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Study On Stress – Strain Behaviour of Hardened Concrete with HVFA, GGBS AND GBS as Partial Replacement Materials

Suvarna Latha Kakara, M V Seshagiri Rao

Abstract :Concrete is the most widely used construction material developed by man. Because of its superior specialty of being cast in any desirable shape, it has replaced stone and brick masonry. Inspite of all this,it has some serious deficiencies which, but for its, remarkable qualities of flexibility, resistance and ability to redistribute stress, would have prevented its use as a building material. Prediction of concrete strength and stress strain behaviour of concrete is an important issue in the concrete industry, since the traditional laboratory approach to determine the strength of concrete attracts some drawbacks such as manual involvement, time consumption and chances of creeping of human error. This paper reports the results of an experimental study, conducted to evaluate the stress-strain behaviour of hardened concrete by partially replacing the concrete by partially replacing the cement by Ground granulated blast furnace slag and High volume Fly ash (GGBS and HVFA)by 0%, 10%, 20%, 30%, 40%, 50%, 60% and 70% for each grade of concrete, M20, M40 and M60 at different ages of 28 days. By taking grade of concrete percentage replacement of GGBS and water cement ratio as the controlling parameters.Another experimental study is also carried out by replacing the sand with Granulated Blast Furnace Slag (GBScoarse) which confirming to zone- II category by 0% to 70% for each grade of concrete M20,M40,and M60 at28 days. From these study analytical equations for the stress– strain behaviour of hardened concrete has been arrived and stress - strain curves were plotted. The experimental and theoretical stress strains are shows good correlation.

Key Words: GBS (coarse) zone-II, Ground Granulated Blast Furnace Slag (GGBS), Hardened concrete, HVFA, Saenz's model equation.

I. INTRODUCTION

The use of GGBS and High volume Fly ash concrete in construction is a solution to environmental degradation being caused by cement industry, and steel plants. Disposal of Fly ash is growing problem as only 12% Fly ash is currently used. GGBS is obtained by quenching molted iron slag (a product of iron and steelmaking) from a blast furnace in water or steam, to produce a glassy granular product that is then dried and grounded into a fine powder. GGBS can be replaced for a substantial portion of ordinary Portland cement – (OPC). Generally about 30% to 70% can be replaced. The higher the replacement of GGBS, the better is the durability. The main draw back of GGBS is, as the replacement level increases, the strength gained at the early stage is somewhat slower, but they continue to gain strength for longer period. GGBS hardens very slowly and, for use in concrete, it needs to be activated by combining it with OPC. The greater the percentage of GGBS, the greater will be the effect on concrete properties.

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K.Suvarna latha, Department of Civil Engineering, JNTUH College of Engineering, Hyderabad, India.

M.V. Seshagiri Rao, Department of Civil Engineering, JNTUH College of Engineering, Hyderabad, India.

The setting time of concrete is influenced by many factors, in particularly temperature and water/cement ratio. With GGBS, the setting time will be extended slightly by 30 minutes. The effect will be more pronounced at high levels of GGBS. An extended setting time is advantageous as the concrete will give better workability.

Higher the replacement of GGBS with OPC, Water content can be reduced to achieve equivalent consistence class. Fresh concrete containing GGBS tends to require less energy for movement. This makes it easier to place and compact, especially while pumping or when mechanical vibration is used. In addition, it will retain its workability for longer time.

As cement industry itself is responsible for 7% of World's Carbon dioxide missions, responsible for global warming, attention needs to be drawn by construction industry to solve the problem. High volume Fly ash concrete mix contains lower qualities of cement and higher volumes of Fly ash (up to 70%) From the literature available, it is found that the proportions of Fly ash in concrete can vary from 30%, 70% for various grades of concrete.

In this study sand is replaced by GGB slag (coarse). Confirming to Zone-II category after Sieve analysis is carried out. Sieve analysis of GGB is also presented in this paper.

II. MATERIALS USED AND THEIR PROPERTIES

- Cement: Ordinary Portland cement of 53 grade confirming to IS:12269-1987 used in the investigation
- Fine aggregate: Locally available, natural River sand confirming to Zone-II used as fine aggregate.
- Coarse Aggregate: Locally available crushed angular coarse aggregates of size 20mm and with sp.gr. of 2.7 was used as C.A
- GGBS: Confirming to IS 12089:1981 for (cement replacement)
- GBS: Confirming to I.S 2386 Part VII for (Sand replacement)
- Water: Locally available potable water confirming to IS 456-2000 is used

III. EXPERIMENTAL INVESTIGATION

In National council for cement and building materials (NCCBM),Hyderabad, Andhra Pradesh, India, Independent testing laboratories, the GGBS is tested for Alkali Aggregative Reactivity as per IS: 2386 Past VCI and the specification is IS 383-1970. The aggregate is found *innocuous* in nature by chemical method.

In this method the potential reactivity of an aggregate with alkalis in Portland cement is indicated by the cement of reaction taking place during 24 hours at 80° between sodium hydroxide solution and the aggregate that has been crushed and sieved to pass a 300 microns IS Sieve and retained on 150 micron IS Sieve. The solution after24 hours is analyzed for silica dissolved and reduction in alkalinity, both expressed as mill moles per liter.

A.ALKALI AGGREGATE REACTIVITY MILLIMOLES/LITER

1. Reduction in alkalinity : 23.00 of 1 N NaoH (Quantity RC)
2. Silica dissolved by 1 N NaoH solution (Quantity Se) :1.00

Comprehensive strength of concrete is the most important parameter to assess its quality. The use of fly ash and GGBS in hardened concrete has been tried for long and sufficient literature and data is available on the topic but very little research has been done in India. Hence there is a scope of studying the effect of varying percentages of fly ash and GGBS on various properties of different grades of concrete. The spherical shape and particle size distribution of fly ash and higher proportion of the strength enhancing Calcium Silicate Hydrates (CSH) in GGBS improves the fluidity of flowable fill, thereby, reducing the demand of mixing and contributing to long team strength of hardened concrete with fly ash and GGBS. Some of the benefits of fly ash and GGBS in concrete are:

- Higher Ultimate Strength
- Improved workability
- Reduced heat of hydration
- Reduced permeability
- Increased resistance to sulphate attack
- Lowered casts
- Reduced shrinkage
- Increased durability

At optimum percentages total numbers of 81 cylinders of 150X300 mm were casted and tested at 28 days of normal curing under water.The cylinders are tested for stress-strain behavior under uni-axial compression.For curve for each mix is plotted. The mixes were designated as

- M2CF –Cement replacement with HVFA for M20 Grade.
- M4CF – Cement replacement with HVFA for M40 Grade.
- M6CF - Cement replacement with HVFA for M60 Grade.
- M2CG - Cement replacement with GGBS for M20 Grade.
- M4CG - Cement replacement with GGBS for M40 Grade.
- M6CG - Cement replacement with GGBS for M60 Grade.
- M2SG –Sand replacement with GBS (Coarse) for M20 Grade.
- M4SG –Sand replacement with GBS (Coarse) for M40 Grade.
- M6SG –Sand replacement with GBS (Coarse) for M60 Grade.

B.Estimation of ε_0 :

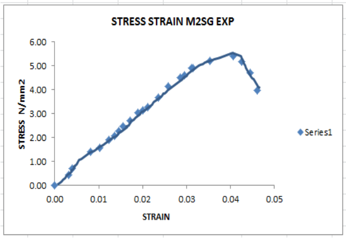
Value of strain corresponding to the peak point in the stress – strain curve is known as strain at maximum stress i.e ε_0 the position of the peak point in the curve is influenced by compressed strength, rate of loading and straining. However the peak point may be consider stable if the rate of straining and load duration are kept constant.

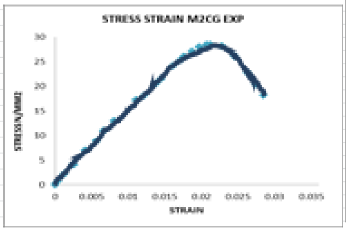
C.Test set up:

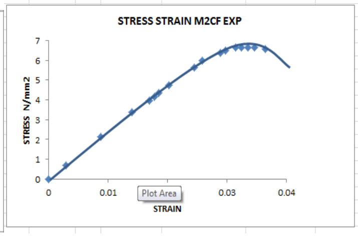
In order to perform uniaxial compression testing of specimens a hydraulic testing machine was used in Strength of Material laboratory of J.N. Technological University, Hyderabad. Bottom jaw of the machine is adjustable in the vertical direction and it is attached to an actuator. While the top is fixed the specimens were tested using 3000KN capacity compressive machine and the data were mentioned using an automatic data acquisition system. The test was continued up to failure under a monotonically increasing concentric load in a displacement control mode. The force and displacement data were obtained by data collecting system of the machine during the test.

D.EXPERIMENTAL VALUES OF STRESSES AND STRAINS OF M2CF, M2CG AND M2SG

M2CF		M2CG				M2SG			
STRAIN ε	STRESS σ N/mm^2	STRAIN ε	STRESS σ N/mm^2	STRAIN ε	STRESS σ N/mm^2	STRAIN ε	STRESS σ N/mm^2	STRAIN ε	STRESS σ N/mm2
0	0	0	0	0.0197	27.95	0.00	0.00	0.03	4.90
0.00289	0.7025	0.000375	0.6785	0.0207	28.37	0.00	0.42	0.03	4.90
0.0087	2.124	0.00124	2.15	0.0212	28.405	0.00	0.69	0.04	5.18
0.014	3.358	0.00254	4.12	0.0228	28.12	0.01	1.40	0.04	5.39
0.01695	3.952	0.004123	6.95	0.0245	26.09	0.01	1.56	0.04	5.15
0.0178	4.156	0.005642	8.795	0.0263	22.65	0.01	1.90	0.04	4.70
0.0185	4.368	0.00665	10.91	0.0274	20.371	0.01	2.06	0.05	3.98
0.0202	4.752	0.00805	12.95	0.0285	18.122	0.01	2.26		
0.0245	5.621	0.0111	17.12			0.02	2.46		
0.0258	5.987	0.0122	18.01			0.02	2.70		
0.0289	6.358	0.01385	20.54			0.02	3.03		
0.0298	6.487	0.0145	21.45			0.02	3.14		
0.0315	6.641	0.157	23.46			0.02	3.26		
0.0324	6.658	0.0161	24.12			0.02	3.65		
0.0335	6.649	0.0172	25.34			0.03	4.13		
0.0346	6.641	0.0176	25.95			0.03	4.49		
0.0365	6.548	0.0187	27.09			0.03	4.60		

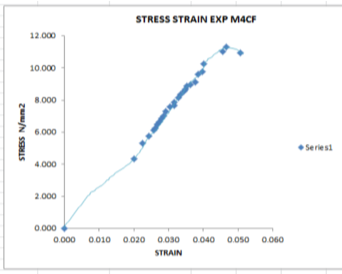


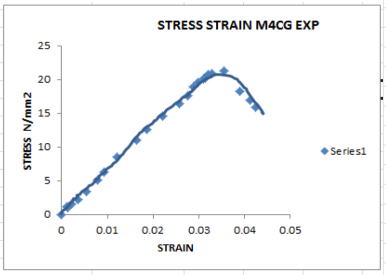


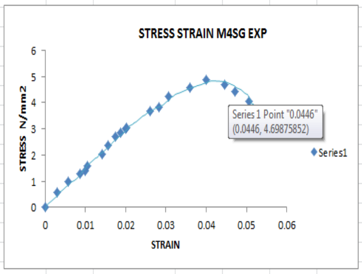


E.EXPERIMENTAL VALUES OF STRESSES AND STRAINS OF M4CF, M4CG AND M4SG

M4CF				M4CG				M4SG	
STRAIN ε	STRESS σ N/mm^2	STRAIN ε	STRESS N/mm^2	STRAIN ε	STRESS N/mm^2	STRAIN ε	STRESS N/mm^2	STRAIN ε	STRESS σ N/mm^2
0.000	0.000	0.046	11.035	0	0	0.0356	21.25	0	0
0.020	4.325	0.047	11.318	0.0011	1.188	0.0389	18.212	0.00298	0.5869
0.023	5.325	0.051	10.922	0.0013	1.05	0.0412	16.95	0.0057	0.96582
0.024	5.758	0.052	10.528	0.0021	1.58	0.0425	15.85	0.0086	1.2859
0.026	6.125	0.038	9.125	0.00365	2.23			0.00995	1.39856
0.026	6.236	0.039	9.584	0.0054	3.395			0.0106	1.5968
0.027	6.490	0.040	9.762	0.0078	5.12			0.0141	2.0198
0.027	6.655	0.040	10.243	0.0092	6.35			0.0156	2.36985
0.028	6.855			0.0121	8.54			0.01755	2.6875
0.029	7.025			0.0163	11.02			0.01875	2.8521
0.029	7.296			0.0186	12.58			0.0201	3.0002
0.030	7.584			0.0221	14.56			0.02015	3.0274
0.032	7.655			0.0258	16.48			0.0261	3.6641
0.032	7.855			0.0275	17.58			0.02825	3.8338
0.033	8.126			0.0289	18.96			0.0306	4.2299
0.034	8.354			0.0299	19.58			0.03589	4.5553
0.035	8.547			0.0311	20.05			0.03995	4.88103
0.035	8.678			0.0315	20.29			0.0446	4.69875
0.035	8.874			0.0321	20.72			0.0471	4.42589
0.036	8.950			0.0328	20.85			0.0505	4.0528



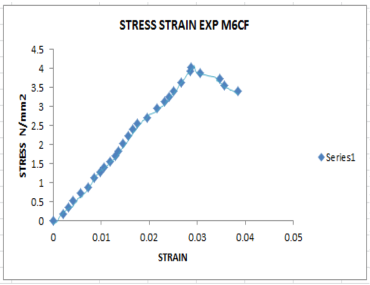


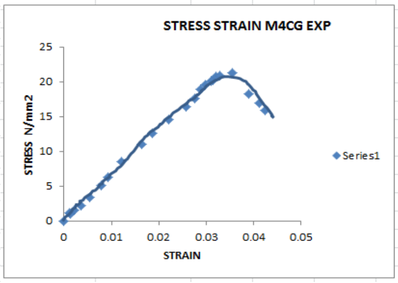


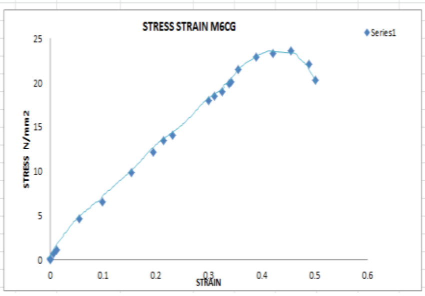
F.EXPERIMENTAL VALUES OF STRESSES AND STRAINS OF M6CF, M6CG AND M6SG

M6CF		M6CG		M6SG	
STRAIN ε	STRESS σ N/mm^2	STRAIN ε	STRESS N/mm^2	STRAIN ε	STRESS N/mm^2
0	0	0	0	0	0
0.0021548	0.1768	0.0011	1.188	0.00081	0.125
0.003258	0.3551	0.0013	1.05	0.00598	0.758
0.004123	0.5263	0.0021	1.58	0.0125	1.15
0.0056894	0.7243	0.00365	2.23	0.0546	4.621
0.007235	0.8644	0.0054	3.395	0.0987	6.58
0.008569	1.1205	0.0078	5.12	0.154	9.895
0.009857	1.2662	0.0092	6.35	0.195	12.12
0.010589	1.4062	0.0121	8.54	0.214	13.45
0.011856	1.5434	0.0163	11.02	0.232	14.12
0.0129658	1.6962	0.0186	12.58	0.299	18.01
0.013569	1.8292	0.0221	14.56	0.31	18.48
0.01458	2.0117	0.0258	16.48	0.325	19.03
0.015698	2.2239	0.0275	17.58	0.339	19.85
0.016589	2.3923	0.0289	18.96	0.342	20.09

0.017589	2.5451	0.0299	19.58	0.355	21.54
0.019586	2.6993	0.0311	20.05	0.389	22.897
0.02158	2.9454	0.0315	20.29	0.421	23.257
0.023154	3.1109	0.0321	20.72	0.455	23.587
0.02415	3.2414	0.0328	20.85	0.489	22.123
0.02514	3.3981	0.0356	21.25	0.502	20.258
0.02658	3.6103	0.0389	18.212	0.526	20.025
0.0286	3.9329	0.0412	16.95		
0.0287	4.0178	0.0425	15.85		
0.0306	3.8622				
0.03465	3.7108				
0.0356	3.5538				
0.03845	3.4004				







Proposed Model for Stress-Strain Behaviour of hardened concrete

Equations in different forms were tried to get the complete stress-strain behaviour of Hardened Concrete.Out of different possible trials, the developed normalized stress-strain curves were fitted with analytical equations using Saenz's model.The developed equation for M20. M40 and M60 are in the form of

- $Y = Ax/(1+Bx^2)$ where
- x - normalized strain,Y- normalized stress
- A, B - are constants for ascending portion and
- A_1, B_1 - for descending portion.

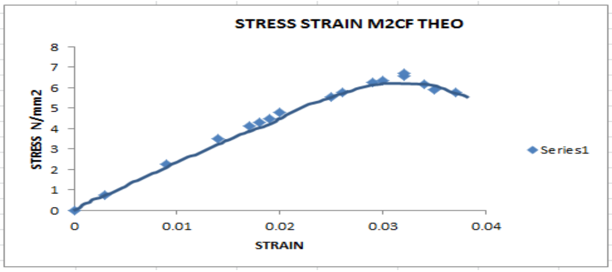
Mix	Equations for ascending portion	Equations for descending portion
M2CF	$Y = 1.27 x/(1+ 0.42 x^{2})$	$Y = 1.34 x/(1+0.68x^{2})$
M2CG	$Y = 1.15 x/(1+0.12 x^{2})$	$Y = 2.21 x/(1+1.32 x^{2})$
M2SG	$Y = 1.42 x/(1+0.45 x^{2})$	$Y = 1.91 x/(1+0.98 x^{2})$
M4CF	$Y = 1.85 x/(1+ 0.58 x^{2})$	$Y = 2.41 x/(1+1.76 x^{2})$
M4CG	$Y = 1.45 x/(1+0.63 x^{2})$	$Y = 3.61 x/(1+2.91 x^{2})$
M4SG	$Y = 1.46 x/(1+0.61 x^{2})$	$Y = 1.33 x/(1+0.45 x^{2})$
M6CF	$Y = 1.17 x/(1+0.34 x^{2})$	$Y = 3.07 x/(1+2.06 x^{2})$
M6CG	$Y = 1.56 x/(1+0.73 x^{2})$	$Y = 2.09 x/(1+1.16 x^{2})$
M6SG	$Y = 0.77 x/(1+0.52 x^{2})$	$Y = 4.31 x/(1+3.13 x^{2})$

Using the boundary condition in the non-dimensional stress – strain curves constants for different hardened concrete mixes are determined and from that the mathematical equations are developed. Ultimately analytical equation s giving the complete stress – strain behaviour developed for M20, M40 and M60 grades hardened concrete with HVFA,GGBS and GBS as replacement materials in cement and sand.

The proposed equation in the form $Y= AX/1+BX^2$

$X= \varepsilon/\varepsilon_0$, $Y = \sigma/\sigma_0$

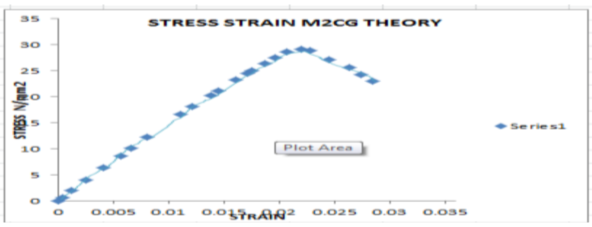
G.Calculation of Theoretical Stresses M2CF



A'	ε	A'ε	B'	$B'\varepsilon^2$	1+B'ε 2	σ= $A'\varepsilon/1+B'\varepsilon^2$	ε	$\sigma=A'\varepsilon/1+B'\varepsilon^2$
262.5424	0	0	258.5411	0	1	0	0	0
262.5424	0.00289	0.758	258.5411	0.0021	1.002159	0.7571	0.003	0.757
262.5424	0.0087	2.284	258.5411	0.0195	1.019569	2.2402	0.009	2.24
262.5424	0.014	3.675	258.5411	0.0506	1.050674	3.4983	0.014	3.498
262.5424	0.01695	4.450	258.5411	0.0742	1.07428	4.1423	0.017	4.142
262.5424	0.0178	4.673	258.5411	0.0819	1.081916	4.3194	0.018	4.319
262.5424	0.0185	4.857	258.5411	0.0884	1.088486	4.4621	0.019	4.462
262.5424	0.0202	5.303	258.5411	0.1054	1.105495	4.7972	0.02	4.797
262.5424	0.0245	6.432	258.5411	0.1551	1.155189	5.5681	0.025	5.568
262.5424	0.0258	6.773	258.5411	0.1720	1.172095	5.7790	0.026	5.779
262.5424	0.0289	7.587	258.5411	0.2159	1.215936	6.2400	0.029	6.24
262.5424	0.0298	7.823	258.5411	0.2295	1.229595	6.3628	0.03	6.363
262.5424	0.0315	8.270	258.5411	0.2565	1.256537	6.5816	0.032	6.582
262.5424	0.0324	8.506	258.5411	0.2714	1.271406	6.6905	0.032	6.691
251.7421	0.0335	8.433	320.0985	0.3592	1.359231	6.2045	0.034	6.175
251.7421	0.0346	8.710	320.0985	0.3832	1.383209	6.2971	0.035	5.925
251.7421	0.0365	9.188	320.0985	0.4264	1.426451	6.4415	0.037	5.789

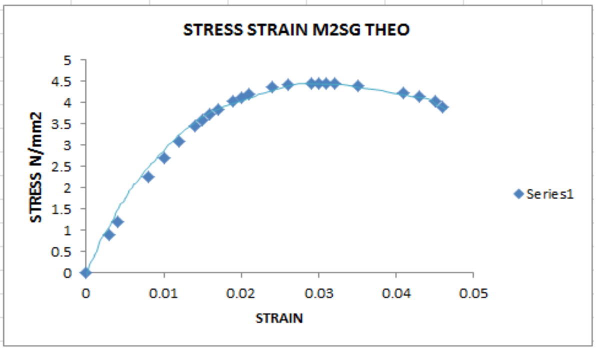
H.Calculation of Theoretical Stresses M2CG

A'	ε	A'ε	B'	B'ε ^{2}	1+B'ε ^{2}	σ = A'ε /1+B'ε ^{2}	ε	σ = A'ε /1+B'ε ^{2}
1540.837	0	0	266.9989	0	1	0	0	0
1540.837	0.000375	0.577814	266.9989	3.75E-05	1.000038	0.5778	0.000375	0.578
1540.837	0.00124	1.910638	266.9989	0.000411	1.000411	1.9099	0.00124	1.91
1540.837	0.00254	3.913727	266.9989	0.001723	1.001723	3.907	0.00254	3.907
1540.837	0.004123	6.352872	266.9989	0.004539	1.004539	6.3242	0.004123	6.324
1540.837	0.005642	8.693404	266.9989	0.008499	1.008499	8.6201	0.005642	8.62
1540.837	0.00665	10.24657	266.9989	0.011807	1.011807	10.127	0.00665	10.127
1540.837	0.00805	12.40374	266.9989	0.017302	1.017302	12.1928	0.00805	12.193
1540.837	0.0111	17.10329	266.9989	0.032897	1.032897	16.5586	0.0111	16.559
1540.837	0.0122	18.79821	266.9989	0.03974	1.03974	18.0797	0.0122	18.08
1540.837	0.01385	21.3406	266.9989	0.051216	1.051216	20.3009	0.01385	20.301
1540.837	0.0145	22.34214	266.9989	0.056137	1.056137	21.1546	0.0145	21.155
1540.837	0.157	241.9115	266.9989	6.581257	7.581257	31.9091	0.157	31.909
1540.837	0.0161	24.80748	266.9989	0.069209	1.069209	23.2017	0.0161	23.202
1540.837	0.0172	26.5024	266.9989	0.078989	1.078989	24.5623	0.0172	24.562
1540.837	0.0176	27.11874	266.9989	0.082706	1.082706	25.0472	0.0176	25.047
1540.837	0.0187	28.81366	266.9989	0.093367	1.093367	26.3531	0.0187	26.353
1540.837	0.0197	30.35449	266.9989	0.10362	1.10362	27.5045	0.0197	27.505
1540.837	0.0207	31.89533	266.9989	0.114406	1.114406	28.6209	0.0207	28.621
1540.837	0.0212	32.66575	266.9989	0.12	1.12	29.1658	0.022	29.166
2953.048	0.0228	67.3295	2936.988	1.526764	2.526764	26.6465	0.0228	28.954
2953.048	0.0245	72.34968	2936.988	1.762927	2.762927	26.1859	0.0245	27.125
2953.048	0.0263	77.66517	2936.988	2.031485	3.031485	25.6195	0.0263	25.62
2953.048	0.0274	80.91352	2936.988	2.204973	3.204973	25.2462	0.0274	24.254
2953.048	0.0285	84.16187	2936.988	2.385569	3.385569	24.859	0.0285	22.987



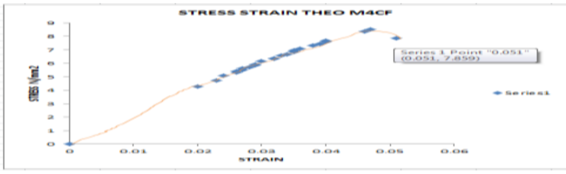
I.Calculation of Theoretical Stresses M2SG

A'	ε	A'ε	B'	B'ε 2	1+B'ε 2	σ A'ε /1+B'ε 2	ε	σ=A'ε 1+B'ε 2
299.3861	0	0	1134.93	0	1	0	0	0
299.3861	0.003	0.898158	1134.93	0.010214	1.010214	0.889	0.003	0.889
299.3861	0.004	1.197545	1134.93	0.018159	1.018159	1.176	0.004	1.176
299.3861	0.008	2.395089	1134.93	0.072636	1.072636	2.233	0.008	2.233
299.3861	0.01	2.993861	1134.93	0.113493	1.113493	2.689	0.01	2.689
299.3861	0.012	3.592634	1134.93	0.16343	1.16343	3.088	0.012	3.088
299.3861	0.014	4.191406	1134.93	0.222446	1.222446	3.429	0.014	3.429
299.3861	0.015	4.490792	1134.93	0.255359	1.255359	3.577	0.015	3.577
299.3861	0.016	4.790178	1134.93	0.290542	1.290542	3.712	0.016	3.712
299.3861	0.017	5.089564	1134.93	0.327995	1.327995	3.833	0.017	3.833
299.3861	0.019	5.688337	1134.93	0.40971	1.40971	4.035	0.019	4.035
299.3861	0.02	5.987723	1134.93	0.453972	1.453972	4.118	0.02	4.118
299.3861	0.021	6.287109	1134.93	0.500504	1.500504	4.19	0.021	4.19
299.3861	0.024	7.185267	1134.93	0.65372	1.65372	4.345	0.024	4.345
299.3861	0.026	7.78404	1134.93	0.767213	1.767213	4.405	0.026	4.405
299.3861	0.029	8.682198	1134.93	0.954476	1.954476	4.442	0.029	4.442
299.3861	0.03	8.981584	1134.93	1.021437	2.021437	4.443	0.03	4.443
299.3861	0.031	9.28097	1134.93	1.090668	2.090668	4.439	0.031	4.439
299.3861	0.032	9.580357	1134.93	1.162168	2.162168	4.431	0.032	4.431
299.3861	0.035	10.47851	1134.93	1.390289	2.390289	4.384	0.035	4.384
299.3861	0.041	12.27483	1134.93	1.907817	2.907817	4.221	0.041	4.221
242.4235	0.043	10.42421	470.8752	0.870648	1.870648	5.573	0.043	4.129
242.4235	0.045	10.90906	470.8752	0.953522	1.953522	5.584	0.045	4.012
242.4235	0.046	11.15148	470.8752	0.996372	1.996372	5.586	0.046	3.876



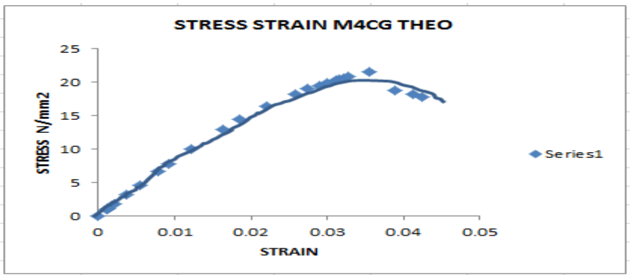
J.Calculation of Theoretical Stresses M4CF

A'	ε	A'ε	B'	B'ε ^{2}	1+B'ε ^{2}	σ= A'ε /1+B'ε ^{2}	ε	σ= A'ε /1+B'ε ^{2}
220.5376	0	0	96.29096	0	1	0	0	0
220.5376	0.02015	4.443833	96.29096	0.039096	1.039096	4.276632604	0.02	4.277
220.5376	0.02255	4.973123	96.29096	0.048964	1.048964	4.740984889	0.023	4.741
220.5376	0.02435	5.370091	96.29096	0.057093	1.057093	5.080055134	0.024	5.08
220.5376	0.0257	5.667817	96.29096	0.063599	1.063599	5.328902856	0.026	5.329
220.5376	0.0261	5.756032	96.29096	0.065594	1.065594	5.4017102	0.026	5.402
220.5376	0.0267	5.888355	96.29096	0.068645	1.068645	5.510113537	0.027	5.51
220.5376	0.0274	6.042731	96.29096	0.072291	1.072291	5.635343948	0.027	5.635
220.5376	0.0279	6.153	96.29096	0.074954	1.074954	5.723966373	0.028	5.724
220.5376	0.0286	6.307376	96.29096	0.078762	1.078762	5.846864373	0.029	5.847
220.5376	0.0291	6.417645	96.29096	0.08154	1.08154	5.933801743	0.029	5.934
220.5376	0.03045	6.715371	96.29096	0.089281	1.089281	6.164955832	0.03	6.165
220.5376	0.03155	6.957962	96.29096	0.095848	1.095848	6.349384513	0.032	6.349
220.5376	0.0317	6.991043	96.29096	0.096762	1.096762	6.374257823	0.032	6.374
220.5376	0.03285	7.244661	96.29096	0.10391	1.10391	6.56272938	0.033	6.563
220.5376	0.0335	7.38801	96.29096	0.108063	1.108063	6.667503094	0.034	6.668
220.5376	0.03455	7.619575	96.29096	0.114943	1.114943	6.834050252	0.035	6.834
220.5376	0.03485	7.685736	96.29096	0.116948	1.116948	6.881018021	0.035	6.881
220.5376	0.03535	7.796005	96.29096	0.120327	1.120327	6.958684838	0.035	6.959
220.5376	0.03625	7.994489	96.29096	0.126532	1.126532	7.096546208	0.036	7.097
220.5376	0.0377	8.314268	96.29096	0.136857	1.136857	7.313378538	0.038	7.313
220.5376	0.0385	8.490698	96.29096	0.142727	1.142727	7.430205466	0.039	7.43
220.5376	0.03965	8.744317	96.29096	0.151381	1.151381	7.59463228	0.04	7.595
220.5376	0.04025	8.876639	96.29096	0.155997	1.155997	7.678771153	0.04	7.679
220.5376	0.0456	10.05652	96.29096	0.200224	1.200224	8.378868567	0.046	8.379
220.5376	0.0467	10.29911	96.29096	0.21	1.21	8.511658678	0.047	8.512
77.55169	0.0507	3.931871	248.0639	0.637646	1.637646	2.400928853	0.051	7.859
77.55169	0.052	4.032688	248.0639	0.670765	1.670765	2.413677997	0.052	7.859



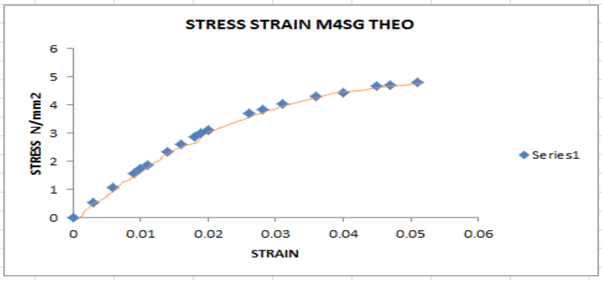
K.Calculation of Theoretical Stresses M4CG

A'	ε	A'ε	B'	B'ε ^{2}	1+B'ε ^{2}	σ = A'ε /1+B'ε ^{2}	ε	σ= A'ε /1+B'ε ^{2}
865.5197	0	0	339.288	0	1	0	0	0
865.5197	0.0011	0.952072	339.288	0.000411	1.000411	0.951680928	0.0011	0.952
865.5197	0.0013	1.125176	339.288	0.000573	1.000573	1.12453076	0.0013	1.125
865.5197	0.0021	1.817591	339.288	0.001496	1.001496	1.814875766	0.0021	1.815
865.5197	0.00365	3.159147	339.288	0.00452	1.00452	3.144931165	0.00365	3.145
865.5197	0.0054	4.673806	339.288	0.009894	1.009894	4.628018246	0.0054	4.628
865.5197	0.0078	6.751053	339.288	0.020642	1.020642	6.614514706	0.0078	6.615
865.5197	0.0092	7.962781	339.288	0.028717	1.028717	7.740494535	0.0092	7.74
865.5197	0.0121	10.47279	339.288	0.049675	1.049675	9.977170467	0.0121	9.977
865.5197	0.0163	14.10797	339.288	0.090145	1.090145	12.94136566	0.0163	12.941
865.5197	0.0186	16.09867	339.288	0.11738	1.11738	14.40751113	0.0186	14.408
865.5197	0.0221	19.12798	339.288	0.165712	1.165712	16.40884756	0.0221	16.409
865.5197	0.0258	22.33041	339.288	0.225844	1.225844	18.21635852	0.0258	18.216
865.5197	0.0275	23.80179	339.288	0.256587	1.256587	18.94162498	0.0275	18.942
865.5197	0.0289	25.01352	339.288	0.283377	1.283377	19.4903945	0.0289	19.49
865.5197	0.0299	25.87904	339.288	0.303327	1.303327	19.8561383	0.0299	19.856
865.5197	0.0311	26.91766	339.288	0.328163	1.328163	20.26684019	0.0311	20.267
865.5197	0.0315	27.26387	339.288	0.336658	1.336658	20.39703458	0.0315	20.397
865.5197	0.0321	27.78318	339.288	0.349606	1.349606	20.58614665	0.0321	20.586
865.5197	0.0328	28.38904	339.288	0.36502	1.36502	20.79753698	0.0328	20.798
865.5197	0.0356	30.8125	339.288	0.43	1.43	21.5472028	0.0356	21.547
2154.846	0.0389	83.82349	2296.112	3.474499	4.474499	18.73360335	0.0389	18.734
2154.846	0.0412	88.77963	2296.112	3.897512	4.897512	18.12749834	0.0412	18.127
2154.846	0.0425	91.58093	2296.112	4.147352	5.147352	17.7918552	0.0425	17.792



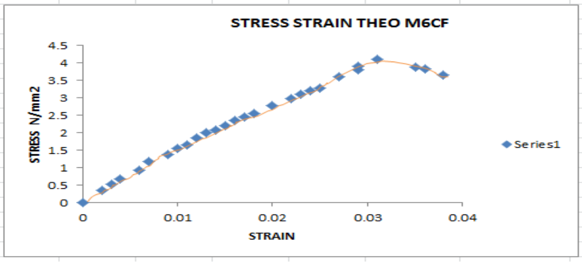
L.Calculation of Theoretical Stresses M4SG

A'	ε	A'ε	B'	B'ε2	1+B'ε2	σ=A'ε /1+B'ε²	ε	σ= A'ε/1+B'ε
178.380	0	0	382.204	0	1	0	0	0
178.380	0.003	0.53514	382.204	0.0034	1.0034	0.5333	0.003	0.5333
178.380	0.006	1.07028	382.204	0.01375	1.01375	1.0558	0.006	1.0558
178.380	0.009	1.60542	382.204	0.03095	1.03095	1.5572	0.009	1.5572
178.380	0.01	1.78380	382.204	0.0382	1.0382	1.7181	0.01	1.7181
178.380	0.011	1.96218	382.204	0.04624	1.04624	1.8755	0.011	1.8755
178.380	0.014	2.4973	382.204	0.07491	1.07491	2.3233	0.014	2.3233
178.380	0.016	2.85409	382.204	0.09784	1.09784	2.5997	0.016	2.5997
178.380	0.018	3.21085	382.204	0.12383	1.12383	2.8571	0.018	2.8571
178.380	0.019	3.38923	382.204	0.13797	1.13797	2.9783	0.019	2.9783
178.380	0.02	3.56761	382.204	0.15288	1.15288	3.0945	0.02	3.0945
178.380	0.02	3.56761	382.204	0.15288	1.15288	3.0945	0.02	3.0945
178.380	0.026	4.63789	382.204	0.25837	1.25837	3.6856	0.026	3.6856
178.380	0.028	4.99466	382.204	0.29964	1.29964	3.8431	0.028	3.8431
178.380	0.031	5.52980	382.204	0.36729	1.36729	4.0443	0.031	4.0443
178.380	0.036	6.42170	382.204	0.49533	1.49533	4.2945	0.036	4.2945
178.380	0.04	7.1352	382.204	0.61152	1.61152	4.4276	0.04	4.4276
162.497	0.045	7.31238	281.954	0.57095	1.57095	4.6547	0.045	4.6547
162.497	0.047	7.63738	281.954	0.62283	1.62283	4.7062	0.047	4.7062
162.497	0.051	8.28737	281.954	0.73336	1.73336	4.7811	0.051	4.7811



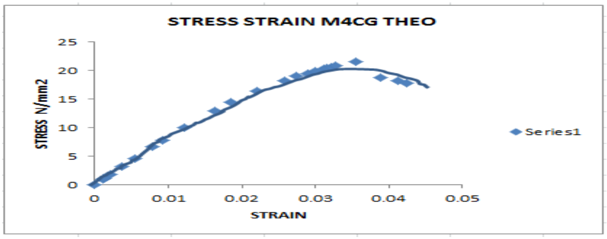
M.Calculation of Theoretical Stresses M6CF

A'	ε	A'ε	B'	B'ε²	1+B'ε²	σ = A'ε/1+B'ε²	ε	σ= A'ε/1+B'ε
163.791	0	0	412.776	0	1	0	0	0
163.791	0.00215	0.35293	412.776	0.00191	1.0019165	0.35226352	0.002	0.352
163.791	0.00325	0.53363	412.776	0.00438	1.0043814	0.53130594	0.003	0.531
163.791	0.00412	0.67531	412.776	0.00701	1.0070168	0.67060823	0.004	0.671
163.791	0.00568	0.93187	412.776	0.01336	1.0133612	0.91959042	0.006	0.92
163.791	0.00723	1.18503	412.776	0.02160	1.0216068	1.15997065	0.007	1.16
163.791	0.00856	1.40353	412.776	0.03030	1.0303092	1.36224372	0.009	1.362
163.791	0.00985	1.61449	412.776	0.04010	1.0401055	1.55224266	0.01	1.552
163.791	0.01058	1.73439	412.776	0.04628	1.0462833	1.65766933	0.011	1.658
163.791	0.01185	1.94191	412.776	0.05802	1.0580218	1.83542159	0.012	1.835
163.791	0.01296	2.12369	412.776	0.06939	1.069392	1.9858863	0.013	1.986
163.791	0.01356	2.22249	412.776	0.076	1.0759995	2.06551354	0.014	2.066
163.791	0.01458	2.38808	412.776	0.08774	1.0877465	2.1954425	0.015	2.195
163.791	0.01569	2.57120	412.776	0.10171	1.101719	2.33381060	0.016	2.334
163.791	0.01658	2.71714	412.776	0.11359	1.1135940	2.43997619	0.017	2.44
163.791	0.01758	2.88093	412.776	0.12770	1.1277019	2.55469530	0.018	2.555
163.791	0.01958	3.20802	412.776	0.15834	1.1583458	2.76948993	0.02	2.769
163.791	0.02158	3.53462	412.776	0.19222	1.192228	2.96472341	0.022	2.965
163.791	0.02315	3.79243	412.776	0.22129	1.2212927	3.10526401	0.023	3.105
163.791	0.02415	3.95557	412.776	0.24074	1.2407406	3.18807412	0.024	3.188
163.791	0.02514	4.11772	412.776	0.26088	1.2608829	3.26574887	0.025	3.266
163.791	0.02658	4.35358	412.776	0.29162	1.2916252	3.37062734	0.027	3.587
163.791	0.0286	4.68444	412.776	0.33763	1.3376347	3.50203721	0.029	3.785
163.791	0.0287	4.70082	412.776	0.34	1.34	3.50807910	0.029	3.897
446.915	0.0306	13.6750	2500.94	2.34178	3.3417810	4.09230839	0.031	4.092
446.915	0.03465	15.4850	2500.94	3.00268	4.002685	3.86880323	0.035	3.869
446.915	0.0356	15.9101	2500.94	3.16959	4.1695924	3.81576223	0.036	3.816
446.915	0.03845	17.1838	2500.94	3.69739	4.6973972	3.65817071	0.038	3.658



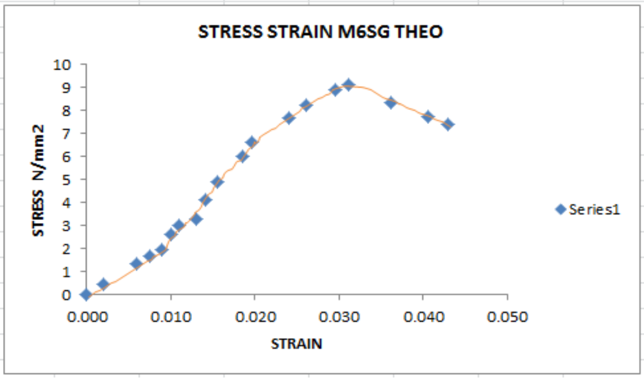
N.Calculation of Theoretical Stresses M6CG

A'	ε	A'ε	B'	B'ε²	1+B'ε²	σ= A'ε/1+B'ε2	ε	σ=A'ε/1+B'ε
865.5197	0	0	339.288	0	1	0	0	0
865.5197	0.0011	0.952072	339.288	0.000411	1.000411	0.951680928	0.0011	0.952
865.5197	0.0013	1.125176	339.288	0.000573	1.000573	1.12453076	0.0013	1.125
865.5197	0.0021	1.817591	339.288	0.001496	1.001496	1.814875766	0.0021	1.815
865.5197	0.00365	3.159147	339.288	0.00452	1.00452	3.144931165	0.00365	3.145
865.5197	0.0054	4.673800	339.288	0.009894	1.009894	4.628018246	0.0054	4.628
865.5197	0.0078	6.751053	339.288	0.020642	1.020642	6.614514706	0.0078	6.615
865.5197	0.0092	7.962781	339.288	0.028717	1.028717	7.740494535	0.0092	7.74
865.5197	0.0121	10.47279	339.288	0.049675	1.049675	9.977170467	0.0121	9.977
865.5197	0.0163	14.10797	339.288	0.090145	1.090145	12.94136566	0.0163	12.941
865.5197	0.0186	16.09867	339.288	0.11738	1.11738	14.40751113	0.0186	14.408
865.5197	0.0221	19.12798	339.288	0.165712	1.165712	16.40884756	0.0221	16.409
865.5197	0.0258	22.33041	339.288	0.225844	1.225844	18.21635852	0.0258	18.216
865.5197	0.0275	23.80179	339.288	0.256587	1.256587	18.94162498	0.0275	18.942
865.5197	0.0289	25.01352	339.288	0.283377	1.283377	19.4903945	0.0289	19.49
865.5197	0.0299	25.87904	339.288	0.303327	1.303327	19.8561383	0.0299	19.856
865.5197	0.0311	26.91760	339.288	0.328163	1.328163	20.26684019	0.0311	20.267
865.5197	0.0315	27.26387	339.288	0.336658	1.336658	20.39703458	0.0315	20.397
865.5197	0.0321	27.78318	339.288	0.349606	1.349606	20.58614665	0.0321	20.586
865.5197	0.0328	28.38904	339.288	0.36502	1.36502	20.79753698	0.0328	20.798
865.5197	0.0356	30.8125	339.288	0.43	1.43	21.5472028	0.0356	21.547
2154.846	0.0389	83.82349	2296.112	3.474499	4.474499	18.73360335	0.0389	18.734
2154.846	0.0412	88.77963	2296.112	3.897512	4.897512	18.12749834	0.0412	18.127
2154.846	0.0425	91.58093	2296.112	4.147352	5.147352	17.7918552	0.0425	17.792



O.Calculation of Theoretical Stresses M6SG

A'	ε	A'ε	B'	B'ε2	1+B'ε2	σ=A'ε /1+B'ε^2	ε	σ= A'ε /1+B'ε^2
228.202	0.000	0	577.777	0	1	0	0.000	0
228.202	0.002	0.45640	577.777	0.00231	1.00231	0.45535229	0.002	0.455
228.202	0.006	1.36921	577.777	0.0208	1.0208	1.34131465	0.006	1.341
228.202	0.008	1.72292	577.777	0.03293	1.03293	1.66799264	0.008	1.668
228.202	0.009	2.05382	577.777	0.0468	1.0468	1.96199942	0.009	1.962
228.202	0.010	2.28202	577.777	0.05777	1.05777	2.157375	0.010	2.587
228.202	0.011	2.51022	577.777	0.06991	1.06991	2.34620020	0.011	2.987
228.202	0.013	2.9666	577.777	0.09764	1.09764	2.70272431	0.013	3.258
228.202	0.014	3.21765	577.777	0.11486	1.11486	2.88612903	0.014	4.125
228.202	0.016	3.55995	577.777	0.14060	1.14060	3.12110418	0.016	4.875
228.202	0.019	4.23315	577.777	0.19881	1.19881	3.53111536	0.019	5.987
228.202	0.020	4.47276	577.777	0.22195	1.22195	3.66032356	0.020	6.589
228.202	0.024	5.47685	577.777	0.3328	1.3328	4.10928571	0.024	7.658
228.202	0.026	5.95608	577.777	0.39358	1.39358	4.27391804	0.026	8.198
228.202	0.030	6.75478	577.777	0.50622	1.50622	4.48457938	0.030	8.854
1277.3	0.031	39.6614	3477.77	3.35293	4.35293	9.11142118	0.031	9.111
1277.3	0.036	46.2397	3477.77	4.55741	5.55741	8.32035863	0.036	8.32
1277.3	0.041	51.8600	3477.77	5.7326	6.7326	7.70278765	0.041	7.703
1277.3	0.043	54.9256	3477.77	6.43041	7.43041	7.39200476	0.043	7.392



IV. DISCUSSION OF TEST RESULTS

The performance of the cylinders under axial load was consistent. At early stages of loading of the specimens the noise related to the micro cracking of the concrete core was evident, indicating the start of stress transfer from the dilated concrete wrap. Prior to the failure cracking noises by frequently heard, the failure was gradual, ending with a sudden and explosive noise. The sudden explosive nature of the failure indicates the release of extraordinary amount of energy as a result of the uniform confining stress provided by the wrap. It is observed that, there is no debonding took place at any stage throughout the loading process.

Based on the stress-strain curves of Hardened Concrete mixes, it is observed that the stress-strain pattern is to be almost similar. But the HVFA, GGBS and GBS for Sand replacement mixes have shown improved stress values. It is observed that for higher grades of concrete with increase in stress there was decrease in strain.Empirical equations for the stress-strain response of Hardened Concrete mixes have been proposed in the form of $\mathbf{Y = Ax/ (1+Bx^2)}$, where x is normalized strain and Y is normalized stress. The same empirical formula is valid for both ascending and descending portions with different values of constants.

V. CONCLUSIONS

The conclusions drawn from this report are:

There is a significant improvement in the compressive strength of Cement replaced GGBS concrete because of the high pozzolanic nature of the GGBS and its void filling ability.

It is observed that there is consistent increase in the strength of concrete when partial replacement of natural sand by GBS. The sharp edges of the particles in GBS provide better bond with cement than rounded particles of natural sand resulting in higher strength up to optimum replacement.

Finally in this study, it is observed that the compressive strength and split tensile strength of all grades of concrete can be improved by partial replacement of GGBS for cement and GBS for fine aggregate.

The dwindling sources of natural sand and its high cost could encourage the adoption of GBS by 40 to 50% replacement of natural sand. Therefore it is feasible to use GBS as sand replacement as long as designer is aware of the effects of the different combinations on the hardened and rheological properties.

GBS has a potential to provide alternative to natural sand and helps in maintaining the environment as well as economical balance. Non-availability of natural sand at reasonable cost, forces to search for alternative material. GBS qualifies itself as suitable substitute for river sand at reasonable cost. The GBS found to have good gradation, which was lacking in natural sand. This had been resulted in good cohesive concrete. This sand replacement material is considered as an ideal for concrete.

In an attempt to explain the behaviour of concrete cylinders with high cement and sand replacement with HVFA and GGBS at partial replacements, small scale specimens' 150X300 mm were subjected to uniaxial compression up to failure and stress – strain behaviour were recorded. The enhancement of strength and ductility of hardened concrete is significant.

At the end an analytical model equations for ultimate stress and strain of hardened concrete has been proposed.

REFERENCES

1. ACI Committee 211, 1993 Guide for selecting proportions for High strengths concrete with Portland cement and Fly ash ACI 211 4R-93 ACI Materials Journal, V01 90, No.3, PP 272. 283.
2. Report No T(S) 006 January 2005 Use of higher volume fly ash in concrete for building sector CBRI Roorkee.
3. ACI 211 4R-93, 1996 "Guide for Selecting Properties for High-Strengths Concrete with Portland cement and fly ash" ACI Manual of Concrete Practice, Part I, American Concrete Institute,
4. Malhotra V.M. May 1999 Making Concrete Greener with fly ash concrete International Vol 21, No 5, PP 61-66.
5. NEVILLE, A.M. "Properties of Concrete" 3rd Edition, The English Language Book Society & Pitman Publishing 1983.
6. Seshagiri Rao, M.V., GaneshwaraRao.P., "Research & Development in low cost building technologies" J.N.T.U.College of Engineering, Anantapur 1998.
7. Seshagiri Rao, M.V.; Dr.R.M.Rao;M.Janardhana; B.Ravindhra Kumar; Vol.80,August 1999; Journal of Institution of Engineers.
8. ASTM C 989-940, Standard specification for GGBS for use in concrete and mortars.
9. A.Oner, S.Akyuz, An experimental study on optimum usage of GGBS for the compressive strength of concrete
10. K.GaneshBabu and V.Sree Rama Kumar, "Efficiency of GGBS in concrete"Cement and concrete Research Volume 30, Issue 7 July 2000 pages 1031 – 1036

K. Suvarna Latha currently pursuing Ph.D in Civil Engineering at JNTUH College of Engineering. She has obtained B.Tech. Degree in Civil Engineering from Nagarjuna University of Andhra Pradesh in 1993 and M.Tech.in "Structural Engineering" from J.N.Technological University, Hyderabad of Andhra Pradesh in 2003. Appointed as Lecturer in Civil Engineering in the Department of Technical education and presently working as Head of the Department in Civil Engineering. She has Co-Coordinator for many ISTE Seminars and she is a life member in ISTE. She has prepared the Curriculum to the Board of Intermediate Education for the Vocational courses in Civil Engineering.

M V Seshagiri Raois Professor in Civil Engineering at JNTUH College of Engineering. Hehas enormous experience in teaching and research for nearly 30 years. He has guided 18 PhDsand published nearly 135 papers in various international/national journals and conferences. Hewon best teacher award in 2009 from State Government of Andhra Pradesh. He has publishedone book on Engineering Mechanics. He is recipient of many more awards and also associated with various professional bodies.