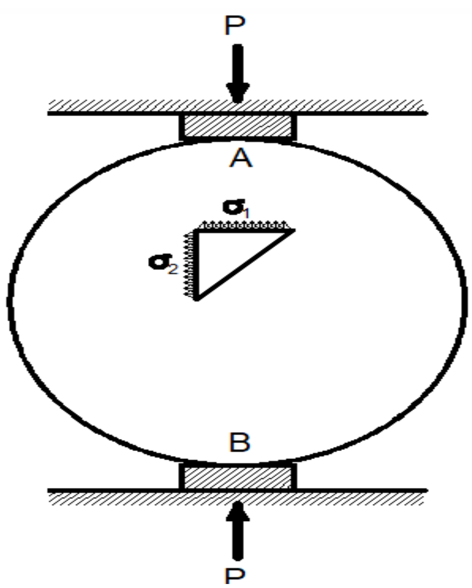

Figure.2: Tensile splitting Analysis

The splitting tensile strength is calculated using the stated formula

$$F_{st} = \frac{2P}{\pi LD} \qquad (2)$$

Where L = Length of Cylinder

P = Maximum applied loads
D = Diameter of Cylinder

3.2 Requirements For Self-Compacting Concrete

3.2.1 Application Area

Self-compacting concrete can be used on pre-cast concrete placed on site. Casting of concrete structures with high quality are now being made possible by the utilization of self-compacting concrete.

3.2.2 Requirements

The workability of self-compacting concrete exceeds the highest class of consistence described in EN 206 and can be characterized by the following properties:

- Filling ability
- Passing ability
- Segregation resistance

A concrete mix can be called a self-compacting concrete if the prerequisites for each of the three qualities are satisfied.

3.2.3 Test Methods

No single method has been discovered which portrays all the pertinent workability viewpoints so every mix design ought to be tried by more than one test technique for the distinctive workability parameters. Different test methods for the different parameters are given in Tables 1 and Table 2 below according to (EFNARC, 2005).

Table 1 List of Test Methods for Workability Properties of Self-Compacting Concrete (SCC)

S.N	Method	Property
1	Slump-flow by Abrams cone	Filling ability
2	T_{50cm} slump flow	Filling
3	J-ring	Passing ability
4	V-funnel	Filling
5	V-funnel at $T_{5minutes}$	Segregation resistance
6	L-box	Passing
7	U-box	Passing

Table 2 Workability Properties of SCC and Alternative Test Methods

Property	Test methods		
	Lab (mix design)	Field (QC)	Modification of test according to max aggregate size
Filling ability	Slump flow T_{50cm} slump flow V-funnel	Slump flow T_{50cm} slump flow V-funnel	none max 20mm
Passing ability	L-box U-box; Fill-box	J-ring	Different openings in L-box, U-box and J-ring
Segregation resistance	GTM test V-funnel at $T_{5minutes}$	GTM test V-funnel at $T_{5minutes}$	None

4. Results and Discussion

Predictive from Derive model Simulation and Experimental values of Split Tensile Strength as shown in tables 3-10.

Table 3: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
2	0.34	0.25
4	0.39	0.322
7	0.43	0.43
8	0.47	0.466
9	0.49	0.502
10	0.51	0.538
11	0.53	0.574
12	0.57	0.61
13	0.61	0.646
14	0.65	0.682
15	0.69	0.718
16	0.73	0.754
17	0.77	0.79
18	0.82	0.826
19	0.85	0.862
20	0.89	0.898
21	0.93	0.934
22	0.97	0.97
23	1.019	1.006
24	1.059	1.042
25	1.099	1.078
26	1.139	1.114
27	1.179	1.15
28	1.219	1.186

Table 4: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
2	0.255	0.251032
4	0.322	0.323128
7	0.435	0.431392
8	0.466	0.467512
9	0.502	0.503648
10	0.538	0.5398
11	0.574	0.575968
12	0.617	0.612152
13	0.646	0.648352
14	0.682	0.684568
15	0.718	0.7208
16	0.754	0.757048
17	0.795	0.793312
18	0.826	0.829592
19	0.862	0.865888
20	0.898	0.9022
21	0.934	0.938528
22	0.974	0.974872
23	1.065	1.011232
24	1.042	1.047608
25	1.078	1.084
26	1.114	1.120408
27	1.155	1.156832
28	1.186	1.193272

Table 5: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
2	0.251036	0.249
4	0.323138	0.321
7	0.431392	0.429
8	0.467542	0.465
9	0.503658	0.501
10	0.539878	0.537
11	0.575965	0.573
12	0.612153	0.609
13	0.648354	0.645
14	0.684567	0.681
15	0.720876	0.717
16	0.757048	0.753
17	0.793312	0.789
18	0.829592	0.825
19	0.865888	0.861
20	0.90228	0.897
21	0.938528	0.933
22	0.974872	0.969
23	1.011232	1.005
24	1.047648	1.041
25	1.084954	1.077
26	1.120438	1.113
27	1.156835	1.149

28	1.193275	1.185

Table 6: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
2	0.259	0.266976
4	0.331	0.328808
7	0.449	0.420971
8	0.465	0.451464
9	0.551	0.481813
10	0.557	0.512
11	0.575	0.542007
12	0.649	0.571816
13	0.665	0.601409
14	0.681	0.630768
15	0.717	0.659875
16	0.753	0.688712
17	0.789	0.717261
18	0.825	0.745504
19	0.861	0.773423
20	0.897	0.801
21	0.933	0.828217
22	0.969	0.855056
23	1.115	0.881499
24	1.141	0.907528
25	1.177	0.933125
26	1.143	0.958272
27	1.169	0.982951
28	1.195	1.007144

Table 7: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
2	0.276976	0.295
4	0.348808	0.351
7	0.450971	0.435
8	0.453464	0.463
9	0.483813	0.491
10	0.542342	0.519
11	0.542007	0.547
12	0.571816	0.575
13	0.621409	0.603
14	0.632768	0.631
15	0.659875	0.659
16	0.688712	0.687
17	0.717261	0.715
18	0.745504	0.743
19	0.773423	0.771
20	0.801245	0.799
21	0.828217	0.827
22	0.855056	0.855
23	0.881499	0.883
24	0.907528	0.911
25	0.933125	0.939
26	0.958272	0.967
27	0.982951	0.995
28	1.037144	1.023

Table 8: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
2	0.297	0.3
4	0.355	0.354
7	0.455	0.435
8	0.465	0.462
9	0.493	0.489
10	0.539	0.516
11	0.548	0.543
12	0.576	0.57
13	0.633	0.597
14	0.634	0.624
15	0.669	0.651
16	0.687	0.678
17	0.715	0.705
18	0.743	0.732
19	0.771	0.759
20	0.799	0.786
21	0.827	0.813
22	0.855	0.84
23	0.885	0.867
24	0.921	0.894
25	0.959	0.921
26	0.967	0.948
27	0.996	0.975
28	1.033	1.002

Table 9: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
7	1.099	1.14
14	1.019	1.19
21	1.259	1.91
28	2.199	2.75

Table 10: Predictive and Experimental of Flexure Strength at Different Curing Age

Curing Age	Predictive Values of Flexure Strength	Experimental Values of Flexure Strength
7	2.499	2.27
14	2.799	3.01
21	2.999	3.31
28	3.199	3.51

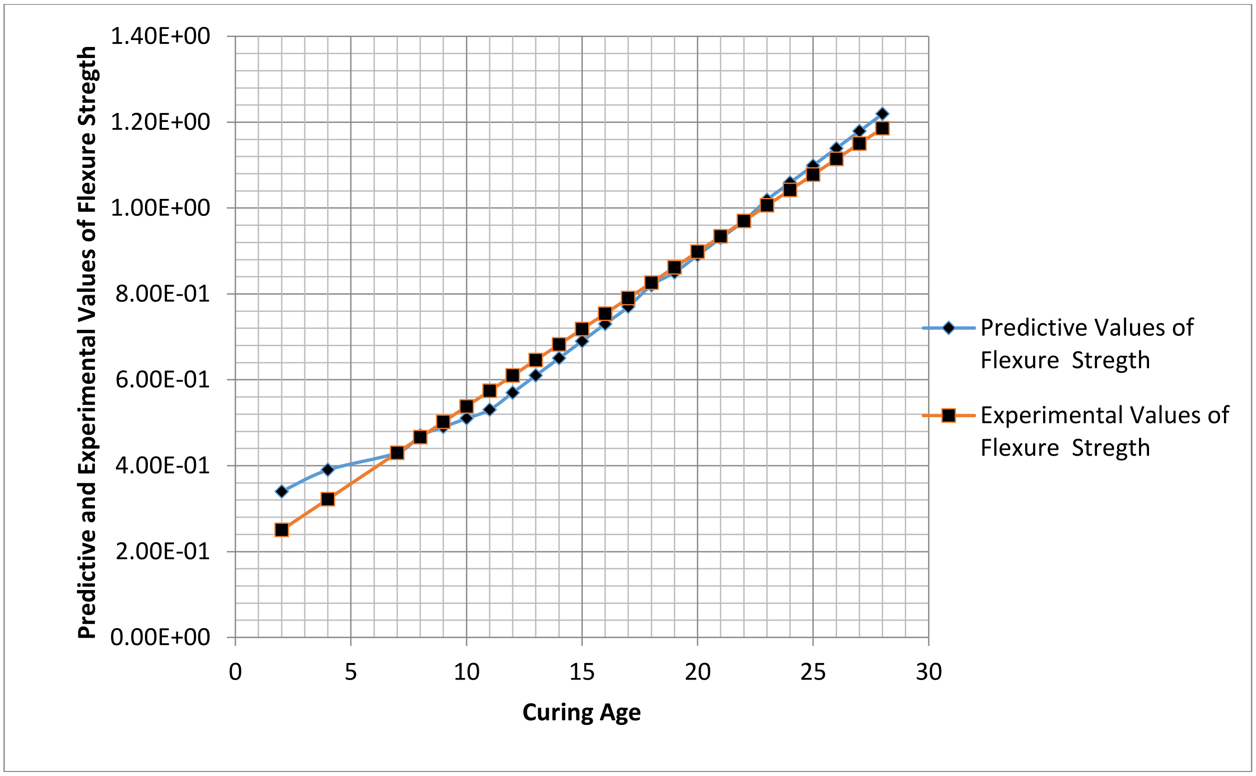

Figure 3: Predictive and Experimental of Flexure Strength at Different Curing Age

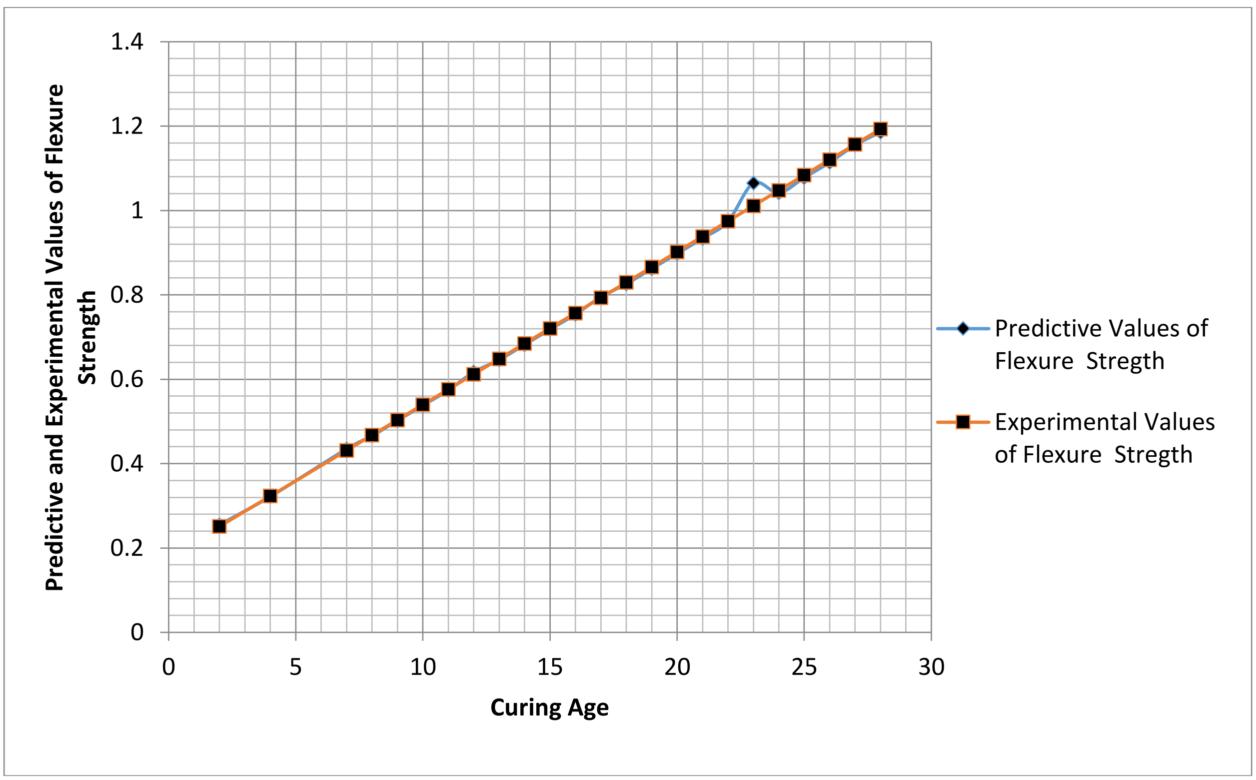

Figure 4: Predictive and Experimental of Flexure Strength at Different Curing Age

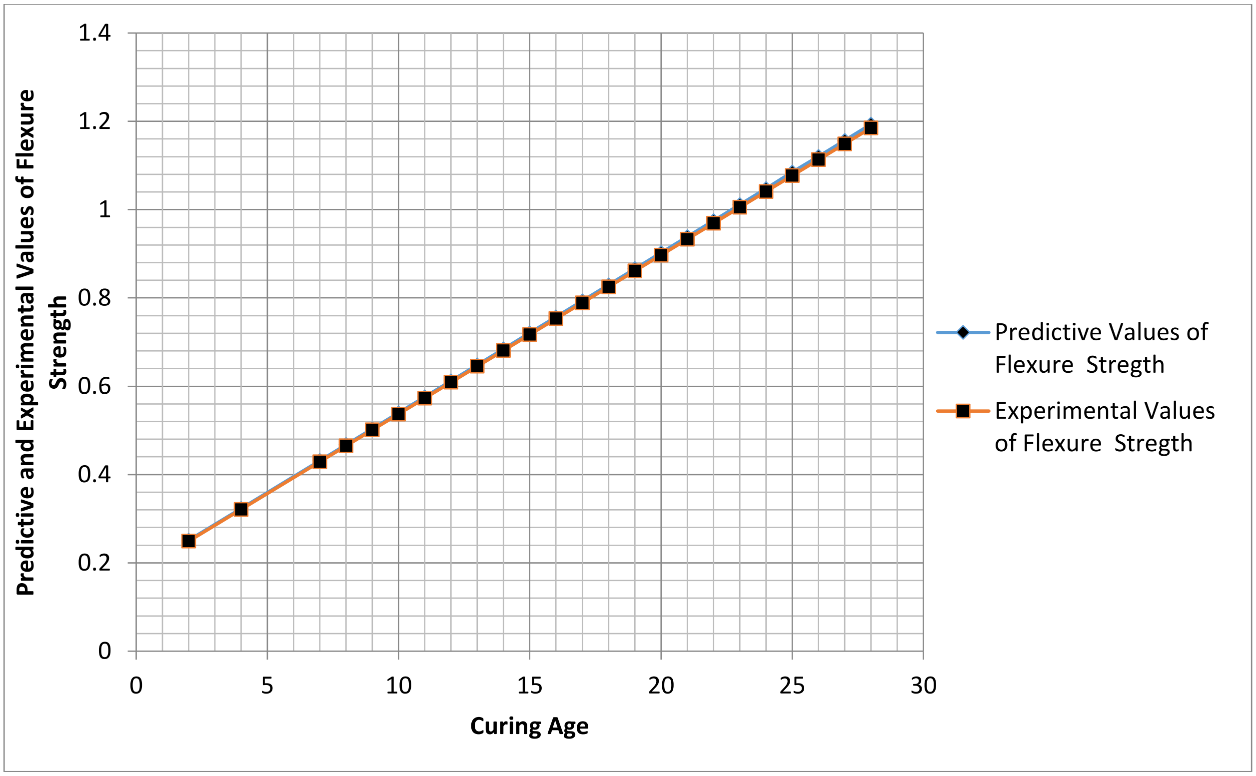

Figure 5: Predictive and Experimental of Flexure Strength at Different Curing Age

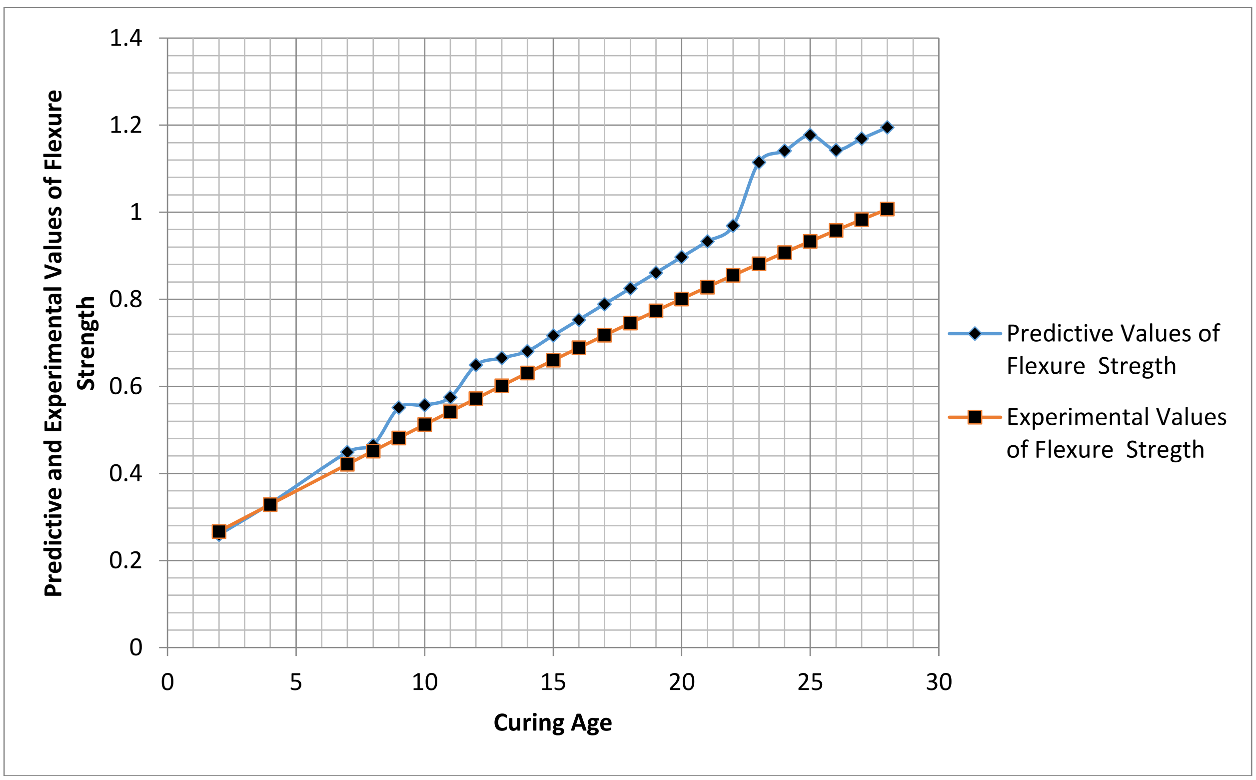

Figure 6: Predictive and Experimental of Flexure Strength at Different Curing Age

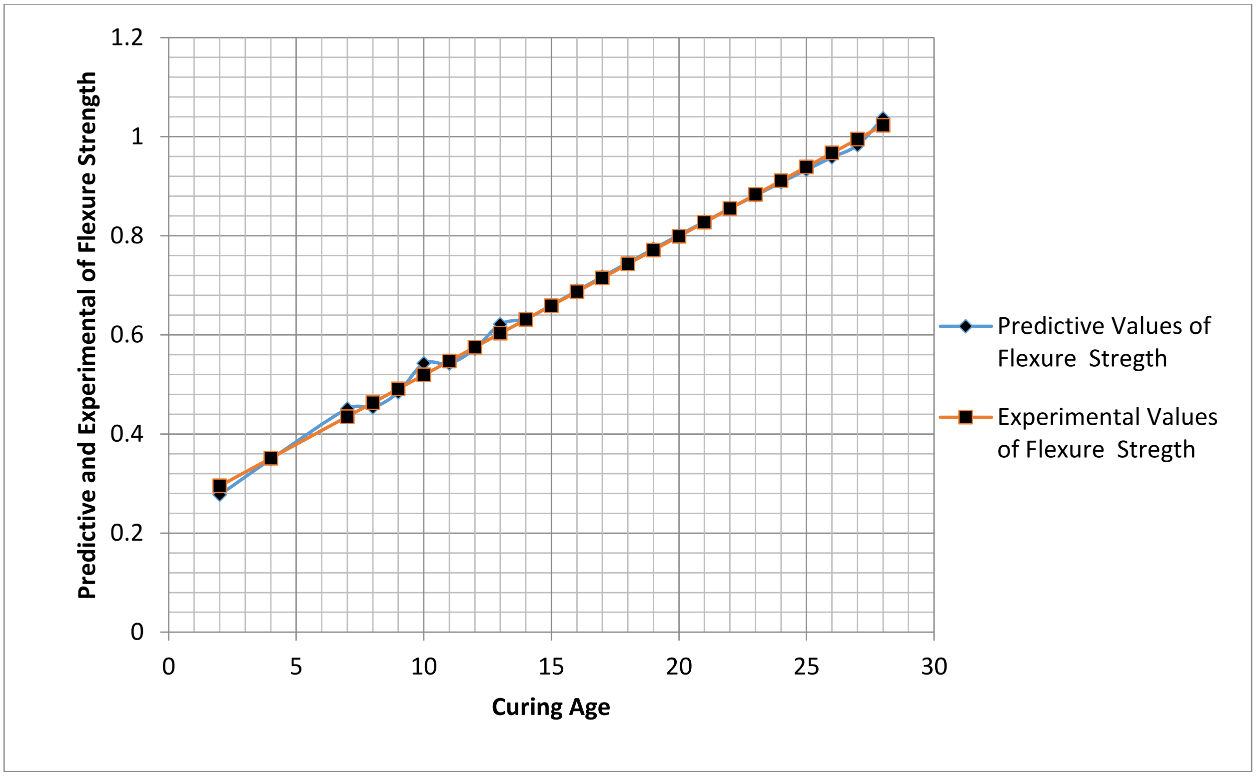

Figure 7: Predictive and Experimental of Flexure Strength at Different Curing Age

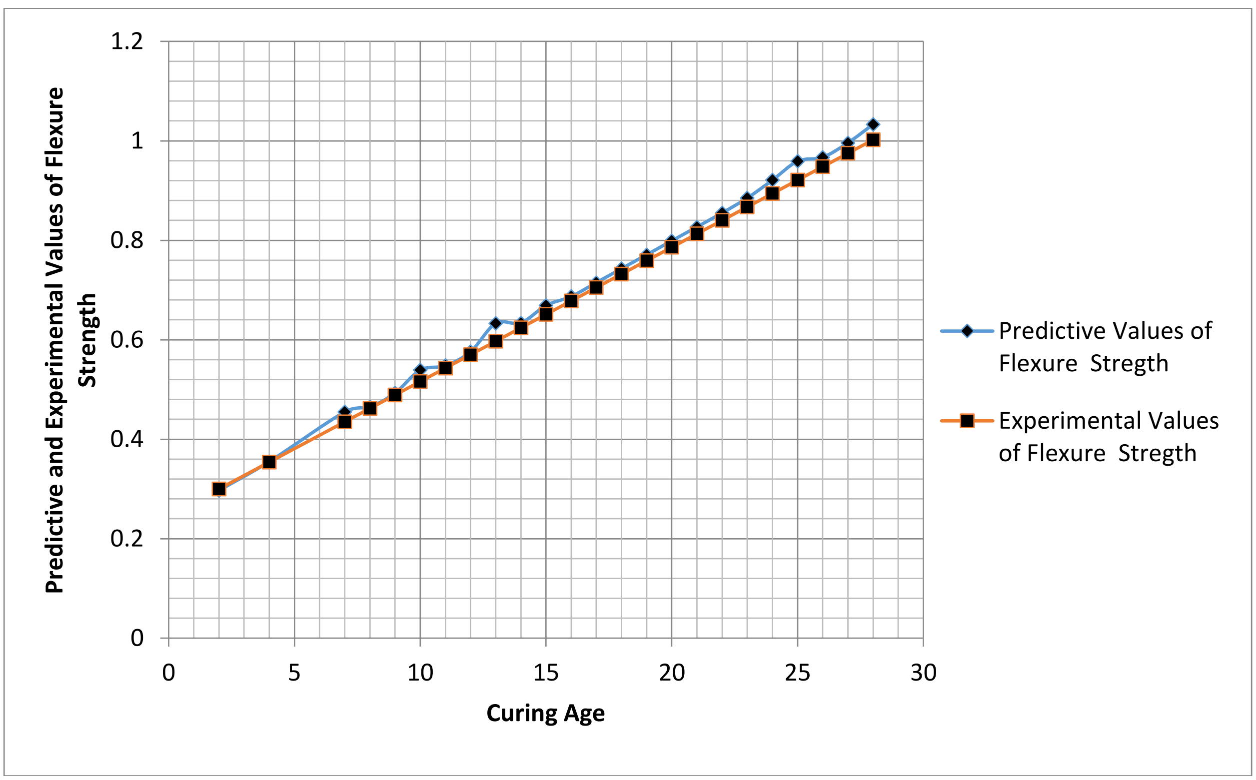

Figure 8: Predictive and Experimental of Flexure Strength at Different Curing Age

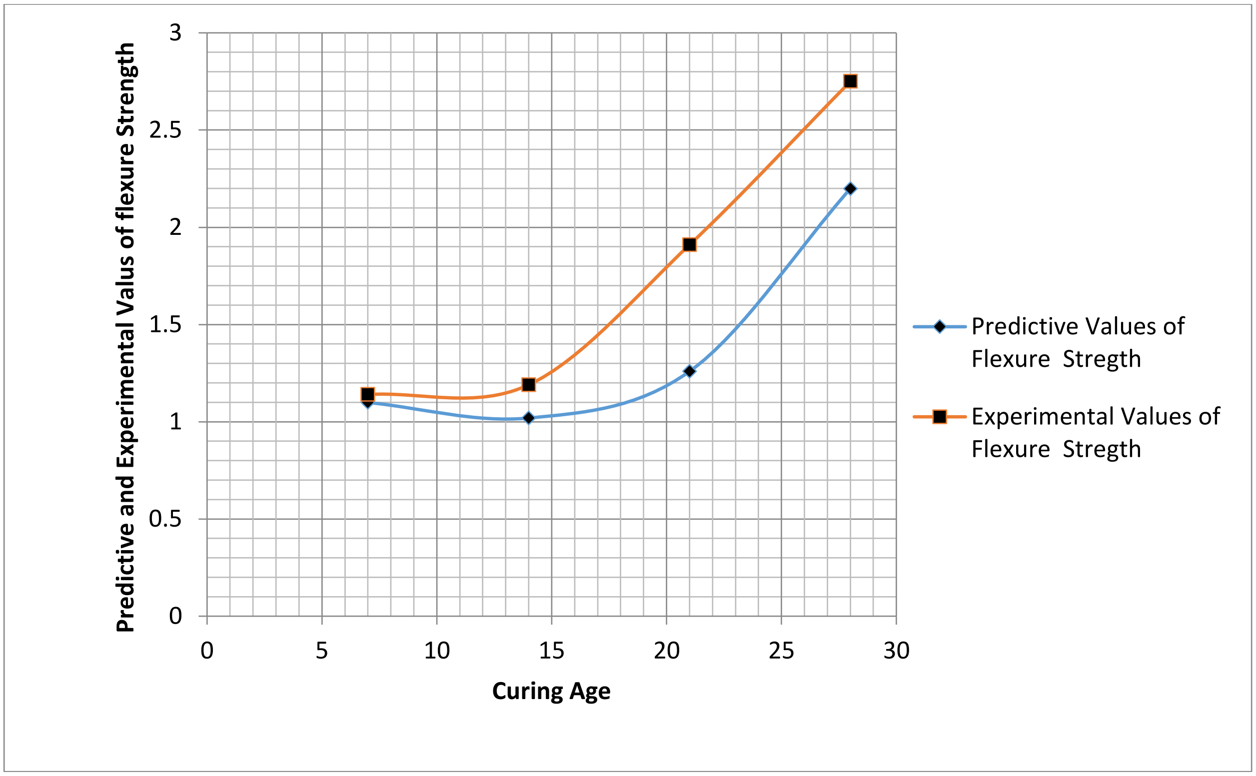

Figure 9: Predictive and Experimental of Flexure Strength at Different Curing Age

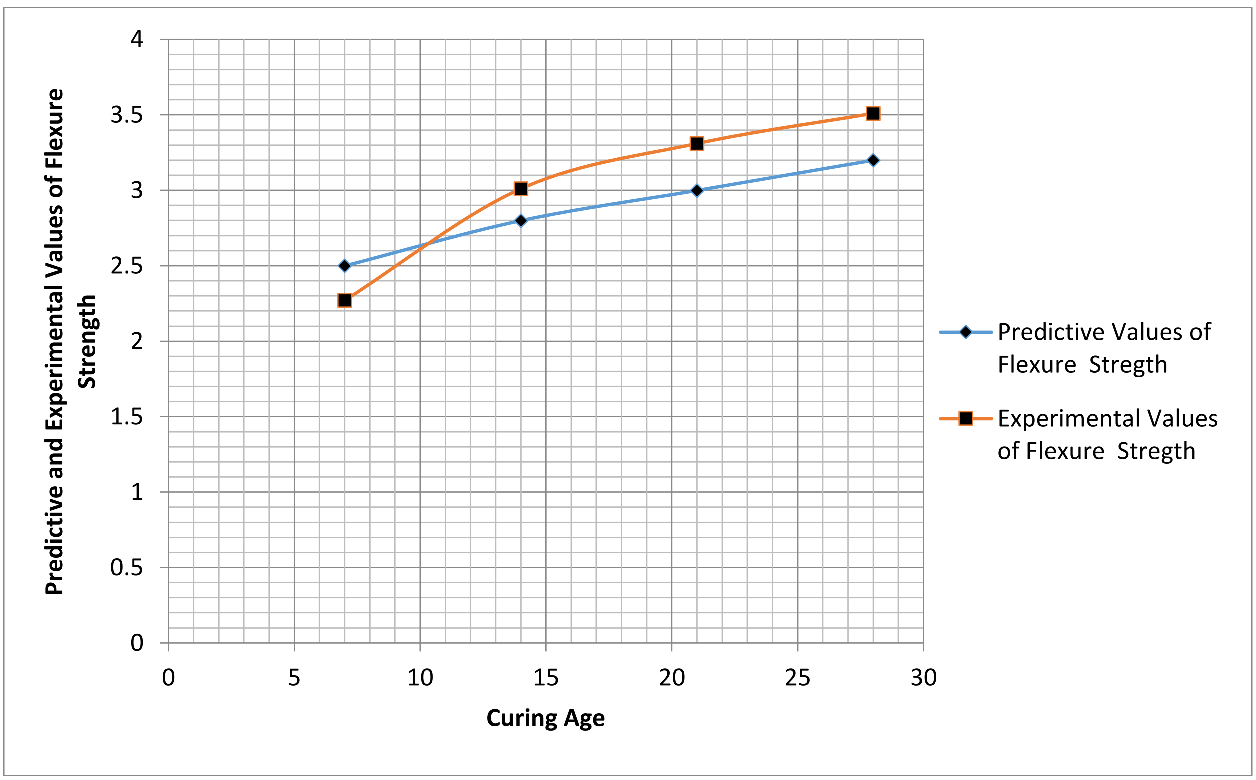

Figure 10: Predictive and Experimental of Flexure Strength at Different Curing Age

Flexural strength, or bend strength, could be known as a material's that has the ability to resist deformation under load. The flexural strength exemplifies highest stress experienced within the material at its moment of rupture. The study from (fig. 3-10) express the rate of flexural strength on exponential phase, the predictive model values monitor the rate of flexural strength numerically. it explained the rate of flexural strength at every twenty four hours, to the optimum rate at twenty eight days, the figures explained the growth influences rate of flexural strength at variations of addictive's such as fly ash and super plasticizers, the rate of flexural strength in this figures defined the behaviour of the strength attained at different curing age, the experimental values also express closed fitness in all the figures that developed numerical values, while the predictive values from analytical concept at interval of seven days experienced exponential phase with fluctuation observed to the optimum rate recorded at twenty eight days. Experimental values in the same vein express closed fits with predictive values.

5. Conclusion

The flexural strength of self-compacting concrete were monitored in two dimensions, analytically and numerical applying deterministic model techniques, such determination of flexural strength are normally generated through the experimental process, where results of flexural are generated at interval of seven days to twenty eight days, but these techniques were applied to developed model to that can predict flexural strength from - non homogeneous system, concrete of such model were observed to investigate its behaviour applying such techniques, the study concept express thorough behaviour of self- compacting concrete modified with addictive's, this type of model concrete are main to solve serious problem in strength development within a short period, this concept explain the primary behaviour of flexural strength as those that experience primarily bending stresses, such as beams. These are structural member that supports applied loads and its own weight primarily by internal moments and shears. The study developed predictive values that monitored the strength at every twenty four hours and interval of seven days, the comparison with experimental values express a favourable fits.

References

[1] Aggarwal, P., Siddique, R., Aggarwal, Y. & Gupta, S. M. (2008). Self-Compacting Concrete – Procedure for Mix Design, Leonardo Electronic Journal of Practices and Technologies, 12, 15-24

[2] Aydin, A. C. (2007). Self-Compatibility of High Volume Hybrid Fiber Reinforced Concrete. Construction and Building Materials, Elsevier, 21(6), 1149-1154

[3] Elinwa, A. U. & Mamuda, A. M. (2014). Sawdust Ash as Powder Material for Self- Compacting Concrete Containing Naphthalene Sulfonate, Journal of Advances in Civil Engineering, 14(1), 2-10.

[4] Elinwa, A. U., Mamuda, M. & Ahmed, M. (2014). Mechanical Strengths of Self- Compacting Concrete Containing Sawdust-Ash and Naphthalene Sulfonate, Journal of Advances in Civil Engineering, 2(4), 300-309

[5] Edamatsu, Y., Sugamata, T. & Ouchi, M. (2003). A Mix-Design Method for Self- Compacting Concrete Based On Mortar Flow and Funnel Tests, Conference Proceedings, International RILEM Symposium on Self-Compacting Concrete, RILEM Publications SARL, (pp. 345 – 354). Retrieved from

[6] Kayode, O. & Ilesanmi O. (2013). Strength Evaluation of Corn-Cob Ash in a Blended Portland Cement, American Scientific Research Journal for Engineering, Technology, and Sciences, 4(1), 851-875.

[7] Mahmoud, A., Mounir, M. K., Mohamed, A. S. & Zeinab, A. E. (2013). Effect of Polypropylene Fibers on Development of Fresh and Hardened Properties of Recycled Self-Compacting Concrete, International Journal of Engineering and Advanced Technology, 2(5), 999-1002. Retrieved from http://www.ijeat.org/v2i5.php. March, 11th 2016.

[8] Okamura, H., Ouchi, H. & Masahiro, O. (2003). Self-Compacting Concrete. Journal of Advanced Concrete Technology, 1(1), 5-15. Retrieved from www.kutarr.lib.kochi-tech.ac.jp. 14th August 2016

[9] Okamura, H. & Ozawa, K. (1995). Mix-design for Self-Compacting Concrete, Concrete Library of Japan Society of Civil Engineers, 25, 107-120.

[10] Ovri, J. E. O. & Umukoro, O. P. (2015). The Compressive and Flexural Strengths of Self- Compacting Concrete Using Rice Husk Ash, International Journal of Advanced Materials Research, 1(3), 80-85.

[11] Tande, S. N. & Mohite, P. B. (2007). Applications of Self-Compacting Concrete, 32nd Conference on OUR WORLD IN CONCRETE & STRUCTURES: 28 – 29 August 2007, CI-Premier PTE LTD, Singapore. Retrieved from http://cipremier.com/100032055. 14th August, 2016.

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