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International Journal of Earth Sciences and Engineering

April 2015, P.P.143-148

ISSN 0974-5904, Volume 08, No. 02

Experimental Investigation of Functionally Graded Concrete with Fly ash

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Abstract: In the present paper mechanical behaviour of functionally graded concrete (FGC) was studied. Generally, concrete used in the field suffers from lack of durability and homogeneity. As cement is the only binding material in concrete and due to hike in its price, researchers have been looking for apt substitutes. For the sake of economy, strength and anti-corrosion functionally graded concrete (FGC) has developed having one layer of normal concrete and another of high volume fly- ash concrete (HVFAC). Compressive strength of FGC specimens was measured in such way that the direction of functionally graded layer was parallel to the direction of applied load. The flexural behaviour FGC has analyzed experimentally in this work with variation in interface as 0, 25, 50, 75 and 100 from bottom. . In this study, HVFAC has prepared with replacement of cement by 30, 40 and 50 % with fly ash for M25 of concrete. The obtained results indicated that the strength of FGC specimens was higher than that anticipated from the rule of mixtures. The highest positive deviation was related to the specimen with FGC layer in the middle of specimen. . It has seemed that there is 12-15% and 4-5% increase in compressive and flexural strength of FGC. As FGC is economical, having more durability and strength, so its adoption enables more sustainability in concrete industry.

Keywords: *Functionally graded concrete, Compressive strength, High volume fly ash, Flexural strength.*

1. Introduction

Functionally graded material (FGM) may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material. The materials can be designed for specific function and applications.

Various approaches based on the bulk (particulate processing), preform processing, layer processing and melt processing are used to fabricate the functionally graded materials.

There are many areas of application for FGM. The concept is to make a composite material by varying the microstructure from one material to another material with a specific gradient. This enables the material to have the best of both materials.

If it is for thermal, or corrosive resistance or malleability and toughness both strengths of the material may be used to avoid corrosion, fatigue, fracture and stress corrosion cracking.

Functionally graded concrete (FGC) is developed based on the concept of functionally graded materials. In functionally graded cross section, some properties change gradually to eliminate the sharp border which is observed in laminated composites, there, it reduces stress concentration by eliminating sharp interfaces. Although in most cases, production of laminated composites reveals better mechanical properties, stress concentration and abrupt fracture resulted from this concentration may occur.

While the strong bond strength in laminated composites results in demolishing performance, weak bonds may cause delamination which is not preferred for general constructions.

FGC specimens not only are capable to solve stress concentration problems, but they can be produced in some way to encapsulate low quality raw materials with minimum harm to the base material.

Functionally graded material beam is shown in Fig. 1.1 with normal concrete and fly ash has the great resistance against corrosion, thermal cracking and have excellent compressive strength.

As the concrete is weak in its tensile strength, so it is economical to use FGB. The weakness of concrete such as shrinkage during coagulation and hardening, low tensile strength, poor crack resistance, brittleness, small ultimate extension and bad impact endurance, which prevails in concrete and limits its application, has been thoroughly dealt with in FGB.

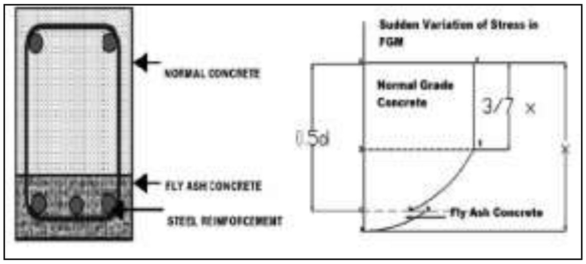

Figure 1 *Functionally graded Beam*

Static and dynamic analyses of FGM structures have attracted various researchers in the last few decades. The researchers have proposed an elastic solution based on Euler–Bernoulli beam theory for functionally graded beam (FGB) subjected to static transverse loads by supposing Young's modulus of the beam differs exponentially through the thickness [1]. Similarly a new finite element beam based on the first-order shear deformation theory had suggested by various literatures [2] to study the thermo- elastic behavior of FGM structure. The researchers have presented an analytical solution to cantilever beam which is based on two dimension elastic theory with indiscriminate graded variation of material distribution [3]. Using third order zigzag theory for estimating effective modulus of elasticity, the scientists have studied [4] a finite element model for static and free vibration responses of layered FGB. The researchers have studied the static behavior of FGB and proposed an analytical solution to bending problem of a synthetic FGB [5, 6].

The concept of functionally graded concrete (FGC) beam is to improve durability over regular reinforced concrete structures has been proposed by various researchers [7]. In this study ultrahigh toughness cementitious composite was used as a replacement for the concrete material that surrounds the main reinforcement in a reinforced concrete structural member. The researchers also studied corrosion durability and structural response of functionally-graded concrete beams [8]. Concerning the complex engineering environment of the Wuhan Yangtze River Shield Tunnel, the principle of functionally graded materials was introduced to design and produce the functionally graded concrete segment (FGCS) [9].

Fly ash is a by-product of crushed coal, is widely used as a cementitious and Pozzolanic ingredient in Hydraulic cement concrete. The cementitious property of fly ash is due to its reactive constituents that reside within fly ash, such as calcium, silicate and aluminates. Fly-Ash enhances the workability, compressive strength, flexural strength, pumpability, durability and concrete finishing. So its use in designing of FGM makes it more economical as compared to normal concrete or fly ash concrete.

The researchers have proposed on high-performance, high-volume fly ash concrete for sustainable development [10].A rational mix design method was developed for concrete with 20–80% fly ash replacement for cement[11-12]. Structural Engineering Research Institute [13] reported that HVFAC exhibited higher strength at later ages and the flexural strength is higher for HVFAC whereas the bond strength for embedded rebar is nearly the same for both the concretes but it shows very low chloride permeability and low water absorption and reduced water permeability and have lower carbonation depth however better abrasion resistance as compared to that of OPC based concrete which increases the age of the concrete.
The main objective of this research is to investigate mechanical behaviour of the FGC for the desired concrete mixes. To compare the strength performance of functionally graded material concrete (FGC) with normal concrete, high volume fly ash concrete (HVFAC).

2. Methodology Adopted

In this investigation the compressive strength of FGC cubes was studied at an interval of 7 and 28 days with replacement of cement@ (30,40,50%)with fly ash with changing interface as 75 and 125mm of M25 grade concrete. Besides this the flexure strength of FGC prisms was determined at an interval of 7 and 28 days with replacement of cement@(30,40,50%) with fly ash with changing interface as 50 and 75 mm of M25 grade concrete. The compressive strength and flexural strength of normal concrete, fly ash concrete, high volume fly ash concrete and functionally graded material concrete is compared.

3. Materials

3.1. Cement

Ordinary portland cement of 53 grade conforming to IS: 12269-1987 (revised 2004) [14] is used throughout the study and it has a specific gravity of 3.10.

3.2. Aggregate

3.2.1. Fine Aggregate

River sand passing through 4.75 mm IS sieve conforming to grading zone II as perIS: 383-1970 (revised 2002) [15] having fineness modulus of 2.51 and specific gravity of 2.61.

3.2.2. Coarse Aggregate

The coarse aggregate used in the concrete mixtures was quarry gravel, having the maximum size of 20 mm, fineness modulus of 6.17 and specific gravity of 2.73. Sieve analysis was performed on the coarse aggregate according to IS: 383-1970 (revised 2002) [15].

3.3. Water

The water used in the mix design was potable water from the water-supply network system; so, it was free from suspended solids and organic materials, which might have affected the properties of the fresh and hardened concrete.

3.4. Fly Ash

For this investigation, Class F Fly ash was used. The chemical composition of fly ash is given in Table1 and specific gravity of fly ash is 2.30.

Table 1: *Chemical Composition of fly ash (Niveli power plant, Tamilnadu)*

Sl. No	Chemical Compositions	% by Mass
1	$SiO_2+Al_2O_3+Fe_2O_3$	65.50
2	SiO_2	35
3	Reactive Silica	20
4	CaO	6.90
5	MgO	5
6	SO_3	1.5
7	Available Alkalis	5
8	Loss of ignition	3.70

3.5. Superplaticiser

In this research, SikaViscoCrete 20HE superplasticiser is used.

Properties

Form: Aqueous sol. of modified polycarboxylates
Color : Light Brown
Density (20^0C) : 1.08 kg/litre
pH Value (20^0C) : 4.3 $\pm$ 0.5
Chloride Content: No added chlorides

As per supplier for high strength, water reduced concrete the normal dosage range is from 0.2-1.0 litres/100 kg of cementitious material. In this study SP is taken as 1% of the weight of the cement.

4. Experimental Investigation

4.1. Detailed of Specimens

Cubes of 150mm size for compressive strength, Cylinders of size 150X300mm for Modulus of elasticity and beam size for flexure test is 500X100X100mm is cast for the testing of the functionally graded concrete. The following Mix designations are used to make FGC specimens.

Table 2: *Mix Designation*

Mix Designation	Description
F0	Control Concrete
F3	30% fly ash replacement in 100 % volume
F4	40% fly ash replacement in 100 % volume
F5	50% fly ash replacement in 100 % volume
FG3-50V	30% fly ash replacement in 50 % volume
FG4-50V	40% fly ash replacement in 50 % volume
FG5-50V	50% fly ash replacement in 50 % volume
FG3-75V	30% fly ash replacement in 75% volume
FG4-75V	40% fly ash replacement in 75% volume
FG5-75V	50% fly ash replacement in 75 % volume

4.2. Mix Design

IS mix design [16-17] was adopted in this study for M25 grade concrete. The mix proportions are given in the Table 3

Mix designation	Cement (kg/m^3)	Fly ash (kg/m^3)	F.A. (kg/m^3)	C.A. (kg/m^3)	Water (lit/m^3)	Super plasticizer (lit/m^3)
F0	320	-	756	742	144	1.44
F3	245	105	742	1204	148	1.58
F4	210	140	735	1196	148	1.58
F5	175	175	734	1189	144	1.58
FG3-50V	282.5	52.5	730.352	1220.5	142	1.51
FG4-50V	265	70	726.85	1216.5	142	1.51
FG5-50V	245	85	722.65	1213	142	1.51
FG3-75V	263.75	78.75	737.84	1206.29	138	1.55
FG4-75V	237.50	105	739.63	1206.25	131	1.55
FG5-75V	211.25	131.25	721.87	1201	142	1.55

5. Results and Discussion

5.1. Compressive Strength

Compression test[18] according to IS: 516(1959) was carried out on the 150 x 150 x 150 mm cubes were tested for the compressive strengths of concrete specimens were determined after 7 days and 28 days of standard curing. For FGC, the results showsthatFG3-50V has more compressive strength compare to all other cubes.FGM cubes having interface at the middle has approximately 12-15% more compressive strength compared to normal concrete and 4-5% more compressive strength compared to fly- ash concrete. The compressive strength results for different FGC mixes and conventional concrete are tabulated in Table 4.

The compressive strength of FGC was increased compared to conventional concrete because of possible multi–layer vibration phenomenon during sample preparation.The compressive strength of HVFACis low at 7 days and enormously increases at 28 days due to presence of high volume silica in fly ash responsible for later gaining of strength.

Table 4: *Compressive Strength at 7 days & 28 days*

Mix Designation	7days Compressive Strength(MPa)	28days Compressive Strength(MPa)	Standard deviation(MPa)	Coefficient of variation (%)	% of strength increase from 7 days to 28 days
F0	21.53	35.43	0.59	1.66	64.56
F3	19.60	34.02	0.55	1.40	73.57
F4	18.20	30.78	0.18	0.52	69.12
F5	16.90	29.54	0.48	1.43	74.79
FG3-50V	20.50	40.80	0.57	1.41	99.02
FG4-50V	19.60	38.32	1.03	2.67	95.91
FG5-50V	19.10	35.55	1.92	5.40	86.12
FG3-75V	17.21	36.63	0.65	5.34	112.84
FG4-75V	15.641	35.92	2.40	6.44	129.6
FG5-75V	15.25	34.76	1.07	3.08	127.93

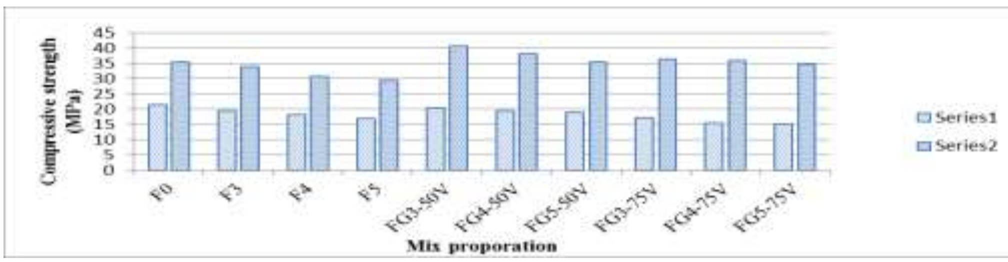

Figure 2 *Compressive Strength at 7 days & 28 days*

5.2. Static Flexural Strength

The flexural strength [18] of FGC and conventional concrete, beams were obtained by conducting flexural test on specimens of size 500x100x100mm by two point load method. The test results have been shown in Table 5. FG3-50V has maximum flexural strength and it has been decrease with increase in amount of fly ash in FGC and also decreases with increase in the position of interface from bottom.

Table 5: *Flexural Strength at 7 days&28 days*

Mix Designation	7days Compressive Strength(MPa)	28days Compressive Strength(MPa)	Standard deviation(MPa)	Coefficient of variation (%)	% of strength increase from 7 days to 28 days
F0	3.93	5.13	0.25	5.27	36.54
F3	4.20	5.53	0.09	1.70	31.75
F4	3.60	5.26	0.25	4.74	46.30
F5	3.60	5.10	0.49	10.21	33.33
FG3-50V	4.13	5.60	0.34	6.14	33.87
FG4-50V	3.53	5.33	0.09	1.77	5094
FG5-50V	3.53	5.13	2.23	43.50	45.28
FG3-75V	3.87	5.33	0.25	4.67	37.93
FG4-75V	3.60	5.27	0.25	4.73	46.30
FG5-75V	3.46	4.95	0.41	8.33	42.31

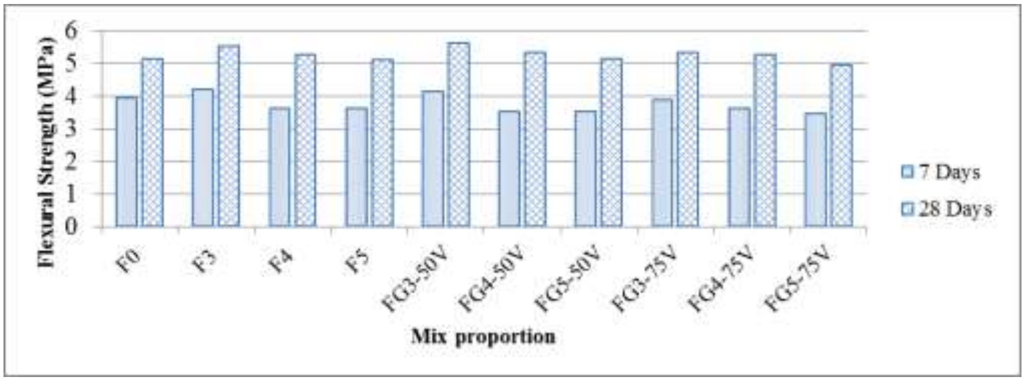

Figure 3 *Flexural Strength at 7 days & 28 days*

5.3. Comparison of Modulus of Elasticity

Cylinders 150mm diameter and 300mm height were used to test the modulus of elasticity [18] of concrete. The comparison of the results with the control concretes, fly ash concrete and FGC concrete are given in Table 6.

Table 6: *Modulus of Elasticity at 28 days*

Mix Designation	Modulus of Elasticityx10^4(MPa)	Standard deviation X10^4(MPa)	Coefficient of Variation (%)
F0	2.512	0.128	5.096
F3	2.872	0.191	6.650
F4	2.575	0.137	5.320
F5	2.479	0.241	9.722
FG3-50V	2.695	0.100	3.711
FG4-50V	2.443	0.097	3.971
FG5-50V	2.411	0.010	0.446

5.4. UPV Test

Ultrasonic Pulse Velocity (UPV) [19] test was conduct on 150mm size cube according to IS: 13311 (Part – 1). Quality of concrete grade was checked by using ultrasonic pulse velocity in km/sec and table 2 in IS: 13311 (Part – 1. The results of ultrasonic pulse velocity for 28 days are given in Table 7.

The failure pattern of FGC specimens were same of conventional specimens, it was observed that failure was not at interface. Based on observations of coefficient of variation in all experiments we conclude that FG3-50V, FG4-50V are follows same as conventional concrete.

Table 7: *Ultrasonic Pulse Velocity of Concrete*

Mix Designation	UPV Test		Standard deviation (km/sec)	Coefficient of Variation (%)
	Velocity (km/sec)	As per IS:13311:part-1		
F0	4.124	Good	0.256	6.217
F3	4.024	Good	0.166	4.130
F4	3.859	Good	0.100	2.580
F5	3.407	Good	0.349	10.231
FG3-50V	4.027	Good	0.086	2.130
FG4-50V	3.483	Good	0.125	3.581
FG5-50V	3.523	Good	0.274	7.788
FG3-75V	3.971	Good	0.108	2.709
FG4-75V	3.964	Good	0.922	23.269
FG5-75V	3.421	Good	0.306	8.943

6. Conclusions

The general objective of this research was to compare the fresh and mechanical properties of functionally graded concrete (FGC) with high volume fly ash concrete (HVFAC) and conventional concrete. Finding the results of the compressive strength, flexural strength, modulus of elasticity and NDT of hardened

FGC specimens, the following conclusions and recommendations are drawn out.

Based on the experimental investigations carried out, the following conclusions are drawn.

FGM cubes having interface at 50 % volume of specimen has approximately 12-15% more compressive strength compared to normal concrete and 4-5% more compressive strength compared to fly- ash concrete. The flexural strength of the prism of FG3-50V and FG4-50V is more even that of conventional concrete and HVFAC.

The compressive strength of FG3-75V AND FG4-75V is same as conventional concrete these are more economical and durable due to resistance against corrosion. The FGC with 30% replacement of fly ash gives more strength and economical.

The modulus of elasticity of the functionally graded concrete is more compared to control mix and approximately same as HVFAC .Based on UPV results, the Quality of functionally graded concrete is good as per IS: 13311: part-1 (1992).So analysing and comparing the hardened properties of FGC as compared to normal concrete and HVFAC, its adoption is beneficial to concrete structure.

References

[1] Sankar, B. V (2003). An elasticity solution for functionally graded beams. *Composites Science and Technology*, 61.5, 689-696.

[2] A. Chakraborty, S. Gopalakrishnan, J.N. Reddy, (2003) A new beam finite element for the analysis of functionally graded materials.*Int. J. Mech. Sci*. 45(3), 519–539.

[3] Z. Zhong, T. Yu, (2007) Analytical solution of a cantilever functionally graded beam. *Compos. Sci. Technol.* 67(3–4), 481–488.

[4] S. Kapuria, M. Bhattacharyya, A.N. Kumar, (2008) Bending and free vibration response of layered functionally graded beam: a theo- retical model and its experimental validation. *Compos. Struct. 318 (4–5*), 1210–1229.

[5] R. Kadoli, K. Akhtar, N. Ganesan, (2008) Static Analysis of functionally graded beams using higher order shear deformation theory. *Appl. Math. Model*.32 (12), 2509–2525.

[6] M.A. Benatta, I. Mechab, A. Touni, E.A. AddaBedia, (2008) Static analysis of functionally graded short beams including wrapping and shear deformation effects. *Comput.Mater. Sci*.44 (2), 765–773.

[7] LiQingHua and ShiLang Xu. (2009) Experimental investigation and analysis on flexural performance of functionally graded composite beam crack-controlled by ultrahigh toughness cementitious composites. *Science in China Series E: Technological Sciences,* 52.6, 1648-1664.

[8] Maalej, Mohamed, Shaikh FU Ahmed, and P. Paramasivam. (2003) Corrosion durability and structural response of functionally-graded concrete beams. *Journal of Advanced Concrete Technology,* 1.3, 307-316.

[9] Ma Baoguo, DinghuaZou, and Li Xu. (2009) Manufacturing technique and performance of functionally graded concrete segment in shield tunnel. *Frontiers of Architecture and Civil Engineering in China*, 3.1, 101-104.

[10] Mehta P. Kumar (2004) High-performance, high-volume fly ash concrete for asustainable development. In *Proceedings of the international workshop on sustainable development and concrete technology*, pp. 3-14.

[11] Siddique Rafat. (2003) Effect of fine aggregate replacement with Class F fly ash on the mechanical properties of concrete. *Cement and Concrete research*, 33.4, 539-547.

[12] Huang, Chung-Ho, et al. (2013) Mix proportions and mechanical properties of concrete containing very high-volume of Class F fly ash. *Construction and Building Materials*, 46, 71-78.

[13] Structural Engineering Research Council. Demonstration of utilizing high volume fly ash based concrete for structural applications. (Chennai, 2005)

[14] IS: 12269-1987 (R1999), Indian Standard Specification for 53Grade Ordinary portland cement, Bureau of Indian Standards, New Delhi.

[15] IS 383-1970 (R2002), Indian Standard Specification for Coarse and Fine aggregates from natural sources for concrete, Bureau of Indian Standards, New Delhi.

[16] IS 456:2000, Code of Practice Plain and Reinforced Concrete (Fourth Revision), Bureau of Indian Standards, New Delhi.

[17] IS 10262: 2009, Indian standard recommended guidelines for concrete mix design, Bureau of Indian Standards, New Delhi.

[18] IS 516-1959 (R1999), Method of tests for strength of concrete, Bureau of Indian Standards, New Delhi.

[19] IS: 13311 –Part-1 (1992), Indian Standard “Non-Destructive testing of concrete – Methods of Test”, Bureau of Indian Standards, New Delhi.

[20] SHETTY, M.S., Concrete Technology, Theory of Practice, S.Chand&Co.Ltd., New Delhi, Revised Edition, 2005.