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OPTIMIZATION OF CEMENT CONTENT IN CONCRETE USING ADDITIVES

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ABSTRACT

This work was carried out to optimize the cement content in concrete using pozzolanic materials as reduction of CO_2 released during the production of cement is major issues of construction industry. In this work behaviour of M20 and M40 grades of concrete was studied by varying different parameters such as water binder ratio(W/B), superplasticizers content(SP), cement content, fine aggregate content and mineral admixtures content (fly ash(FA), ground granulated blast slag(GGBS) and silica fume(SF)). Taguchi method of design of experiments was used to determine the optimum mix proportions of concrete with minimum cement content. A standard L16 (4^5) orthogonal Array (OA) was selected for the experimental programme with five parameters at four levels, giving rise to a total of 16 trial mixes. Therefore, sixteen trial mixes were chosen for casting and testing in each case, i.e. for each concrete grade and pozzolana type. Results were analyzed manually as well as by Taguchi method in terms of Signal to Noise ratio (S/N). Influences of the parameters on concrete mixes obtained in both cases are comparable to each other. The study showed that both mineral and chemical admixtures can be effectively used to reduce the cement content in concrete. For the materials and range of parameters used in this research the present study has established optimum mixes both in terms of target strength and workability using minimum cement content.

Keywords; Concrete, Minimum cement content, Taguchi method, Mineral admixture, Chemical admixture.

1 INTRODUCTION

In this work attempts have been made to reduce the cement content in concrete using pozzolanic materials as cost and environment impact is major issue of construction industry. Cement is the costliest ingredient of concrete and concrete is the most commonly used construction material and their design consumes almost total cement production of the world. Production and use of cement on large scale has increased the CO_2 emission and due to this the greenhouse effect is increasing day by day. It is quite obvious that any saving in the cement consumption would result into a direct saving in the overall cost of the construction. Replacing a portion of the cement with supplementary cementing materials has the advantage of lower costs and better durability, but disadvantage of a longer setting time and a slower early strength development. Different techniques have been applied to increase the reactivity of natural pozzolans to overcome these disadvantages. Reduction in early age strength can be improved by decreasing the water cement ratio (Khokhar et al, 2010, Hinislioglu et al, 2004) and for these reasons; some superplasticizers are added to increase the workability in addition to these materials in concrete. Hence cement content in a concrete mix may be minimized by replacing cement with different supplementary cementitious materials (Abbasi et al, ok1987 Ahmed, 2011, Bentz et al, 2011). The cement content in concrete mix can also be minimized by increasing the fineness of cement, replacing cement with different amount of cementitious materials, and by selecting different types, shapes and gradation of fine and coarse aggregates in concrete mix. From literature it was found that these supplementary cementing materials can improve the mechanical and microstructural properties of concrete (Barbhuiya et al, 2009 Pandey et al, 2011, Rashid et al, 2011, Kadri et al, 2012 Khmiri et al, 2012, Sengual et al, 2009). Taguchi method has been extensively employed to optimize various parameters that affect the performance of concrete mix. (Ozbay et al, 2009, Nuruddina et al, 2009, Olivia et al, 2012, Turkmen et al, 2003 2008). A successful application of artificial neural network (ANN) has been also implemented by many authors (Lim et al, 2004, Tao et al, 2006, Yeh et al, 1999, 2007) to improve the performances of concrete.

2 MATERIAL PROPERTIES

Locally manufactured commercially available ordinary Portland cement (OPC) of 43 grade complying with IS 8112:1989 was used for preparing concrete mixes. Table-1 provides the details of physical and chemical properties of the cement used. The fine aggregate used was naturally available river sand, fineness modulus and specific gravity of sand were 2.69 and 2.65 respectively. Coarse aggregate was locally available siliceous type crushed aggregate with 20 mm nominal size. The fineness modulus and specific gravity for coarse aggregate were 7.72 and 2.68 respectively. The sand and coarse aggregate were used in saturated surface dry condition for preparing the mix. The chemical properties of mineral admixtures have been shown in Table-2. In this study, commercially available high range water reducing admixture based on modified poly-carboxylic ether (PCE) polymer with solid content of 9.2% was used to prepare the concrete.

Table 1. Properties of cement

Physical properties		Chemical composition (%)	
Grade	OPC	Silicon dioxide	21.6
Specific gravity	3.14	Sulfur trioxide (SO_3)	1.5
Standard consistency of	0.28	Ferric Oxide (Fe_2O_3)	3.9
Initial setting time (min.)	68	Alumina(Al_2O_3)	6.2
Final setting time (min.)	190	Calcium Oxide(CaO)	61.7
3 days strength of cement	22.80	Magnesia	2.4
7 days strength of cement	35.50	Sodium Oxide(Na_2O)	0.23
28 days strength of cement	44.10	Potassium Oxide	0.18
Soundness Le Chatelier	1	LOI	1.1
Fineness of cement (cm^2/gm)	2830	IR	1.2

Table 2. Chemical properties of mineral admixtures

Properties	GGBS (%)	Silica Fume (%)	Fly Ash (%)
Silicon dioxide (SiO_2)	26.3	92.4	68.10
Sulfur trioxide (SO_3)	1.88	1.23	0.24
Ferric Oxide (Fe_2O_3)	2.07	1.2	0.90
Alumina(Al_2O_3)	19.57	3.8	20.80
Calcium Oxide(CaO)	32.3	31.6	2.50
Magnesia Oxide(MgO)	7.9	2.6	0.98
Sodium Oxide(Na_2O)	1.2	0.45	0.09
Potassium Oxide (k_2O)	0.92	0.32	0.23
LOI	0.88	3.07	2.18
IR	2.2	11.1	0.25

3 METHODOLOGY AND EXPERIMENTAL PROGRAMME

3.1 Taguchi method

The Taguchi method helps to reduce the no of trials by design of experiments and it is feasible to study the effect of factors and their interactions. The number of possible trial for P parameter at L level as per factorial method design is $N=L^P$ where L=number of levels for each factor and P=number of factors involved. For ex- if we have 4 parameter at 3 level then total no of combination=3^4=81 but with the help of OA minimum number of trials for these combination is

No. of parameter*(no of level-1) = 4*(3-1) =8. (1)

S/N ratio (signal-to-noise)

It is a performance characteristic, instead of the average value to interpret the trial result. The S/N measures the level of performance and the effect of noise factors on performance and is an evaluation of the stability of performance of an output characteristic. There are three categories of performance characteristics for evaluating the performance of parameters namely larger-the better, smaller-the better and nominal-the better:

a) ***Smaller the better*****:** chosen when goal is to minimize the response.

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} Y_i^2\right) \quad (2)$$

b) ***Larger the better*****:** chosen when goal is to maximize the response.

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} \frac{1}{Y_i^2}\right) \quad (3)$$

c) ***Nominal the better*****:** chosen when goal is to target the response and it is required to base the S/N ratio on standard deviations only.

$$S/N = -10 * \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} (Y_i - Y_o)^2\right) \quad (4)$$

Where Y_i is a performance value of the i^{th} trial and n is the number of repetitions for an experimental combination.

3.2 Experimental programme

An experimental program was designed to determine the optimum mix proportions of concrete with minimum cement content for each case i.e. for each concrete grade and pozzolana type. For this purpose, the design of experiments based on Taguchi method was formulated considering five parameters at four levels. Before carrying out actual experimentation using OA several trials were carried out for control mixes as per IS: 10262-2009 for M20 as well as for M40 grade of concrete. Final mix design obtained for control mixes are shown here in Table-3.

Table 3. Mix design for control mixes

Grade of concrete	W/B	Water Content (Litre)	Cement content (Kg/m^3)	Coarse aggregate (Kg/m^3)	Fine aggregate (Kg/m^3)	SP (%)	Target Strength (Mpa)
M20	0.53	187	353	1045	838	0.30	26.6
M40	0.40	188	470	1028	742	0.35	48.25

Using the results obtained for control mixes parameters and their levels were decided for each grade of concrete. The chosen parameters were then varied around these control mixes on the basis of past experience and literature review, levels of water to binder ratio and cement content were decreased while the level of SP content, mineral admixture content and fine aggregate content were increased. Combination details for 16 trials for each case i.e. for each concrete grade and pozzolana type is shown in Appendix-1. The experiments were carried out and cubic specimens of size 150 × 150 × 150 mm were cast to evaluate the influence the various mix parameters and thereby to optimize the cement content in concrete. Total of 3 specimens for each trial were caste to take the average compressive Strength at the end of 28 days.

Table 4. Parameters and levels for M20 & M40

Parameters	M20				M40			
Level	1	2	3	4	1	2	3	4
W/B ratio	0.53	0.52	0.51	0.50	0.4	0.39	0.38	0.37
Cement content	353	343	333	323	470	460	450	440
(SP) %	0.30	0.35	0.40	0.45	0.35	0.4	0.45	0.5
(FA) %	0	30	40	50	0	30	40	50
(SF) content %	0	5	10	15	0	5	10	15
GGBS content %	0	40	50	60	0	40	50	60
Fine Aggregate	830	842	854	866	742	754	766	778

4 RESULTS AND DISCUSSION

Results obtained were analyzed manually and statistically to determine the influence of the factors. Compressive strength and S/N ratio of each grade with fly Ash, GGBS and Silica Fume are shown in Appendix-1 in Table 1, Table 2 and Table 3. Larger the better criteria was chosen for analyzing the results to maximize the compressive strength of concrete mixes. S/N plots of different mixes with mineral admixture and corresponding response tables are shown in Figure 1 to Figure 6 and Table 5 to Table 7. Plots for S/N ratio indicates that more will be the variation of S/N value of any parameter at their different level more will be the influence of that parameter on the response of the product and rank shown in response table indicates the order of influence of the parameter on the compressive strength of mix.
Delta is the difference of maximum and minimum S/N value of any parameter. The numerical value of the maximum point in each graph marks the best value of that particular parameter in enhancing the compressive strength of mixes.

4.1 S/ N ratio analysis of fly ash mixes

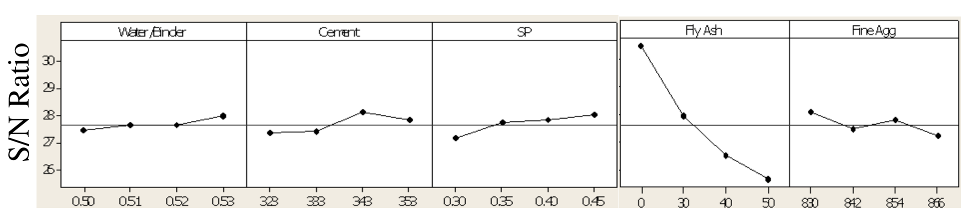


Figure 1. S/N plots for M20 Fly Ash mixes

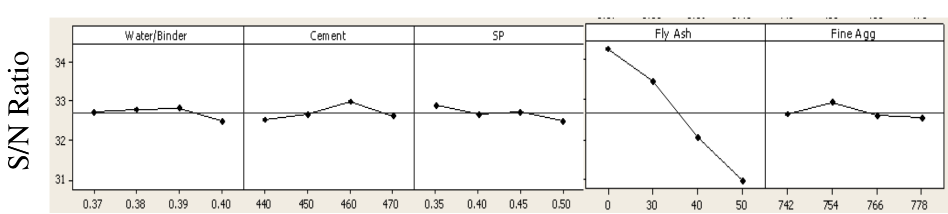


Figure 2. S/N plots for M40 Fly Ash mixes

Table 5. Response table for S/N ratio for Fly Ash mixes

	M20					M40				
	(A)	(B)	(C)	(D)	(E)	(A)	(B)	(C)	(D)	(E)
1	27.4	27.3	27.1	30.5	28.1	32.7	32.5	32.9	34.3	32.6
2	27.6	27.4	27.7	28.0	27.5	32.8	32.6	32.7	33.5	32.9
3	27.6	28.1	27.8	26.5	27.8	32.8	33.0	32.5	32.0	32.6
4	27.9	27.8	28.0	25.7	27.2	32.5	32.6	32.7	31.0	32.5
Delta	0.4	0.76	0.85	4.8	0.84	0.32	0.45	0.38	3.3	0.42
Rank	5	4	2	1	3	5	2	4	1	3

4.2 S/N ratio analysis of GGBS mixes

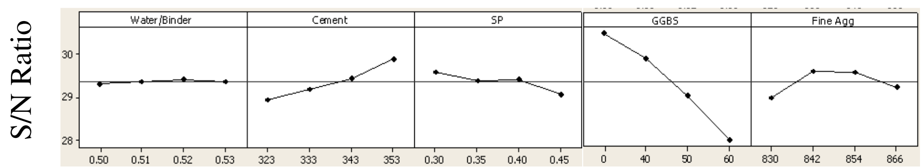


Figure 3. S/N plots for M20 GGBS mixes

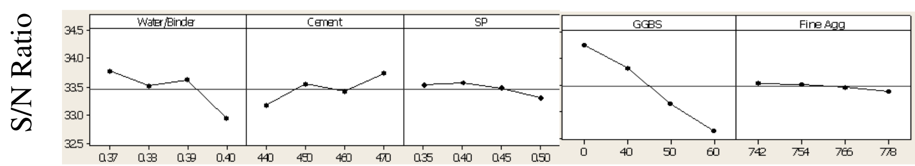


Figure 4. S/N plots for M40 GGBS mixes

Table 6. Response table for S/N ratio for GGBS mixes

	M20					M40				
Level	(A)	(B)	(C)	(D)	(E)	(A)	(B)	(C)	(D)	(E)
1	29.3	28.9	29.6	30.5	29.0	33.8	33.2	33.5	34.3	33.5
2	29.4	29.2	29.4	29.9	29.6	33.5	33.6	33.6	33.8	33.5
3	29.4	29.4	29.4	29.0	29.6	33.6	33.4	33.3	33.2	33.5
4	29.3	29.9	29.1	28.0	29.2	33.0	33.7	33.5	32.6	33.4
Delta	0.09	0.92	0.51	2.47	0.62	083	0.56	0.25	1.62	0.14
Rank	5.00	2.00	4.00	1.00	3.00	2	3	4	1	5

4.3 S/N ratio analysis of Silica Fume mixes

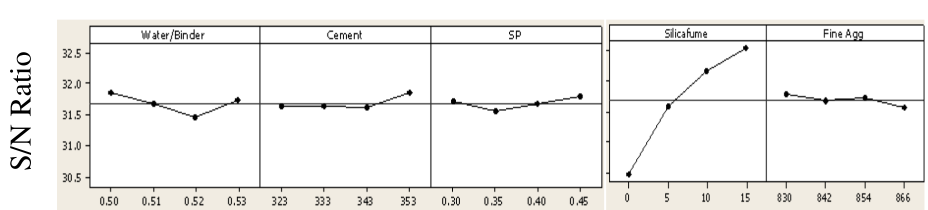


Figure 5. S/N plots for M20 Silica Fume mixes

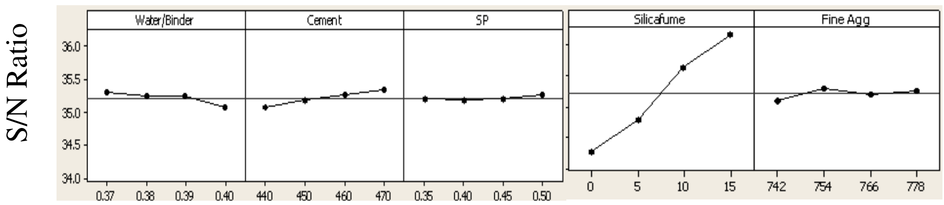


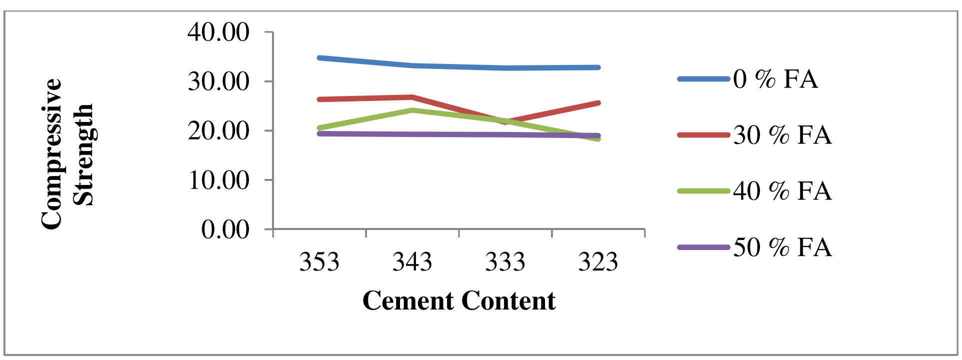
Figure 6. S/N plots for M40 Silica Fume mixes

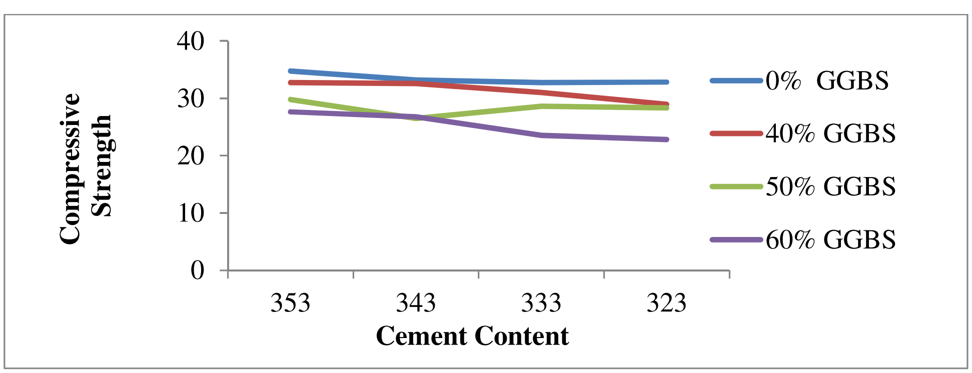
Table 7. Response table for S/N ratio for Silica Fume mixes

	M20					M40				
Level	(A)	(B)	(C)	(D)	(E)	(A)	(B)	(C)	(D)	(E)
1	31.9	31.7	31.7	30.5	31.8	35.3	35.1	35.2	34.3	35.1
2	31.7	31.6	31.6	31.6	31.7	35.2	35.2	35.2	34.8	35.3
3	31.5	31.6	31.7	32.2	31.7	35.2	35.3	35.2	35.6	35.2
4	31.8	31.9	31.8	32.6	31.6	35.1	35.3	35.3	36.2	35.3
Delta	0.40	0.26	0.27	2.09	0.18	0.22	0.27	0.08	1.90	0.21
Rank	2	4	3	1	5	3	2	5	1	4

4.4 Manual Analysis

Influence of mineral admixture content on compressive strength of the mix irrespective of the effect of others parameter were analyzed manually by plotting the graph on the basis of mineral admixture content and cement content which are shown here in Figure 8.





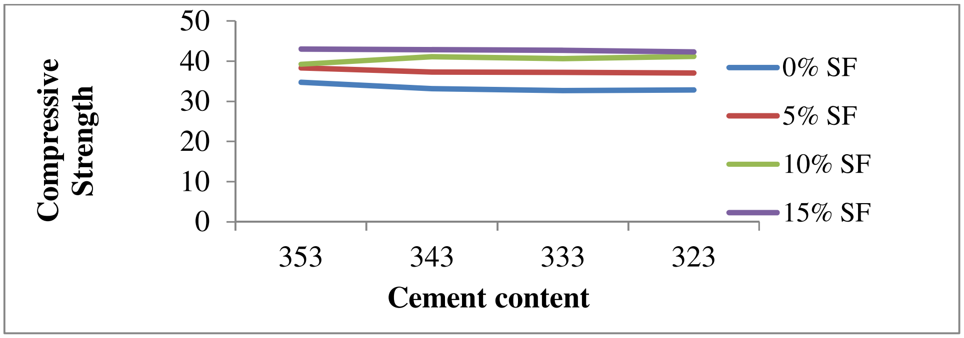


Figure. 8 6 Strength variation on the basis of mineral admixture and cement content

4.5 Summary of results

Optimum mix obtained by Taguchi method of design is on the basis of maximum compressive strength by taking the peak point of each parameter from S/N curve whereas on the basis of minimum cement content it was taken by target strength of each grade of concrete.

Table-8 Optimum mix combination of Taguchi results

Mix name	Water binder ratio	Cement content	SP content (%)	Replacement (%)	Fine agg (Kg/m^3)
	28 Days	28 Days	28 Days	28 Days	28 Days
M2O FA	0.53	343	0.45	0	830
M20 GGBS	0.52	353	0.30	0	842
M20 SF	0.50	353	0.45	15	830
M40 FA	0.39	460	0.35	0	754
M40 GGBS	0.37	470	0.40	0	742
M40 SF	0.37	470	0.50	15	754

Table-9 Optimum mix combination on the basis of minimum cement content

Mix name	Water binder ratio	Cement content	SP content (%)	Replacement (%)	Fine agg (Kg/m^3)
	28 Days	28 Days	28 Days	28 Days	28 Days
M2O FA	0.53	343	0.35	30	842
M20 GGBS	0.52	343	0.30	60	854
M20 SF	0.53	333	0.40	10	854
M40 FA	0.40	460	0.40	30	754
M40 GGBS	0.39	440	0.45	40	742
M40 SF	0.40	440	0.50	15	778

5 CONCLUSIONS

- The study showed that both mineral and chemical admixtures can effectively be used to reduce the cement content in concrete.
- The test results indicated that the overall most influencing parameter in case of fly ash, GGBS and silica fume added mixes was mineral admixture content whereas, fine aggregate content was the least influencing parameter.
- The study showed that for silica fume and GGBS at same replacement level of mineral admixtures, strength decreased with decrease in the cement content in most

of the mixes but the same was not found to be true for fly ash, cement with 3rd level in both the grade exhibited better strength than 4th level (maximum level).

- In all of the mixes influence of higher cement content, lower fine aggregate content and lower w/b were dominating factor.
- After analysing the result, it was found that instead of increasing the levels of fine aggregate decreasing it yielded better strength.
- Comparative analysis of strength at 28 and 56 days indicated that taking 56 days strength as characteristic criteria could help to reduce cement content more significantly.
- Slump obtained in M40 mixes are higher than that of M20 for all mixes using pozzolanic material either with Fly Ash or GGBS or Silica Fume.
- The study showed that Taguchi method can be used efficiently and economically for designing the experiments and for determining the optimum process parameters.

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Appendix-1

Table-1 L_{16} (4^5) Orthogonal array (OA) (M20 and M40)

Exp. no	Parameters										
	A		B		C		D			E	
	W/B		Cement Kg/m^3		(SP) (%)		Either SF, FA Or GGBS (%) of cement			Fine agg Kg/m^3	
	M 20	M 40	M 20	M 40	M 20	M 40	M20 & M40			M 20	M 40
1	.53	.40	353	470	0.3	0.35	0	0	0	830	742
2	.53	.40	343	460	0.35	0.4	5	30	40	842	754
3	.53	.40	333	450	0.4	0.45	10	40	50	854	766
4	.53	.40	323	440	0.45	0.5	15	50	60	866	778
5	.52	.39	353	470	0.35	0.4	10	40	50	866	778
6	.52	.39	343	460	0.3	0.35	15	50	60	854	766
7	.52	.39	333	450	0.45	0.5	0	0	0	842	754
8	.52	.39	323	440	0.4	0.45	5	30	40	830	742
9	.51	.38	353	470	0.4	0.45	15	50	60	842	754
10	.51	.38	343	460	0.45	0.5	10	40	50	830	742
11	.51	.38	333	450	0.3	0.35	5	30	40	866	778
12	.51	.38	323	440	0.35	0.4	0	0	0	854	766
13	.50	.37	353	470	0.45	0.5	5	30	40	854	766
14	.50	.37	343	460	0.4	0.45	0	0	0	866	778
15	.50	.37	333	450	0.35	0.4	15	50	60	830	742
16	.50	.37	323	440	0.3	0.35	10	40	50	842	754

Table-2 Compressive Strength and S/N ratio for all mixes.

Trial Mixes	Slump (mm)		M20		M40	
	M20	M40	Compressive Strength (Mpa)	S/N Ratio	Compressive Strength (Mpa)	S/N Ratio
FA1	135	150	34.75	30.82	50.86	34.13
FA2	141	151	26.8	28.56	48.67	33.75
FA3	148	155	21.98	26.84	38.67	31.75
FA4	65	122	18.95	25.55	32.50	30.24
FA5	128	131	20.55	26.26	39.33	31.89
FA6	53	60	19.27	25.7	37.50	31.48
FA7	151	157	32.7	30.29	52.48	34.40
FA8	110	158	25.63	28.17	46.65	33.38
FA9	129	110	19.38	25.75	36.67	31.29
FA10	45	148	24.18	27.67	40.67	32.19
FA11	37	110	21.73	26.74	47.52	33.54
FA12	132	151	32.81	30.32	50.67	34.10
FA13	115	145	26.36	28.42	45.34	33.13
FA14	142	152	33.2	30.42	52.68	34.43
FA15	45	61	19.2	25.67	34.88	30.85
FA16	35	35	18.33	25.26	41.42	32.34
GGBS1	135	150	34.75	30.82	50.86	34.13
GGBS2	175	185	32.55	30.25	46.65	33.38
GGBS3	178	180	28.63	29.14	43.16	32.70
GGBS4	146	176	22.8	27.16	37.93	31.58
GGBS5	154	168	29.8	29.48	47.80	33.59
GGBS6	145	172	26.8	28.56	43.67	32.80
GGBS7	151	157	32.7	30.29	52.48	34.40
GGBS8	148	168	28.92	29.22	48.65	33.74
GGBS9	162	155	27.61	28.82	44.61	32.99
GGBS10	156	130	26.45	28.45	44.90	33.04
GGBS11	128	145	30.96	29.82	49.70	33.93
GGBS12	132	151	32.81	30.32	50.67	34.10
GGBS13	145	130	32.7	30.29	51.45	34.23
GGBS14	142	152	33.2	30.42	52.68	34.43
GGBS15	128	130	23.54	27.44	45.63	33.19
GGBS16	130	125	28.33	29.04	46.12	33.28
SF1	135	150	34.75	30.82	50.86	34.13
SF2	140	145	37.33	31.44	54.64	34.75
SF3	133	139	40.67	32.19	59.01	35.42
SF4	48	111	42.33	32.53	62.93	35.98
SF5	135	112	39.23	31.87	61.67	35.80
SF6	44	53	42.87	32.64	64.67	36.21
SF7	151	157	32.70	30.29	52.48	34.40
SF8	141	144	37.06	31.38	53.48	34.56
SF9	46	72	43.08	32.69	66.12	36.41
SF10	138	141	41.12	32.28	60.42	35.62
SF11	125	102	37.21	31.41	54.93	34.80
SF12	132	151	32.81	30.32	50.67	34.10
SF13	145	139	38.33	31.67	56.38	35.02
SF14	142	152	33.20	30.42	52.68	34.43
SF15	35	55	42.67	32.60	63.48	36.05
SF16	30	31	41.23	32.30	60.62	35.65